AAS/AIAA
Astrodynamics Specialists Conference

Hilton Quebec
Quebec City, Quebec, Canada

30 July – 2 August 2001

PROGRAM

	General Chairs	**Technical Chairs**
AAS	Arun K. Misra McGill University	David B. Spencer Pennsylvania State University
AIAA	Ronald J. Lisowski US Air Force Academy	Calina C. Seybold Jet Propulsion Laboratory

TABLE OF CONTENTS

Meeting Information

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

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

All rates are in US dollars. Payment can be made in equivalent Canadian dollars ($ 290 for members, $360 for non-members and $60 for students.) **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".

The registration desk will be open in the "Foyer Salle de bal" at the following times:

Sunday Evening	1600-1900
Monday	0700-1600
Tuesday and Wednesday	0800-1600
Thursday	0830-1130

CONFERENCE PROCEEDINGS
Conference attendees will be able to order the proceedings at the registration table at a pre-publication cost of $190. After the conference, the proceedings will cost $450. These rates are in US dollars only.

SOCIAL EVENTS

Sunday: Early Bird Reception in the Panorama Room (22nd Floor) from 1830 to 2000
Tuesday: Tour of the Parliament Buildings and Conference Dinner from 1830 to 2200. Awards presentation will take place at the dinner.
Wednesday: Happy Hour in the Panorama Room from 1700 to 1900

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

AAS General Chair
Arun K. Misra
Dept of Mechanical Eng.
McGill University
817 Sherbrooke St. West
Montreal, QC, H3A 2K6
Canada
514-398-6288
514-398-7365 (fax)
email: misra@mecheng.mcgill.ca

AIAA General Chair
Ronald J. Lisowski
Dept of Astronautics
US Air Force Academy
2354 Fairchild Drive, Suite 6J71
Colorado Springs, CO 80840
719-333-4110
719-333-3723 (fax)
email: Ron.Lisowski@usafa.af.mil

Technical Program

TECHNICAL SESSIONS

There are 23 technical sessions scheduled over a 4-day period with a total of 183 papers on the agenda. The technical sessions will run in parallel with 3 morning sessions and 3 afternoon sessions most days. Tuesday afternoon will have two sessions. All regular technical sessions will be held either in the Ste-Foy/Portneuf, Courville/Montmorency, Beauport, or Beaumont rooms. Morning and afternoon coffee breaks will be held mid-way through each technical session in the corridor near the meeting rooms.

SPEAKER'S BRIEFINGS

Authors who are presenting papers and session chairs will meet for a light breakfast and short briefing each morning at 0730 in the Salon Villeray. Please attend only on the day of your presentation.

PRESENTATIONS

Morning technical sessions will start at 0830, and afternoon technical sessions will start at 1330 each day. All presentations are scheduled for 20 minutes: 15 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 ($1.50 Canadian) per paper in the Lauzon room. Bound copies of the conference proceedings may be ordered at the registration desk.

COMMITTEE MEETINGS

All committee meetings will be held from 1200-1330 in the Salon Villeray according to the following schedule:

Monday: AIAA Astrodynamics Technical Committee
Tuesday: AAS Space Flight Mechanics Technical Committee
Wednesday: AIAA Astrodynamics Standards Committee

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

AAS Technical Chair
David B. Spencer
Pennsylvania State University
233 Hammond Building
University Park, PA 16802-1401
814-865-4537
814-865-7092 (fax)
email: dbs9@psu.edu

AIAA Technical Chair
Calina C. Seybold
Jet Propulsion Laboratory
Mailstop 301-180
4800 Oak Grove Drive
Pasadena, CA 91109-8099
818-354-8685
calina.c.seybold@jpl.nasa.gov

Quebec Information

CONFERENCE LOCATION

Hilton Quebec
1100 Boul. Rene-Levesque Est,
Quebec, CA
Tel: 1-418-647-2411
Fax: 1-418-647-6488
http://www.hilton.com

The hotel is situated on Parliament Hill, at the gates of the old walled city. The Hilton Quebec is directly linked to the new convention centre. Moreover, the Hilton Quebec is also linked to the Government buildings via Place Quebec, a modern underground complex with several boutiques and restaurants. All guestrooms offer a panoramic view of North America's oldest city and of Laurentian Mountains.

QUEBEC CITY

Spread over Cap Diamant and the banks of the St Lawrence, Quebec City is Canada's most beautifully located and most historic city. Vieux-QuÈbec, surrounded by solid fortifications, is the only walled city in North America, a fact that prompted UNESCO to classify it as a World Heritage Treasure in 1985. In both parts of the Old City - Haute and Basse - the winding cobbled streets are flanked by seventeenth- and eighteenth-century stone houses and churches, graceful parks and squares, and countless monuments.

Arriving from Montreal you're immediately struck by the differences between the province's two main cities. While Montreal is international and modern, Quebec City is very much traditional, a residue of the days when the city was the bastion of the Catholic Church in Canada. On the other hand, the Church can claim much of the credit for the creation and preservation of the finest buildings, from the quaint Notre-Dame-des-Victoires to the decadently opulent Basilique Notre-Dame de Quebec and the vast Seminary. In contrast, the austere defensive structures, dominated by the massive Citadelle, reveal the military pedigree of a city dubbed by Churchill as the "Gibraltar of North America", while the battlefield of the Plains of Abraham are now a national historic park. Of the city's rash of museums, two are essential visits - the modern Musee de la Civilisation, in Vieux-Quebec, expertly presenting all aspects of French-Canadian society, and the recently expanded Musee du Quebec, in the Haute-Ville, west of Vieux-Quebec, which has the finest art collection in the province.

Outside the city limits, the town of Levis and the Huron reservation, Wendake, make worthwhile excursions, whilst the churches and farmland of the Cote-de- Beaupre and the ‘le d'Orleans hark back to the days of the seigneurs and habitants. The gigantic Basilique de Ste-Anne-de-Beaupre, attracting millions of pilgrims annually, is one of the most impressive sights in Quebec, and for equally absorbing natural sights there are the spectacular waterfalls at Montmorency and Sept-Chutes, and the wildlife reserve in the Laurentians.

TRANSPORTATION

Driving Directions (from the Hilton Quebec site):

From highway 20 (Jean Lesage Highway) coming from Montreal, take exit Quebec City that will take you on Pierre Laporte Bridge. After crossing the bridge, take exit Boulevard Laurier and follow it all the way until you get to Parliament Building corner of Dufferin. Turn left at light sign and left again on Rene Levesque Boulevard. From highway 40, follow Boulevard Charest turn right on St-Sacrement up to Rene Levesque Boulevard where you will turn left. Follow Rene Levesque Boulevard, which ends at our hotel across from the Parliament Buildings.

Local Airport:

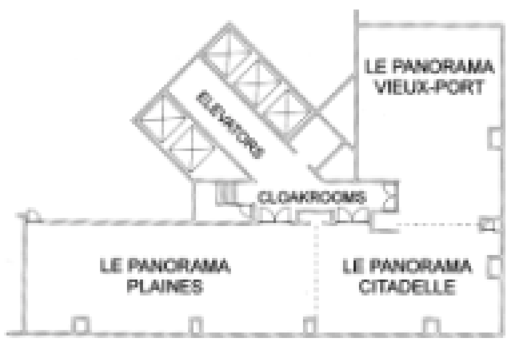
Jean Lesage Int'l Airport
Distance from hotel: 20 km.
Drive time: 20
Directions: Turn right when exiting the airport road. Drive to the Charest East onramp and follow to St Sacrement. Turn right until Rene Levesque Boulevard where you will turn left. Follow it until you get to the hotel.

Getting to and from the Airport:

Bus Service, typical minimum charge is CAD 9.00
Taxi, typical minimum charge is CAD 22.00

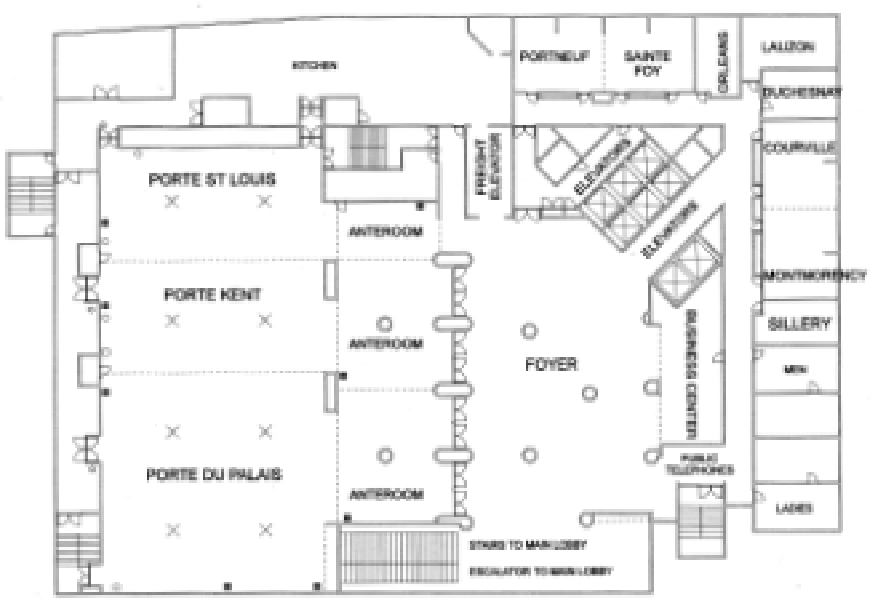
LOCAL AREA MAP

HOTEL FLOORPLAN



23RD FLOOR

2ND FLOOR



1ST FLOOR

PROGRAM SUMMARY

Date/Time	Event	Location
Sunday, 29 July		
1600-1900	Conference Registration	Foyer Salle de Bal
1830-2000	Early-Bird Reception	Panorama Room
Monday, 30 July		
0700-1600	Conference Registration	Foyer Salle de Bal
0730-0830	Speaker's Breakfast & Briefing	Salon Villeray
0800-1700	Paper Sales	Lauzon Room
0830-1130	Technical Sessions 1,2,3	* *
1130-1330	Lunch	
1200-1330	AIAA Technical Committee Mtg	Salon Villeray
1330-1630	Technical Sessions 4,5,6	* *
Tuesday, 31 July		
0730-0830	Speaker's Breakfast & Briefing	Salon Villeray
0800-1600	Conference Registration	Foyer Salle de Bal
0800-1700	Paper Sales	Lauzon Room
0830-1130	Technical Sessions 7,8,9	* *
1130-1330	Lunch	
1200-1330	AAS Technical Committee Mtg	Salon Villeray
1330-1630	Technical Sessions 10,11	* *
1830-2200	Dinner & Parliament Bldg. Tour	
Wednesday, 1 August		
0730-0830	Speaker's Breakfast & Briefing	Salon Villeray
0800-1600	Conference Registration	Foyer Salle de Bal
0800-1700	Paper Sales	Lauzon Room
0830-1130	Technical Sessions 12,13,14	* *
1130-1330	Lunch	
1200-1330	AIAA Standards Committee Mtg	Salon Villeray
1330-1630	Technical Sessions 15,16,17	* *
1700-1900	Happy Hour	Panorama Room
Thursday, 2 August		
0730-0830	Speaker's Breakfast & Briefing	Salon Villeray
0800-1130	Conference Registration	Foyer Salle de Bal
0800-1700	Paper Sales	Lauzon Room
0830-1150	Technical Sessions 18,19,20	* *
1150-1330	Lunch	
1330-1630	Technical Sessions 21,22,23	* *

**All regular technical sessions will be held either in the Ste-Foy/ Portneuf, Courville/ Montmorency, Beauport, or Beaumont rooms.

Session 1 Libration Point I
0830 Monday, 30 July

Chair Martin Lo
Jet Propulsion Laboratory

0830 AAS 01 - 301

INVARIANT MANIFOLDS AND MATERIAL TRANSPORT IN THE SOLAR SYSTEM

G. Gomez – Universitat de Barcelona, Spain; W. Koon – California Institute of Technology; M. Lo – Jet Propulsion Laboratory; J. Marsden – California Institute of Technology; J. Masdemont – Universitat Politecnica de Catalunya, Spain; S. Ross – California Institute of Technology

The invariant manifold structures of the collinear libration points for the restricted three-body problem provide the framework for understanding transport phenomena from a geometric point of view. In particular, the stable and unstable invariant manifold ``tubes" associated to libration point orbits are the phase space conduits transporting material between primary bodies for separate three-body systems. These invariant manifold tubes can be used to construct new spacecraft trajectories, such as a ``Petit Grand Tour" of the moons of Jupiter. Previous work focused on the planar circular restricted three-body problem. The current work extends the results to the three dimensional case.

0850 AAS 01 - 302

CHARACTERIZING THE ORBIT UNCERTAINTY DYNAMICS ALONG AN UNSTABLE ORBIT

D. Scheeres – The University of Michigan

The characterization of orbit determination performance along an unstable orbit is considered. For the current approach, the instantaneous flow in the neighborhood of a trajectory is used to model the dynamics of the orbit uncertainty distribution. The proposed characterization is based on the relative geometry between the instantaneous local flow and the generalized partials of the orbit determination measurement. We present a systematic account of the theory and apply it to a few unstable trajectories in the vicinity of the Earth-Sun libration points. The ability of the proposed characterization methodology to capture actual variations in orbit determination performance is evaluated.

0910 AAS 01 - 303

CONTINUATION OF PERIODIC ORBITS AROUND LAGRANGE POINTS AND AUTO2000

R. Paffenroth – California Institute of Technology; E. Doedel – Concordia University

AUTO is a software for continuation and bifurcation problems in ordinary differential equations originally written in 1980 and widely used in the dynamical systems community. In this talk we will discuss the parameter continuation algorithms that underly the AUTO2000 software and demonstrate how they may be applied to the gravitational N-body problem. Our computational focus will be the families of periodic orbits which eminate from the Lagrange points in the Restricted Three Body problem. In addition, computations of invariant manifolds for a periodic orbit in the Planar Restricted Three Body Problem will be described, including heteroclinic and homoclinic connections.

0930 AAS 01 - 305

SIMULATION OF FORMATION FLIGHT NEAR L_2 FOR THE TPF MISSION

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. Since the TPF instruments needs a cold and stable environment, near Earth orbits are unsuitable. 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. The formation flight problem near the Lagrange points is of great interest. Our work in the study of the feasibility of formation flight near the Lagrange points indicates that: 1) Formation flight near L2 is dynamically possible for the TPF Mission and 2) Linear control around a nonlinear baseline libration orbit near L2 is adequate for the TPF Mission.

0950 BREAK

1010 AAS 01 - 306

SUMMER LAUNCH OPTIONS FOR THE GENESIS MISSION

R. Wilson, B. Barden – Jet Propulsion Laboratory; K. Howell, B. Marchand – Purdue University

In October of 2000, the decision was made to delay launch of the Genesis mission from February 2001 to some time in the summer of that same year. Given the nature of libration point trajectories and the unique characteristics of the Genesis mission, a complete redesign of the trajectory was required. The ensuing effort was thus focused on establishing potential baseline options and clearly defining and exploring the trade space. Once a specific baseline was identified, the trade space was defined to include such things as launch period characteristics, Sun-Earth-Probe angle history, eclipsing prior to end-of-mission atmospheric entry, deterministic maneuver dates (to avoid DSN conflicts), error ellipse footprint at collection site (Utah Test and Training Range), and favorable geometry allowing automated deboost maneuver prior to entry.

1030 AAS 01 - 307

THE ROLE OF HUMANS IN LIBRATION POINT MISSIONS WITH SPECIFIC APPLICATION TO AN EARTH-MOON LIBRATION POINT GATEWAY STATION

G. Condon, D. Pearson – NASA/Johnson Space Center

Human presence in space has already shown significant benefits. Human crews have repaired and re-deployed ailing spacecraft, such as Hubble Space Telescope, Solar Max satellite, and Leasat 3. Astronauts provided enhancements to the originally myopic Hubble Space Telescope and, on a separate occasion, replaced critical failed control gyros, thus saving a national resource that now continues to provide tremendous scientific discovery. In addition, human crews have retrieved both ailing spacecraft, such as Westar and Palapa, and experiment platforms such as the Long Duration Exposure Facility (LDEF). The notion of human missions to libration points has been proposed for more than a generation. Satellite servicing of science packages strategically located at libration points provides but one of numerous potential mission concepts. Other human mission concepts have examined the viability and utility of human missions in the vicinity of libration points in the Sun-Earth, Earth-Moon and possibly Sun-Mars systems. This report addresses the role of humans in libration point space missions and addresses particular mission design considerations for an example Earth-Moon libration point gateway station.

Session 2 Attitude Determination
0830 Monday, 30 July

Chair Mark Pittelkau
JHU/Applied Physics Laboratory

0830 AAS 01 - 308

ESTIMATION OF INERTIA PARAMETERS FOR GYROSTATS SUBJECT TO GRAVITY-GRADIENT TORQUES
M. Peck – Boeing Satellite Systems

This study evaluates a technique for extracting the mass properties of a spinning rigid body with internal angular momentum when gravity-gradient torques are not negligible. Our recent work in this area, which derives a nonlinear estimator that is insensitive to data dropouts, is adapted to incorporate orbital ephemeris data. Using the classical model of gravity-gradient torques, which is linear in the components of the inertia matrix, this adaptation extracts inertia estimates (without the need for linearization) from data collected during constant-rate slew maneuvers and constant earth pointing as well as arbitrary attitude motions. Issues of observability and data richness are discussed in a theoretical context and demonstrated via simulations.

0850 AAS 01 - 309

ATTITUDE REPRESENTATIONS FOR KALMAN FILTERING
F. Markley – NASA/Goddard Space Flight Center

The four-component quaternion has the lowest dimensionality possible for a globally nonsingular attitude representation, it represents the attitude matrix as a homogeneous quadratic function, and its dynamic propagation equation is bilinear in the quaternion and the angular velocity. The quaternion is required to obey a unit norm constraint, though, so Kalman filters often employ a quaternion for the global attitude estimate and a three-component representation for small errors about the estimate. We consider these mixed attitude representations for both a first-order Extended Kalman filter and a second-order filter, as well for quaternion-norm-preserving attitude propagation.

0910 AAS 01 - 310

SPACECRAFT ATTITUDE DETERMINATION USING THE BORTZ EQUATION
M. Pittelkau – JHU/Applied Physics Laboratory

The reduced-order attitude determination filter based on the quaternion has been successfully used on many missions, but certain technical questions still exist. In this paper, an alternative derivation of the spacecraft attitude determination filter is developed to avoid questions of quaternion normalization or attitude matrix orthogonality constraints, singular covariance matrices, and approximations used to circumvent these problems. This derivation is based on the Bortz equation for the rotation vector. Since the rotation vector is an unconstrained representation of attitude, the aforementioned questions do not arise. Singularities in the state dynamics equation are avoided by maintaining the predicted body attitude as the inertial reference for the filter. A simple discrete solution to the Bortz equation provides accurate attitude propagation for highly maneuverable spacecraft.

0930 AAS 01 - 311

DESIGN AND IMPLEMENTATION OF A NANOSATELLITE ATTITUDE DETERMINATION AND CONTROL SYSTEM
K. Makovec, A. J. Turner, C. Hall – Virginia Polytechnic and State University

The Virginia Tech HokieSat is part of an Air Force Initiative for students to design and build satellites. The mission requires an attitude determination and control system (ADCS) that provides adequate control of the spacecraft within a satellite formation, despite its relatively small size and constrained budget, while minimizing power use during flight operations. This paper outlines the development of such a control system using simple, inexpensive off-the-shelf parts and unique algorithms that provide for reliable control over the mission lifetime. A comparison between the traditional and adaptive control algorithms is presented.

0950 BREAK

1010 AAS 01 - 312

STAR TRACKER RELATIVE ALIGNMENT CALIBRATION AND ITS APPLICATION ON ABSOLUTE POINTING DETERMINATION
S. Bae, B. Schutz – The University of Texas at Austin

This paper will introduce two algorithms developed for relative alignment calibration between CCD star trackers. The first approach uses the attitude information determined by multiple star observations in each CCD star tracker. In the second approach, a set of alignment parameters that represent the alignment errors between the primary star tracker and other star trackers will be estimated. These parameters can be solved by the least squares method. The estimated parameters will be used for the absolute pointing determination of the object which is detected in a star tracker, but cannot be identified from the previously known information.

1030 AAS 01 - 313

CALIBRATION OF THE SKEWED AQUA SATELLITE GYROS
R. Harman, I. Bar-Itzhack – NASA/Goddard Space Flight Center

This work presents a new approach to gyro calibration where, in addition to being used for computing attitude that is needed in the calibration process, the gyro outputs are also used as measurements in a Kalman filter. The calibration algorithm presented in this work was derived for the set of quadruplet gyros to be flown by the EOS-AQUA satellite. This required the derivation of a new error model, particularly for the gyro misalignments. Simulations were carried out to demonstrate the effectiveness of the new algorithm, and the results are presented.

1050 AAS 01 - 314

POST-FLIGHT ATTITUDE RECONSTRUCTION FOR THE SHUTTLE RADAR TOPOGRAPHY MISSION

E. Wong, W. Breckenridge, D. Bayard, P. Brugarolas, D. Boussalis, J. Spanos, G. Singh – Jet Propulsion Laboratory

The Shuttle Radar Topography Mission (SRTM) is the first mission to provide high accuracy near-global topographic coverage of the Earth's land surface using a long-baseline interferometry approach. It uses a synthetic aperture radar instrument to produce a digital elevation map with 16 m absolute vertical height accuracy at 30 meter postings. The mission involves a large space structure (60 meter mast) deployable from the Shuttle payload bay and requires precision attitude and position determination to arc-minute and millimeter levels. Onboard flight sensors include electro-optical metrology sensors, a target tracker, a star tracker, gyros, and GPS receivers. On the first day of flight, system identification of the mast frequency and damping was conducted in near real-time on the ground using flight sensor telemetry data for proper tuning of the Shuttle attitude control system. Post-flight reconstruction of the attitudes and positions of the outboard and inboard antennas over a nine-day period was conducted. A description of the ground software system architecture and the data processing methodology is provided. Implementation and results of various attitude reconstruction methods for minimizing the radar height errors involving large space structures, such as optimizing structural and time misalignments, data interpolation, time synchronization, estimator and model tuning, and nonlinear filtering, are described.

Session 3 GEO Collocation
0830 Monday, 30 July

Chair George Chao
The Aerospace Corporation

0830 AAS 01 - 316

MATHEMATICAL DERIVATIONS OF THE "e-i" AND HALO GEO COLLOCATION METHODS
C. Chao – The Aerospace Corporation

This paper provides an explanation of two geostationary Earth orbit (GEO) collocation methods through mathematical derivations and numerical examples. The purpose of this report is to understand how the eccentricity-inclination or the "e-i" separation and the halo formation methods were formulated for the collocation of geostationary satellites. The sun-pointing stationkeeping strategy currently used for several GEO missions is explained through eccentricity librations induced by solar radiation pressure effects. This peper also includes a comparison between the "e-i" method, currently used by the ASTRA and EUTELSAT missions, and the halo method. The mathematical formulations may be used as a reference for the design and analysis of GEO collocation strategies.

0850 AAS 01 - 317

EUTELSAT SATELLITE COLLOCATION
L. Pattinson, V. Chechik – EUTELSAT, France

EUTELSAT has collocated geosynchronous communications satellites at 13 deg. East since April 1995. Nowadays this constellation consists of five HotBird(TM) spacecraft of different platform families. The operational constraints and orbital configuration are described. Description of constellation build-up and the results of its day-to-day maintenance over these years are presented. The expected evolution for this collocation group is also given.

0910 AAS 01 - 318

COLLOCATION STUDY FOR A GEO SATELLITE AND AN INCLINED GSO
J. Chan, K. Raman – INTELSAT; C. Chao, G. Peterson – The Aerospace Corporation

Three collocation strategies were studied for a geostationary (GEO) satellite and an inclined geosynchronous (GSO) satellite sharing the same mean station-keeping longitude. The longitude control box for the GEO satellite is +/- 0.05 degree and that for the GSO satellite is +/- 0.15 degree. The station-keeping maneuver cycle for the GEO satellite is 28 days with east/west maneuvers every 14 days. The inclination control for the GEO satellite is to keep the inclination control band to within +/- 0.05 degree and the north/south maneuver station-keeping cycle is every 28 days. The station-keeping maneuver cycle for the GSO satellite is 28 days with only east/west maneuvers. The inclination of the GSO satellite is about 3.5 degrees. The three strategies studied were (1) separation by longitude, (2) separation by eccentricity and

(3) improved monitoring with no separation strategy was employed. All three strategies require minimum coordination in orbital control between the two satellites. One-year simulation was performed for each strategy and the statistics of conjunction probability were calculated for each case. The details of the three strategies as well as the results will be discussed.

0930 AAS 01 - 319

GEOSYNCHRONOUS SATELLITE COLLOCATION AT SPACE SYSTEMS/LORAL
B. Sauer, M. Chow – Space Systems/Loral

Sensitive to the needs of its customers, Space Systems/Loral has been developing collocation strategies for several years. Since most of SS/L's customers are interested in collocating only 2-3 satellites, there is no need to implement complicated strategies that require shortened north/south stationkeeping cycles. Instead the 4-6 week cycle can be maintained without compromising the required minimum separation distance. This allows the operators to maintain much of their heritage stationkeeping plan and minimize the amount of extra work involved with collocation.

0950 BREAK

1010 AAS 01 - 320

GPS-BASED NAVIGATION OF SATELLITE FORMATIONS
M. Menn, G. Peterson, C. Chao – The Aerospace Corporation

A Monte Carlo simulation program, CLUSTER, has been written to determine the performance of GPS-based navigation and control of user satellite formations. A master satellite is assumed to be equipped with a GPS receiver while the subordinates may have receivers or frequency translators. The motivation for use of frequency translators is that GPS-to-subordinate-to-master measurements might eliminate the need for precision clocks on the subordinates. Both code and carrier measurements are used and there is an optional master-to-subordinate ranging measurement. GPS message errors may be generated according to current system, Accuracy Improvement Initiative (AII), and navigation message update assumptions. User formations and clock and force model qualities will be varied.

1030 AAS 01 - 321

RISK MANAGEMENT OF UNINTENTIONALLY COLLOCATED GEOSYNCHRONOUS SPACECRAFT
R. Gist, D. Oltrogge – The Aerospace Corporation

Some objects in the geosynchronous belt are unintentionally located near each other and pose a measurable risk of collision unless dealt with through mitigation, cooperative maneuvering, or constant monitoring. Experiences with some instances of unplanned collocation and their resolution are discussed.

1050 AAS 01 - 322

COLLISION RISK MITIGATION IN GEOSTATIONARY ORBIT

L. Anselmo, C. Pardini – Istituto CNUCE, Italy

A new modeling approach and specific software tools were developed to investigate the effectiveness of end-of-life re-orbiting for long-term collision risk mitigation in geostationary orbit. Several satellite explosions, on and above the geostationary altitude, were simulated and propagated for many decades, including all the relevant perturbations. For each fragmentation, the additional contribution to the object density and flux in the geostationary ring was computed as a function of time and debris size. These results were therefore evaluated in order to assess the long-term effectiveness of the mitigation measures recommended at international level.

1110 AAS 01 - 323

COMPARISON OF THE RUSSIAN AND US ALGORITHMS FOR CATALOG MAINTENANCE FOR GEOSYNCHRONOUS SATELLITES

K. Alfriend, S. Paik – Texas A&M University; V. Boikov, Z. Khutorovsky, A. Testov – Vympel Corporation

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

Session 4 Libration Point II
1330 Monday, 30 July

Chair **Kathleen Howell**
Purdue University

1330 AAS 01 - 324

LYAPUNOV AND HALO ORBITS ABOUT L2
M. Kim – Vienna University of Technology, Austria; C. Hall – Virginia Polytechnic Institute and State University

We develop and illustrate techniques to obtain periodic orbits around the second Lagrangian point L2 in the Sun-Earth system based on the Restricted Three-Body Problem. It is shown that in the case of Lyapunov (planar) orbits, the solutions to the linearized equations of motion allow the generation of the entire family of orbits. For Halo orbits, however, the method of strained coordinates is applied to generate higher-order approximate analytic solutions. Subsequent application of Newton's method improves the initial conditions to obtain periodic solutions to the equations of motions.

1350 AAS 01 - 325

REGULARIZATION OF THE RESTRICTED ELLIPTIC THREE-BODY PROBLEM IN THE SUN-EARTH L1-CENTERED ROTATING SYSTEM
J. Kechichian – The Aerospace Corporation

The singular differential equations of motion of the restricted elliptic three-body problem in the sun-earth L1-centered rotating system are regularized in order to remove the singularity near the earth center allowing thereby the use of unconstrained optimization software in solving through an iterative scheme the transfer problem from a low circular parking orbit to any location in the vicinity of L1. The trajectory is integrated backwards from an arbitrarily selected point near L1 and the maneuver velocity change components are searched on in order to achieve certain target parameters at closest approach to the earth. Unlike the restricted circular problem where use is made of the Jacobi constant in order to reduce the order of the differential system, the present restricted elliptic problem requires the addition of a differential equation for the energy variable resulting in a system of ten first order equations cast in terms of the Levi-Civita-Kustaanheimo-Stiefel regularized u-variables. It is shown that the transfer solution obtained with the circular assumption fails to reach the desired halo-insertion location near L1 when the trajectory is run within the framework of the more accurate elliptic model justifying thereby the use of this latter model for higher fidelity trajectory generation.

1410 AAS 01 - 326

ON THE DETECTION OF ENERGETICALLY EFFICIENT TRAJECTORIES FOR SPACECRAFT

M. Dellnitz, O. Junge – University of Paderborn, Germany; M. Lo – Jet Propulsion Laboratory; B. Thiere – University of Paderborn, Germany

We propose a new method for the detection of energetically efficient trajectories for spacecraft. Based on ideas from dynamical systems theory a *shotgun shooting approach* is presented which systematically searches for approximate low-cost trajectories between two specified regions in phase space. These guesses are then meant to serve as initial values for a more detailed determination of the final trajectory. As an application a new and shortened pseudo-trajectory has been found for part of the trajectory of the Genesis Discovery Mission whos trajectory had recently to be redesigned.

1430 AAS 01 - 327

TRAJECTORY SENSITIVITIES FOR SUN-MARS LIBRATION POINT MISSIONS

J. Strizzi, J. Kutrieb, P. Damphousse – Naval Postgraduate School; J. Carrico – Analytical Graphics, Inc.

Previous research analyzed missions utilizing communication relay spacecraft in orbits about the Sun-Mars L1 and L2 points. This effort examines trajectories for various Earth-Mars transfer and Lissajous injection options, including using braking maneuvers at Mars close approach. Also investigated are the sensitivities effecting the insertion and phasing of a two-satellite constellation, including using a loose control technique for stationkeeping. Commercial desktop simulation and analysis tools are used to provide numerical data; and on-going collaboration between military and industry researchers in a virtual environment is demonstrated. The resulting data should provide new information on these trajectories to future researchers and mission planners.

1450 BREAK

1510 AAS 01 - 328

DYNAMICS OF A TETHERED SYSTEM NEAR THE EARTH-MOON LAGRANGIAN POINTS

A. Misra – McGill University, Canada;V. Modi – University of British Columbia, Canada

The paper considers the dynamics of a tethered system in the vicinity of the Earth-Moon Lagrangian points. Equilibrium configurations of the tethered system near all five Lagrangian points are determined and their stability is examined. An analysis of the coupled motion, i.e. motion of the center of mass of the tethered system and tether libration, is carried out for the case when the system is near the translunar libration point.

1530 AAS 01 - 329

INTEGRATION OF LIBRATION POINT ORBIT DYNAMICS INTO A UNIVERSAL 3-D AUTONOMOUS FORMATION FLYING ALGORITHM

D. Folta – NASA/Goddard Space Flight Center

The autonomous formation flying control algorithm developed and demonstrated by the Goddard Space Flight Center (GSFC) for the New Millennium Program (NMP) Earth Observing-1 (EO-1) mission is investigated for applicability to libration point orbit formations. In the EO-1 formation-flying algorithm, control is accomplished via linearization about a reference transfer orbit with a state transition matrix (STM) computed from state inputs. The effect of libration point orbit dynamics on this algorithm architecture is explored via computation of STMs using the flight proven code, a monodromy matrix developed from a N-body model of a libration orbit, and a standard STM developed from the gravitational and coriolis effects as measured at the libration point. A comparison of formation flying Delta-Vs calculated from these methods is made to a standard linear quadratic regulator (LQR) method. The universal 3-D approach is optimal in the sense that it can be accommodated as an open-loop or closed-loop control using only state information.

1550 AAS 01 - 330

A NON-LINEAR APPROACH TO SPACECRAFT FORMATION CONTROL IN THE VICINITY OF A COLLINEAR LIBRATION POINT

R. Luquette – NASA/Goddard Space Flight Center; R. Sanner – University of Maryland

A non-linear satellite trajectory control strategy is developed, based on a Hamiltonian formulation of the equations of motion. System dynamics are defined in the general framework of the restricted three body problem with the two primary bodies orbiting their common, inertially fixed, center of mass. Circular/planar motion restrictions are not required. Lyapanov analysis demonstrates guaranteed global asymptotic convergence. Controller performance is evaluated using FreeFlyer and MATLAB for a ìleaderî spacecraft stationed near a collinear libration point, with a ìfollowerî spacecraft tracking a pre-defined trajectory referenced to the ìleaderî position. Evaluation metrics are fuel usage and tracking accuracy.

1610 AAS 01 - 331

MONTE-CARLO MANEUVER ANALYSIS FOR THE MICROWAVE ANISOTROPY PROBE

T. Goodson, W. Bollman – Jet Propulsion Laboratory

The Microwave Anisotropy Probe (MAP) spacecraft is part of NASA's Explorers Program. It will orbit about the Sun-Earth L2 Lagrange point. A sequence of phasing loops achieves the necessary lunar gravity assist. Correction maneuvers are planned at apogees and perigees of phasing loops. These maneuvers are the subject of a Monte-Carlo analysis, accounting for modeling of injection, orbit determination, and maneuver execution errors. The software, LAMBIC, uses linearization to both simplify the problem and speed-up execution. As a result, particular attention is paid to the linear range of the trajectory's maneuvers. Also, important differences between MAP project plans and the maneuver modeling capabilities of LAMBIC are discussed.

Session 5 Orbit Determination
1330 Monday, 30 July

Chair Michael Gabor
U. S. Space Command/Analysis Directorate

1330 AAS 01 - 332

STAR ACCELEROMETER DATA PROCESSING AND RESULTS: I
R. Biancale, F. Perosanz, J. Lemoine, S. Loyer, S. Bruinsma – Centre National d'Etudes Spatiales (CNES), France

The STAR accelerometer onboard the german satellite CHAMP, launched in July 2000, measures the nongravitational accelerations to which it is subjected. The measurements have to be preprocessed to correct them for several effects. The GPS receiver assures a continuous orbit tracking. Using both instruments in the orbit computation yields an orbit accuracy of approximately 10 cm, validated by SLR data. The comparison of the measured with the modeled accelerations contributes to our better understanding of model error and its impact on the orbit restitution.

1350 AAS 01 - 333

STAR ACCELEROMETER DATA PROCESSING AND RESULTS: PART II
S. Bruinsma, R. Biancale – Centre National d'Etudes Spatiales (CNES), France

The German satellite CHAMP, carrying the STAR accelerometer onboard, has been launched in July 2000. The CHAMP mission profile is compatible with thermospheric studies: it provides good geographical coverage over a period of five year. The processing of the accelerometer data consists of correcting them for maneuvers, specific events, instrumental bias, and the accelerations due to radiation. The total density can then be retrieved, employing a model for the aerodynamic coefficient. Assimmilation of these data in a thermosphere model will probably significantly increase its accuracy, which, in turn, will improve satellite drag modeling, and thus orbit accuracy.

1410 AAS 01 - 334

CHAMP PRECISION ORBIT DETERMINATION
H. Rim, Z. Kang, P. Nagel, S. Yoon, S. Bettadpur, B. Schutz, B. Tapley – The University of Texas at Austin

Since the successful launch of CHAMP in July 2000, CHAMP collects valuable data for determining precise CHAMP orbit. Those include GPS tracking data from JPL's Blackjack GPS receiver, accelerometer data, and precise attitude data from star trackers. A data set of one day, August 7th, 2000, was made public in February this year, and more data will be made public in May this year. This paper describes the CHAMP Precision Orbit Determination (POD) results using the published data set. At 450 km of CHAMP orbit, the current geopotential model, such as EGM-96, predicts more than 35 cm radial orbit errors. To reduce the effect of gravity model errors with the limited data set, two different approaches were employed. One was to solve empirical parameters, such as one-cycle-per-revolution parameters, frequently. The other was to solve the selected geopotential parameters as empirical parameters to absorb gravity model error. The accelerometer data was used to replace the non-conservative force models, such as drag and radiation pressure forces. The resulting orbit accuracy was assessed by analyzing the data residual, comparison with other institute's solutions, such as JPL's reduced dynamic solution, and the Satellite Laser Ranging (SLR) residual analysis.

1430 AAS 01 - 335

RADIATION FORCE MODELING FOR ICESAT PRECISION ORBIT DETERMINATION

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

Launching in December, 2001, the Ice, Cloud, and Land Elevation Satellite (ICESat) will carry the Geoscience Laser Altimeter System (GLAS) in an effort to quantify temporal variations in ice-sheet topography. This objective requires that the GLAS position be determined to within 5 cm, radially, and 20 cm, horizontally. Precision orbit determination (POD) will use dynamic estimation to process the GPS data collected on-board. For the solar and Earth radiation models, *a priori* values of the satellite optical properties have been computed. Their correlations, their recoverability during POD, and the effect of residual errors on orbit accuracy have also been examined.

1450 BREAK

1510 AAS 01 - 336

ITERATIVE FILTERING OF ANTENNA POINTING ANGLES FOR ORBIT DETERMINATION

F. Curti, F. Longo – University of Rome "La Sapienza", Italy

The paper concerns the angle-only orbit determination problem for the Italian satellite MITA from the Malindi Telemetry Station. The method, presented here, is based on the nonlinear estimation theory of the Extended Kalman Filter. Assuming an initial guess of the orbital parameter at the beginning of the pass, the filter processes the whole tracking angle data of the pass, to correct the orbital parameter at the time of the initial guess. The Iterative Kalman Filter, devised in this work, is converging when at least two passes are processed, and the results show its applicability even in the case of few contacts over the station with short duration (which is the case of the MITA mission).

1530 AAS 01 - 337

MEASUREMENT BIAS EFFECTS ON SATELLITE ORBIT ESTIMATION AND PREDICTION

F. Hoots, R. France – GRC International

The catalog of low altitude satellites is maintained with tracking data from radar sites. The radar measurements are characterized by a calibration procedure that determines the mean and standard deviation of each component of the radar measurement. These calibration values are used in orbit determination for satellites by assuming the mean is

a constant bias. The standard deviation is used to weight the components of the observations. If the actual range bias is different from the calibrated bias or if it is not constant, then the effects on the orbit determination and prediction are very interesting. A simple analytic model is developed to examine the functional effect of an unmodeled bias. There are many surprising findings. The most significant is that a range bias will introduce a secularly increasing error in the along track prediction.

1550 AAS 01 - 338

PARALLEL LEAST SQUARES METHODS FOR MULTISATELLITE ORBIT DETERMINATION

P. Nagel, B. Schutz – The University of Texas at Austin

Previous studies of parallel processing methods for use with satellite related, many parameter estimation problems indicated the need for faster numerical integration methods. A study of parallel numerical integration methods for use in satellite orbit determination showed only slight improvement over the fastest serial methods. This result prompted the re-examination of the role of numerical integration in a parallel estimation scheme. A parallel orbit determination scheme, parallel in both observation processing and least squares solution, was implemented. Implementation details will be discussed and performance results of the parallel scheme compared to a serial orbit determination package will be presented.

Session 6 Constellations and Clusters
1330 Monday, 30 July

Chair Karen Richon
NASA/Goddard Space Flight Center

1330 AAS 01 - 339

INVARIANT MANIFOLD MANEUVER TARGETING FOR SATELLITE CLUSTERS

W. Wiesel – Air Force Institute of Technology

Maneuver costs for stationkeeping satellite clusters using the periodic orbit / Floquet theory vary quadratically with the physical size of the cluster, due to the neglect of quadratic terms in the relative motion solution when calculating the maneuvers. We use the theory of invariant manifolds to extend the zero drift manifold from the linear to the nonlinear realm, and show that targeting maneuvers into this manifold results in a decrease of maneuver costs over the linear theory.

1350 AAS 01 - 340

THE AUTONOMOUS DEPLOYMENT OF SATELLITE FORMATIONS USING GENERIC POTENTIAL FUNCTIONS.

F. McQuade, R. Ward – Science Systems (Space) Ltd., United Kingdom

The feasibility of satellite formations and their correct deployment is dependent on the autonomy and flexibility of the control architecture. The deployment control method that is considered within this study is the Potential Function Method. Considering a formation state vector that describes the current state of the formation, it is possible to derive a function that describes the <x-charset iso-8859-1>? correctness? of the formation state vector relative to a desired solution. This function is described as a Potential Function and is derived to conform to laws of Lyapunov?s Second Method i.e. when the Potential Function is zero, the formation is considered ?correct?. Lyapunov?s method allows the analytical derivation of control inputs that will continually force the formation state vector down the potential well, reducing the potential and correctly deploying the formation.

1410 AAS 01 - 341

INITIAL DEPLOYMENT AND NEAR OPTIMAL CONTROL FOR MAINTAINING CONSTANT DISTANCE BETWEEN SATELLITES IN AN ELLIPTICALLY ORBITING CONSTELLATION

Z. Tan, P. 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. The technique for maintaining separation error within _0.45% between satellites in Keplerian orbit was developed in a previous paper. This paper will discuss the initial deployment (the method to distribute the satellites packed together in a launch vehicle to the constellation positions from the transient orbit), and a near optimal control to eliminate the remaining errors from the initial deployment and compensate the effects from various perturbations.

1430 AAS 01 - 342

TRAJECTORY ESTIMATION FOR SATELLITE CLUSTERS
R. Bordner, W. Wiesel – Air Force Institute of Technology

The problem of estimating satellite cluster trajectories can be separated into the problem of estimating the cluster reference orbit (here a periodic orbit consistent with the earth's zonal harmonics), and the problem of estimating satellite relative motion. Using simulated GPS data, we have tracked the cluster center to meter level accuracy, including the entire earth gravity field and air drag. Relative trajectories can be estimated to centimeter level using either differential GPS or satellite to satellite range data. The accuracy levels for the two estimators are decoupled, permitting high accuracy in the relative motion without needing that same accuracy in the reference orbit.

1450 BREAK

1510 AAS 01 - 343

A STUDY OF LINEAR VS. NONLINEAR CONTROL TECHNIQUES FOR THE RECONFIGURATION OF SATELLITE CLUSTERS
D. Irvin, D. Jacques – Air Force Institute of Technology

This paper investigates several linear and nonlinear feedback control methods for satellite formation reconfigurations and compares them to a near optimal open loop, discrete-time, impulsive maneuver. The reconfigurations are done in terms of a set of relative parameters that define an orbit about the leader satellite (or center reference position if a leader satellite does not exist at the center of the formation). The purpose of the study is two-fold, to compare the control usage of continuous feedback control methods versus a discrete burn method and to determine if nonlinear control techniques offer significant improvement over more conventional linear control laws. Linear Quadratic Regulators (LQR), LQR with linearizing feedback, and State Dependent Riccatti Equation (SDRE) are considered. Simulations showed that reconfigurations for small relative orbits were adequately controlled using linear techniques.

1530 AAS 01 - 344

ZONAL COVERAGE OPTIMIZATION OF SATELLITE CONSTELLATIONS WITH AN EXTENDED SATELLITE TRIPLET METHOD
F. Dufour – Centre National d'Etudes Spatiales (CNES), France

The design of a constellation is often based on coverage objectives. Many methods have been developed to evaluate the coverage efficiency of a constellation pattern but they are often restricted to global coverage analyses. Unfortunately, a global coverage is often not the most cost effective paradigm. For example, the commercial viability of a constellation is bound to a good coverage of the market (usually USA, Europe and Japan). So, we also need tools to optimize a constellation with zonal coverage objectives (often defined as latitude bands with a specific coverage level). Walker's triplet method is originally dedicated to continuous global coverage analyses only (1-fold to n-fold). In this paper, we will show how to extend the method to zonal coverage evaluation and optimization. With a few additional tests on zonal boundaries, we can precisely assess the zonal coverage efficiency of any constellation pattern where all satellites are using circular orbits with identical orbital periods. As an illustration of the method, we will design a Galileo-like constellation.

1550 AAS 01 - 345

A PARAMETRIC EXAMINATION OF SATELLITE CONSTELLATIONS TO MINIMIZE REVISIT TIME FOR LOW EARTH ORBITS USING A GENETIC ALGORITHM

T. Lang – The Aerospace Corporation

In the design of satellite constellations, it is not always required to provide continuous coverage of the region of interest. Allowing viewing gaps or revisit times enables the mission to be performed using fewer satellites. In this paper the Genetic Algorithm is employed to optimize the arrangement, in terms of right ascension of ascending node, mean anomaly, and common inclination, of from 3 to 5 satellites so as to minimize the average and maximum values of revisit time. A parametric approach is used to cover the LEO regime from 700 to 1500 km in altitude.

1610 AAS 01 - 346

MULTI-OBJECTIVE OPTIMIZATION APPROACH APPLY OF THE STATION KEEPING OF SATELLITE CONSTELLATIONS

E. Rocco, M. Souza, A. Prado – Instituto Nacional de Pesquisas Espaciais (INPE), Brazil

In this work we study the problem of orbital station keeping maneuvers of satellites constellations with minimum fuel consumption and time constraint. Due to their (geometrical, etc.) constraints, we have the problem of simultaneously optimizing the maneuvers for *n* satellites. In this way an appropriate strategy should be adopted to control the satellites. Therefore, we have a multi-objective problem. Thus, the goal of this work is to formulate and to study maneuver strategies that, in some way, makes it possible to obtain solutions with small fuel consumption considering all the satellites in the constellation.

Session 7 Earth and Lunar Missions
0830 Tuesday, 31 July

Chair Scott Dahlke
U.S. Air Force Academy

0830 AAS 01 - 348

STS-99 SHUTTLE RADAR TOPOGRAPHY MISSION DYNAMICS AND CONTROL - MISSION OVERVIEW
L. Sackett, J. Hamelin, R. Barrington, D. Zimpfer – The Charles Stark Draper Laboratory, Inc.

Draper Laboratory performed an extensive analysis of the Space Shuttle flight control system requirements needed to accomplish the Shuttle Radar Topography Mission (SRTM) on STS-99 in February 2000. During the flight there were two significant hardware failures which affected the dynamics and control. This paper will present an overview of the dynamics and control analysis performed prior to the flight and also a description of the flight experience, which included changing flight control parameters and procedures in response to the failures, thus helping ensure a successful mission. Prior to flight, significant dynamics and control issues included ensuring control stability while meeting the extremely tight pointing requirement for mapping; meeting tight propellant and time constraints during attitude maneuvers; and implementing an unusual “flycasting” orbit trim maneuver using the attitude control system while meeting structural loads constraints.

0850 AAS 01 - 347

STS-99 SHUTTLE RADAR TOPOGRAPHY MISSION STABILITY AND CONTROL
J. Hamelin, M. Jackson, C. Kirchwey, R. Pileggi, L. Sackett – The Charles Stark Draper Laboratory, Inc.

The Shuttle Radar Topography Mission (SRTM) flew aboard Space Shuttle Endeavor February 2000 and used interferometry to map 80% of the Earth’s landmass. SRTM employed a 200-foot deployable mast structure to extend a second antenna away from the main antenna located in the Shuttle payload bay. Mapping requirements demanded precision pointing and orbital trajectories from the Shuttle on-orbit Flight Control System (FCS). Mast structural dynamics interaction with the FCS impacted stability and performance of the autopilot for attitude maneuvers and pointing during mapping operations. A damper system added to ensure that mast tip motion remained within the limits of the outboard antenna tracking system while mapping also helped to mitigate structural dynamic interaction with the FCS autopilot. Late changes made to the payload damper system, which actually failed on-orbit, required a redesign and verification of the FCS autopilot filtering schemes necessary to ensure rotational control stability. In-flight measurements using three sensors were used to validate models and gauge the accuracy and robustness of the pre-mission notch filter design.

0910 AAS 01 - 349

ORBIT DYNAMICS FOR RE-SUPPLYING SPACE STATION USING A MODEST-COST SPACE TUGBOAT

A. E. Turner – Space Systems/Loral

This paper discusses the maneuvers undertaken by a modest-cost space tugboat used for International Space Station (ISS) re-supply. A launch vehicle (LV) available for rapid call-up is assumed to launch a high-priority payload into an orbit from which the ISS can be reached using maneuvers of modest magnitude. The LV payload is assumed to have no on-orbit maneuvering capability. The space tugboat would include the appropriate guidance and control capability and redundancy to rendezvous and dock with the LV payload, captive-carry it to the ISS, and to operate in the ISS environment to support delivery of the payload.

0930 AAS 01 - 350

ORBIT DYNAMICS FOR REDUCED-COST SPACECRAFT DEPENDENT ON FREQUENT NON-INTRUSIVE SERVICING

A. E. Turner – Space Systems/Loral

This paper discusses the maneuvers undertaken by a client spacecraft and a support vehicle where the spacecraft is completely dependent upon the support vehicle for on-orbit position-keeping and repositioning. This vehicle would act as a space tug for captive-carry through maneuvers and/or as a short-term/just-in-time propellant supplier for maneuvers performed by the client. These maneuvers include atmospheric drag compensation for spacecraft in low orbits and north-south stationkeeping for spacecraft in geosynchronous orbit. The support vehicle would rendezvous and dock with each client for a few hours each week or each month as appropriate, and would service a dozen clients.

0950 BREAK

1010 AAS 01 - 351

ORBITAL DESIGN FOR HYPSEO MISSION

A. Foni – CNUCE, Italy; V. De Cosmo, M. Crisconio – Italian Space Agency

HypSEO is the name of a small satellite aiming to demonstrate the functionalities and capabilities of an advanced design hyperspectral sensor for Earth observation. The program, sponsored and managed by the Italian Space Agency, consists in a demonstration flight to be performed before the end of year 2003. Because of the demonstration and experimental purpose of the mission, the orbit design and mission analysis have considered also the possibility of inclined orbits besides the classical sun-synchronous orbit normally used for such electro-optical sensors. The paper discusses the studies and analyses carried out in the field of the orbit dynamics for HypSEO Mission.

1030 AAS 01 - 352

DESIGN AND SYSTEM IDENTIFICATION OF A NANOSATELLITE STRUCTURE

C. Stevens, J. Schwartz, C. Hall – Virginia Polytechnic Institute and State University

The Virginia Tech Ionospheric Scintillation Mission, known as HokieSat, is a 15 kg nanosatellite being designed and built by graduate and undergraduate students. The satellite is part of the Ionospheric Observation Nanosatellite Formation which will perform ionospheric measurements and conduct formation flying experiments. In this paper we describe the design of the primary satellite structure, including the analysis used to arrive at the design. We also describe the internal and external configurations of the spacecraft and how we estimate the mass, mass center, and moments of inertia.

1050 AAS 01 - 353

NEAR-EARTH SOLAR SAIL NAVIGATION: PRELIMINARY RESULTS

E. Christensen, B. Williams, R. Ionasescu – Jet Propulsion Laboratory

Preliminary analyses have been conducted to assess the demands solar sails will make on the design of future navigational systems. A simulation of a 40mx40m solar sail used for raising the altitude of a 157 kg sun-synchronous Earth orbiter in a ~1000 km altitude, nearly circular, spiral orbit was performed. Though the forces and orbit perturbations introduced by the sail are quite small, we were able to calibrate the accelerations acting on the sail to within ~ $6x10^{-4}$ $mm/s^{2.}$ in ~3 days, with one pass of Deep Space Network (DSN) tracking per day. Our paper will focus on this, other near Earth missions, and will also include some preliminary observations relevant to deep space and interstellar solar sail missions.

1110 AAS 01 - 354

LUNAR LANDING TRAJECTORIES, A COMPARISON OF CURRENT AND PAST TECHNIQUES

M. Loucks – Space Exploration Engineering; J. Carrico – Analytical Graphics, Inc.

The authors compare historical lunar landing trajectories from Apollo and Surveyor to current plans for a commercial lunar landing mission. Direct transfer and landing trajectories are explored, along with phasing loop and weak stability boundary trajectories such as those suggested by Belbruno.

Session 8 Collision Avoidance and Tracking
0830 Tuesday, 31 July

Chair **Kim Luu**
Air Force Research Laboratory

0830 AAS 01 - 356

REDUCTION OF THE ERROR VOLUME FOR RSO COLLISION PREDICTIONS BY THE APPLICATION OF ATMOSPHERIC DRAG FORCE INFORMATION
S. Knowles – Raytheon Technical Services Company

A primary driver in the current effort to improve orbital accuracy is to reduce the size of the error ellipsoid attaching to the predicted position of both the colliding and collided RSO. This is because the present predictive ellipsoids for LEO satellites are so large as to be a limiting factor in the protection possible. Underlying current error methodology is the assumption that the error ellipses of the two objects are statistically independent. In this contribution it is shown that application of the knowledge that a variation in the atmospheric density causes a covarying effect on the orbits of the two close approaching RSOs, together with the now-accepted determination of the empiricial mean ballistic coefficient for each from extended orbit determination, enables a significant reduction in this error volume.

0850 AAS 01 - 357

DETERMINING IF TWO ELLIPSOIDS SHARE THE SAME VOLUME
S. Alfano, M. Greer – The Aerospace Corporation

A new satellite conjunction prediction technique has been developed by adding an extra dimension to the covariance space. The subset of eigenvalues that are associated with intersecting degenerate quadric surfaces are then examined. The same method is also used to determine if two ellipsoids appear to share the same projected area based on viewing angle. The approach yields direct results without approximation, iteration, or any form of numerical search. It is computationally efficient in the sense that no scaling, rotating, or transformations are needed. It applies to all quadric surfaces and is not limited to ellipsoids. This method expands the two-dimensional work of Kenneth Hill in his formulation of degenerate conics. It also furthers his work by examining the associated eigenvalue behavior.

0910 AAS 01 - 358

A SIMPLE MATHEMATICAL APPROACH FOR DETERMINING INTERSECTION OF SURFACES DESCRIBED BY QUADRATIC FORMS
K. Chan – The Aerospace Corporation

This paper is primarily concerned with the mathematical formulation of the conditions for intersection of two surfaces described by quadratic forms. Of special interest is the application to the case of two positional error ellipsoids in the three dimensional space associated with the pairwise close encounters arising from thousands of space orbiting objects listed in the US Satellite Catalog. These error ellipsoids are obtained from the covariance matrices associated with these tracked objects. The determination of intersection is used in collision screening in order to eliminate cases which do not require more detailed further analysis. Even the simplest of traditional approaches to intersection determination has been based on a relatively computation intensive constrained numerical optimization. An alternative novel technique, used by Alfano and Greer, is based on formulating the problem in four dimensions and then determining the eigenvalues of the associated degenerate quadric surface. This method has strictly relied on many numerical observations of the eigenvalues to arrive at the conclusion whether these ellipsoids intersect. This paper provides a rigorous mathematical formulation to explain the myriads of numerical observations obtained through trial and error. Moreover, these results also find application in computer graphics and robotics. In these areas, one frequently has to deal with geometric objects and determine whether they intersect or obscure one another.

0930 AAS 01 - 359

MANEUVER OPTIMIZATION FOR COLLISION RISK MINIMIZATION
R. Patera, G. Peterson – The Aerospace Corporation

As the population of orbiting vehicles and associated space debris grows, the risk of collision increases. One method to mitigate collision risk is to perform a collision avoidance maneuver. During actual spacecraft operations, there is not much time between final determination of the collision risk and the time when a maneuver decision must be made. Therefore, a quick and accurate means of identifying optimal burns that will reduce the risk to an acceptable level is needed by mission operators. A methodology is presented that can perform this function. Comparisons show this method is orders of magnitude faster than other methods while yielding a solution that is just as accurate.

0950 BREAK

1010 AAS 01 - 360

MODERNIZING THE NAVAL SPACE SURVEILLANCE SYSTEM-PART 1
M. Zedd – Naval Research Laboratory; E. Najmy – Naval Space and Warfare Systems Command (SPAWAR)

In 1999 and 2000, the Navy began the groundwork for a ten-year program to update the Naval Space Surveillance System. Administrative plans, initial design concepts, and analyses are progressing toward modernizing the Fence system. Because of intense interest within the AAS/AIAA conference programs in Fence products, this paper introduces you to new system expectations. Also, there is a new Department of Defense requirement to detect and determine the orbits of objects as small as 5 cm (down from the current Fence capability of around 30 cm). Therefore, the updated Fence will have enhanced capabilities to newly detect an estimated 110,000 objects compared to the 10,000 objects in today's catalog. This paper broadly reviews the goals for the new Fence and the processes the Navy is using to achieve these goals.

1030 AAS 01 - 361

NAVAL SPACE SURVEILLANCE SYSTEM CALIBRATION USING SATELLITE LASER RANGING

J. Seago, M. Davis, A. Reed – Naval Research Laboratory; E. Lydick, P. Schumacher, Jr. – Naval Space Command

The Naval Space Command's Naval Space Surveillance System, commonly known as the Fence, is one of the world's largest antenna systems and serves as the only continuously operated, uncued satellite detection system in the US. Highly accurate satellite orbits determined from laser ranging provide a suitable reference for estimating the true errors in interferometric Fence observations. Long term analyses of the estimated Fence residuals suggest that some error features are static and therefore reproducible using an error model. A set of empirically-tuned models are evaluated in this paper. The residual errors are also assessed to characterize the temporal errors that cannot be accommodated by these models. A revised concept of operations is described for implementing the preferred error model.

Session 9 Control
0830 Tuesday, 31 July

Chair Don Mackison
University of Colorado

0830 AAS 01 - 363

ON REDUCING MINIMUM TIME FOR SMALL ANGLE SLEWING OF A FLEXIBLE BODY

A. Banerjee – Lockheed Martin Advanced Technology Center

Command shaping for slewing a flexible body through a large angle in minimum time with vibration suppression requires a slew time of rigid body minimum time plus the period of vibration to be suppressed. Increasing the torque level so as to reduce the rigid body minimum time by the period of vibration was recently proposed to reduce the minimum time. This method becomes inapplicable when the rigid body slew time is less, as in small angle slewing, than the period of vibration excited. The present paper gives two exact methods of command shaping in this case.

0850 AAS 01 - 364

TRAJECTORY TRACKING CONTROL OF A MULTIMODULE DEPLOYABLE MANIPULATOR: ANALYSES AND EXPERIMENTS

Y. Cao, V. Modi , C. de Silva – University of British Columbia, Canada; A. Misra – McGill Univeristy, Canada

This paper presents results of trajectory tracking performance of a two-module (i.e., four-link) space platform-based manipulator with two revolute and two prismatic joints. The control approach here is based on the Feedback Linearization Technique (FLT). The paper considers trajectories in the form of straight lines and circles in the vertical *x–y* plane. Finally, the numerical simulations are complemented with the experimental results, obtained using a ground-based prototype manipulator specifically designed to assess the controlled performance of the novel design.

0910 AAS 01 - 366

NONLINEAR OPTIMAL CONTROL APPLIED TO SPACECRAFT CONTROL

A. An – Beijing University of Aeronautics and Astronautics, China; H. Fujii, M. Iwasaki, T. Kusagaya, M. Horikoshi – Tokyo Institute of Technology, Japan

A nonlinear optimal control algorithm based on both geometry nonlinear feedback decoupling method and hierarchical differential method is presented and applied to a spacecraft control problem. The algorithm deals with the system each pair of input and output separately and enables one to solve optimal feedback control problems without solving the Riccati Equations or adjoint vectors. Performance of the present algorithm is verified for the present example of spacecraft control by numerical simulation.

0930 AAS 01 - 367

A SPACECRAFT SIMULATOR FOR RESEARCH AND EDUCATION
B. Kim, E. Velenis, P. Kriengsiri, P. Tsiotras – Georgia Institute of Technology

We present the details for the design and construction of a spacecraft simulator at the School of Aerospace Engineering of the Georgia Institute of Technology. The main purpose of this spacecraft simulator is the experimental validation of various spacecraft control strategies on the ground. A virtually torque-free environment is achieved by carefully balancing the spacecraft platform (the spacecraft ``bus") on a hemi-spherical air bearing. Three DC motors drive the custom-made steel wheels that are used as reaction wheels to control the attitude of the spacecraft. Attitude and attitude rate information is provided by a dynamic measurement unit, while a PC104 type Pentium 266MHz board and an additional data acquisition board are used as a central control unit. A remote PC monitors the status of the device by means of a wireless RS-232 interface. A special-purpose software was developed for both the remote PC and control computer. We also briefly discuss the major issues raised during the design and construction of the simulator (such as sensor output filtering, motor gain identification, etc). Finally, we present some experimental results from the application of a simple LQR attitude stabilizing controller on the spacecraft simulator.

0950 BREAK

1010 AAS 01 - 368

GENERATING DEFLECTION-LIMITING COMMANDS IN THE DIGITAL DOMAIN
M. Robertson, W. Singhose – Georgia Institute of Technology

A method for creating deflection-limiting commands in the digital domain is described and evaluated. The major advantage of this method is that the problem is solvable with a linear optimization, rather than a nonlinear optimization. Characteristics of the command profile are presented as a function of deflection limit and slew distance. This method compares favorably to techniques which create the deflection-limiting commands in the continuous domain.

1030 AAS 01 - 369

GENERALIZED MATCHED BASIS FUNCTION REPETITIVE CONTROL
H. Chen, B. Agrawal – Naval Postgraduate School; R. Longman – Columbia University

Spacecraft often have multiple sources of vibrations such as imbalances in momentum wheels, reactions wheels, control moment gyros, cryo pumps, etc. The needed characteristics are outlined for a control system to be able to eliminate multiple unrelated periodic vibrations from such causes at the location of some fine pointing equipment. Experiments are performed on an Ultra Quiet Platform, a Steward platform for isolating sensitive equipment. This platform is similar to platforms that will be flown on several future spacecraft. Previous research by the authors reported results that handle well the disturbance form one fundamental frequency and its harmonics. Also, methods were presented that eliminate the need for and extra sensor at the disturbance source. In this paper we develop more sophisticated methods to handle the case of multiple unrelated frequencies. In addition, more finely tuned methods are developed, extending the matched basis function repetitive control approach so that it can handle this more general disturbance environment.

Session 10 Special Session: NEAR at EROS
1330 Tuesday, 31 July

Chair Bob Farquhar
JHU/Applied Physics Laboratory

1330 AAS 01 - 370

NEAR SHOEMAKER AT EROS: RENDEZVOUS, ORBITAL OPERATIONS, AND A SOFT LANDING
R. Farquhar, D. Dunham, J. McAdams – JHU/Applied Physics Laboratory

On February 14, 2000, the NEAR Shoemaker spacecraft was placed into a 321 x 364 km. orbit around the near-Earth asteroid 433 Eros. NEAR's orbit was adjusted many times during its year–long operations at Eros, reaching a minimum altitude of only 2.74 km. Finally on February 12, 2001, NEAR executed a perfect three–point landing on the surface of Eros. The estimated impact velocity of 1.7 m/sec may be the lowest landing speed ever. NEAR's landing on Eros was the first time that a spacecraft had touched down on a small body.

1350 AAS 01 - 371

NAVIGATION FOR NEAR SHOEMAKER: THE FIRST MISSION TO ORBIT AN ASTEROID
B. Williams, P. Antreasian, J. Bordi, E. Carranza, S. Chesley, C. Helfrich, J. K. Miller, W. Owen, T. Wang – Jet Propulsion Laboratory

When the Near Earth Asteroid Rendezvous (NEAR) Shoemaker spacecraft began its orbit about the asteroid 433 Eros on February 14, 2000, it marked the beginning of many firsts for deep space navigation. Among these were the design and estimation techniques that were necessary to plan and execute an orbit about an irregularly shaped small body. Knowledge of the mass, gravity distribution, and spin state of Eros had to be quickly improved on final approach in order to predict the effect of trajectory correction maneuvers for capture and orbit control around Eros. This required the use of optical landmark tracking, which used pictures of craters on Eros as landmark information, in addition to the more traditional radio metric tracking from NASA's Deep Space Network. The operational use of optical landmark tracking was another navigation first for the NEAR mission. As part of the ongoing effort to improve the Eros physical model, altimeter data from the NEAR laser range instrument was also processed and analyzed. This paper describes the navigation strategy and results for the rendezvous and orbit phases of the NEAR mission. Included are descriptions of the new techniques developed to deal with navigation challenges encountered during the yearlong orbit phase. The orbit phase included circular orbits down to 35 km radius and elliptical orbits that targeted overflights to within 2.7 km above the surface. Many of these methods should prove useful for navigation of future missions to asteroids and comets.

1410 AAS 01 - 372

THE DESIGN AND NAVIGATION OF THE NEAR SHOEMAKER LANDING ON EROS

P. Antreasian, S. Chesley, J. K. Miller, J. Bordi, B. Williams – Jet Propulsion Laboratory

After a 4.5 hour controlled descent using five open-loop maneuvers on February 12, 2001, the Discovery-class NEAR-Shoemaker spacecraft successfully landed on the surface of Eros becoming the first spacecraft ever to touchdown on an asteroid. This landing was made extraordinary by the fact that the spacecraft was not designed for landing and it remained in telecommunications with NASA's Deep Space Network afterwards. The descent trajectory was designed primarily to acquire as many close range high-resolution images (< 1 km) as possible while providing optimal viewing geometries and secondarily to ensure the safety of the spacecraft by minimizing its impact velocity. Since the spherical harmonic representation of Eros' gravity diverges below the sphere circumscribing the asteroid (< 18 km), a polyhedral gravity field based on our Eros shape determination was used for integrating the trajectory below this limit. This paper discusses the design, navigation and the Monte Carlo error analyses that were critical to the design of this landing scenario. Also described is the reconstruction of the landing trajectory using radio metric, optical landmark and laser ranging tracking data, which determined the characteristics of the landing to be well within the error analyses.

1430 AAS 01 - 373

THE ORBITAL DYNAMICS ENVIRONMENT OF 433 EROS

D. Scheeres – The University of Michigan; J. K. Miller, D. Yeomans – Jet Propulsion Laboratory

The NEAR-Shoemaker mission has achieved a number of ``firsts". From an orbital dynamics point of view one of the firsts accomplished by the spacecraft was the practical navigation of a spacecraft in the most severely perturbed orbital environment (relative to the standard 2-body problem) ever experienced by a spacecraft. Thus it is of interest to discuss and review the orbital dynamics of the NEAR-Shoemaker spacecraft in light of the total orbit dynamic environment at Eros. During the course of its mission, the NEAR-Shoemaker spacecraft served as a probe for determining the force environment and, hence, the dynamical environment in the vicinity of 433 Eros. As a direct result of radio science measurements and the navigation of the spacecraft, detailed models of the Eros mass, bulk density, gravity field, shape, and rotation state were estimated. This paper first provides a review of these measured parameter values. Next, an evaluation of the resulting orbital dynamics environment in the vicinity of Eros is made using these measurements. In particular, the limits for stable and unstable motion about Eros, the dynamical environment on the surface of the asteroid, and the extent of its sphere of influence relative to the sun are discussed. Finally, the orbital motion of the NEAR-Shoemaker spacecraft during the mission is discussed in light of the Eros dynamical environment.

1450 BREAK

1510 AAS 01 - 374

MODELING AND PERFORMANCE OF NEAR'S G&C SYSTEM DURING THE EROS ORBITAL PHASE AND CONTROLLED DESCENT
G. Heyler, J. Ray – JHU/Applied Physics Laboratory; A. Harch, B. Carcich – Cornell University

NEAR's one year orbital phase about asteroid 433 Eros consisted of daily science data collection events and 25 Orbit Correction Maneuvers (OCMs) requiring precise s/c pointing and thrusting control. The mission was culminated with a five hour controlled descent and soft landing on the surface. The G&C system was critical for such events; a quick overview of the G&C system is given. The process for modeling and developing the attitude and thrusting plans is described. A critical component of this development process was the close interaction between the imaging scientists, the G&C engineers, and the Navigation team all utilizing high fidelity truth models of the spacecraft, asteroid shape, and asteroid gravity. Designed vs achieved OCM statistics are given. Of particular interest was the controlled descent that consisted of five pointing and thrusting events. This event was monitored in real-time by considering the laser ranger as a surrogate altimeter; range data were plotted against a pre-generated predicted range curve and used as a metric to assess trajectory performance as the descent unfolded.

1530 AAS 01 - 375

433 EROS ORBITAL MISSION OPERATIONS - IMPLEMENTING THE FIRST ORBITAL OPERATION AROUND A SMALL BODY
M. Holdridge – JHU/Applied Physics Laboratory

On February 14, 2000, the NEAR spacecraft became the first spacecraft to orbit a small body, 433 Eros. The intensive year long orbital mission the ensued included numerous orbit changes and instrument operations designed to maximize the science return. The NEAR team performed this operations feat with processes and tools developed during the four year long cruise period preceding Eros orbit insertion. During this cruise period a relatively small mission operations team also carried out several important mission events including the flyby of asteroid 253 Mathilde , a Deep Space Maneuver, and an Earth flyby. Lessons learned from these early events helped shape the mission operations team and its tools into a well integrated team that carried out the first ever intensive orbital science mission around a small body. This paper discusses the operations processes and systems developed at JHU/APL that permitted a small team to conduct the Eros orbital mission in a highly effective manner.

1550 AAS 01 - 376

NEAR OPTICAL NAVIGATION AT EROS
W. Owen, Jr., T. Wang – Jet Propulsion Laboratory; A. Harch, M. Bell, C. Peterson – Cornell University

Successful navigation of the spacecraft NEAR Shoemaker during its orbit phase at the asteroid Eros depended critically on optical navigation. The irregular shape of Eros and its large apparent size precluded the use of traditional optical navigation techniques whereby the center of mass of a target body is located relative to stars in onboard imaging. Rather, optical navigation during NEAR Shoemaker's orbit phase consisted

of locating small craters in images of Eros' surface and using those landmarks to infer Eros' rotation state, the body-fixed coordinates of each landmark, and the trajectory of the spacecraft.

Session 11 Attitude Dynamics and Control
1330 Tuesday, 31 July

Chair **Alfred Treder**
Dynacs Engineering Co., Inc.

1330 AAS 01 - 377

COMMAND GENERATION FOR FLEXIBLE SPACECRAFT MANEUVERS USING SINGLE GIMBAL CONTROL MOMENT GYROSCOPES

G. Avanzini – Polytechnic of Turin, Italy; G. de Matteis – University of Rome "La Sapienza", Italy

The objective of this study is the development of control laws for reorientation maneuvers of flexible spacecraft using single gimbal control moment gyroscopes (SGCMG). An inverse simulation algorithm based on a local optimization technique is applied to a simplified dynamical model of the vehicle where the gimbal dynamics is neglected and a gimbal rate command is considered. As an application of the method, rest--to--rest maneuvers of a rigid hub with three elastic appendages, featuring the classic pyramid--type configuration of four SGCMGs for control torque generation, are dealt with. The characteristics of the obtained steering laws are discussed in detail in terms of singularity avoidance, elastic mode excitation and real--time implementation.

1350 AAS 01 - 378

STABLE RELATIVE EQUILIBRIA OF A DISSIPATIVE CONTROLLER FOR GYROSTAT ATTITUDE

M. Peck – Boeing Satellite Systems

This paper offers explicit solutions for the stable relative equilibria of a gyrostat (i.e. a rigid body with internal angular momentum) under a type of active control designed to dissipate kinetic energy. The controller is mathematically equivalent to existing models of viscous fluid dampers, but the control torques are provided by the internal momentum wheels or control-moment gyros. A Lyapunov analysis demonstrates the stability of the closed-loop equilibria of this system, which can accommodate a body-fixed, constant wheel momentum command (to establish dynamic balance relative to an arbitrary axis, for example). A general solution for these equilibria is provided. Then, explicit expressions for these equilibria are derived for some special cases, providing a root locus for the body-frame angular-velocity vector associated with each equilibrium solution.

1410 AAS 01 - 379

SPACECRAFT ATTITUDE CONTROL AND POWER TRACKING WITH SINGLE-GIMBALED VSCMGS AND WHEEL SPEED EQUALIZATION

H. Yoon, P. Tsiotras – Georgia Institute of Technology

A control law for an integrated power/attitude control system (IPACS) for a satellite using variable speed single-gimbal control moment gyros (VSCMG) is introduced. While the wheel spinning rates of the conventional CMGs are controlled to be a constant, the rates of VSCMGs are allowed to have variable speeds. Therefore,

VSCMGs have extra degrees of freedom and can be used for additional objectives such as energy storage as well as attitude control. The gimbal rates are mainly used to provide the reference-tracking torques and the wheels to provide not only the reference-tracking torque but also the power to the spacecraft, storing or releasing their kinetic energy. Moreover, control laws for equalizing the wheel speeds to minimize the possibility of saturation and singularity are also presented. Finally, a numerical example for a satellite in a low Earth near-polar orbit is provided to test the proposed IPACS algorithm.

1430 AAS 01 - 380

MOMENTUM MANAGEMENT FOR THE MESSENGER MISSION

R. Vaughan, D. Haley, D. O'Shaughnessy, H. Shapiro – JHU/Applied Physics Laboratory

Planning is now underway for the MESSENGER mission to Mercury. Scheduled for launch in 2004, MESSENGER will orbit the planet for 1 Earth-year beginning in April 2009. Reaction wheels will be the primary actuators for attitude control, making momentum management an essential guidance and control task. This paper summarizes momentum modeling for the MESSENGER spacecraft and describes different momentum management strategies. The paper explores the trade space between momentum storage capacity of the reaction wheels, offloading of momentum using thruster dumps, and passive reduction of system momentum using torque generated from solar pressure on the spacecraft's Sun shade.

1450 BREAK

1510 AAS 01 - 381

ATTITUDE DETERMINATION USING WINDOWED QUATERNION ESTIMATOR

I. Kim – INHA University, Korea; J. Kim – Swales Aerospace; C. Park – INHA University, Korea; S. Rhee – Korea Aerospace Research Institute

The combination techniques of the sequential and the single frame determination algorithms have been studied since QUEST. They need the rate information for the state transition from time to time. In the paper, we would choose the rate estimates rather than the gyro sensor. We determine them utilizing the successive two quaternion estimates from QUEST and take the finite moving average. Besides, the disturbance accommodating control (DAC) observer, which estimates the total applied torque in control system, compensates the estimation error during slew rate. The application example for two star trackers is given for verification.

1530 AAS 01 - 382

TARGETING OF PRECESSION MANEUVER WITH ACTIVE NUTATION CONTROL

S. Tanygin – Analytical Graphics, Inc.

Targeting using differential correction is proposed for simultaneous precession maneuver and active nutation control. The method utilizes analytic first guess and analytic sensitivity matrix. Nominally, only certain ratios of axial and transverse moments of inertia facilitate nutation cancellation for precession maneuver. Spacecraft with other ratios can be subjected to significant residual nutation, which may need to be actively controlled. The proposed method modifies start and stop times of each pulse during the precession maneuver in order to reduce residual nutation while maintaining precession accuracy.

1550 AAS 01 - 383

COMPLETE NONLINEAR OPTIMAL SOLUTION OF THE SPACECRAFT ATTITUDE CONTROL PROBLEM

A. Tewari – Indian Institute of Technology, Kanpur, India

Nonlinear optimal feedback control of the complete, three-axis, asymmetric spacecraft attitude dynamics and kinematics is presented. The optimality condition is obtained through Hamilton-Jacobi formulation for the minimization of a cost function in terms of rotational velocities, kinematic parameters, and control torques. A positive-definite Lyapunov function is derived for asymptotic stability with arbitrarily large initial conditions using appropriately selected cost parameters. Numerical results for a rigid spacecraft undergoing large, rapid rotational maneuvers establish the superiority of the present nonlinear controller when compared to a semi-optimal controller derived using cascade interconnection between the kinematic and dynamic equations.

1610 AAS 01 - 384

TIME-OPTIMAL REORIENTATION OF ASYMMETRIC RIGID BODIES

R. Proulx – The Charles Stark Draper Laboratory, Inc.; I. M. Ross – Naval Postgraduate School

We investigate the numerical determination of time optimal controls for an *asymmetric* rigid body towards the goal of developing a method for constructing globally optimal maneuvers. We use a direct shooting method coupled with genetic algorithms (GA) to find coarse estimates of the global optimal. These are used to seed the recently developed Legendre pseudospectral transcription technique. Our investigation revealed that GA did not always yield the optimal solution. It sometimes converged to an objective function of approximately twice the optimal value. The pseudospectral method converged to approximately the same solutions. The solution optimality was checked using estimated costates derived quickly and easily from the pseudospectral costate mapping theorem.

Session 12 Mars Missions I
0830 Wednesday, 1 Aug

Chair **Daniel Lyons**
Jet Propulsion Laboratory

0830 AAS 01 - 385

AEROBRAKING AUTOMATION OPTIONS
D. Lyons – Jet Propulsion Laboratory

Two interplanetary missions, Magellan and Mars Global Surveyor have successfully used aerobraking to supply a delta-V change of 1200 m/s. Both of these missions required extensive commanding from the ground in order to keep the activities on the spacecraft, especially those during the pass through the atmosphere, synchronized with the actual orbit. This paper will first describe how aerobraking operations have been done in the past, and will then explore some options for automating some of these activities in order to reduce the strain on both the DSN resources and the Flight Team sanity. Automating the aerobraking process will be especially important for the Mars Reconnaissance Orbiter (MRO) mission, which is planned to launch in August 2005.

0850 AAS 01 - 386

ACCELEROMETER DATA AS AN OBSERVATION TYPE FOR MARS AEROBRAKING MISSIONS: A PHASE "A" STUDY
M. Jah – University of Colorado

For interplanetary missions, NASA's Deep Space Network (DSN) is employed for the purpose of communicating with spacecraft. However, the needed DSN-spacecraft communications geometry is not continuously maintained throughout aerobraking. Being that some spacecraft are equipped with accelerometers, this research focuses upon the possibility of using accelerometer data as a means of augmenting the current state knowledge of the spacecraft. The specifics of accelerometers, mathematical formulations of the measured acceleration, and a method by which this data may be applied toward improving spacecraft navigation are all addressed. The research shows that this method provides for an improvement to spacecraft navigation accuracy.

0910 AAS 01 - 387

AN APPROACH FOR AUTONOMOUS AEROBRAKING TO MARS
J. Hanna – NASA/Langley Research Center; R. Tolson – The George Washington University

Atmospheric aerobraking was an essential component in establishing the science orbit for the Mars Global Surveyor (MGS) and will most likely be incorporated in every future Mars orbiting mission. In the past, this method required intensive manpower during operations. Automating the process with onboard measurements could significantly reduce this burden and in addition reduce the potential for human error. Two levels of automation are presented and validated using part of the MGS aerobraking sequence. The approach is also compared with high fidelity Mars 2001 Odyssey aerobraking sequence simulations.

0930 AAS 01 - 388

ATTITUDE CONTROL DURING AUTONOMOUS AEROBRAKING FOR NEAR-TERM MARS EXPLORATION

W. Johnson, J. Longuski – Purdue University; D. Lyons – Jet Propulsion Laboratory

We investigate an autonomous attitude control scheme for Mars aerobraking missions which eliminates the need for propulsive angular momentum dumping maneuvers. The Mars Global Surveyor wasted propellant in managing the spacecraft's angular momentum and required continuous monitoring and control from the ground. In our proposed scheme, reaction wheels can be used to control the spacecraft's attitude during each atmospheric flythrough and automatically compensate for changes in the spacecraft's angular momentum. We develop robust control laws to foster automation of the aerobraking procedure. The most challenging aspect of this research is that only angular rate feedback is measured (i.e., dynamic pressure, acceleration, atmospheric density, angle of attack, position, and velocity measurements are not available). Preliminary results indicate that angular momentum can be managed with reaction wheels alone and without wasting propellant.

0950 BREAK

1010 AAS 01 - 389

DEVELOPMENT OF A MONTE CARLO MARS-GRAM MODEL FOR MARS 2001 AEROBRAKING SIMULATIONS

A. Dwyer – NASA/Langley Research Center; R. Tolson – The George Washinton University; M. Munk, P. Tartibini – NASA/Langley Research Center

During the aerobraking phase of the Mars Global Surveyor (MGS) mission, drag measurements indicated significant variability in the atmosphere. These results suggest that Monte Carlo simulations are an appropriate approach for determining maneuver budgets, aerobraking duration and maneuver strategies. Using MGS data, statistical distributions are determined for the mean density and the amplitude and phase of stationary atmospheric waves. This model is then used in Monte Carlo simulations for the Mars 2001 Odyssey mission. Examples of Monte Carlo results are presented along with interpretation of contributions of various terms in the statistical atmospheric model.

1030 AAS 01 - 390

OPTIMIZING MASS DELIVERED TO THE MARS MAPPING ORBIT USING AEROBRAKING FOR THE 2005 LAUNCH OPPORTUNITY

R. Anderson – University of Colorado; D. Lyons – Jet Propulsion Laboratory

In this study, the Earth to Mars phase of the mission for the 2005 opportunity was analyzed by solving the Lambert problem and examining the corresponding porkchop plots. The next portion of the study focused on an Earth to Mars Type I trajectory launching on August 17, 2005 and arriving on March 1, 2006. Simulating Mars orbit insertion and aerobraking showed that the desired mean local solar time of the longitude of ascending node could be reached for a twenty-day launch window. Finally, the study showed that capture DV could be reduced by using later launch and arrival dates.

1050 AAS 01 - 391

2001 MARS ODYSSEY MISSION DESIGN

D. A. Spencer, R. Mase, J. Smith, J. Bell – Jet Propulsion Laboratory; B. Sutter – Lockheed Martin Astronautics

The 2001 Mars Odyssey Project is part of an ongoing series of robotic missions to Mars within the Jet Propulsion Laboratory's Mars Exploration Program. The 2001 Mars Odyssey orbiter carries scientific payloads that will determine surface mineralogy and morphology, provide global gamma-ray observations for a full Mars year, and study the Mars radiation environment from orbit. In addition, the orbiter spacecraft will serve as a data relay for future landers. This article describes the Odyssey mission design and navigation strategy.

1110 AAS 01 - 392

STRATEGIES FOR ON-ORBIT RENDEZVOUS CIRCLING MARS

P. Labourdette – Centre National d'Etudes Spatiales (CNES), France; A. Baranov – Russian Academy of Sciences

Usual rendezvous on orbit last few days. Orbits are in general near-circular and by choosing time of launch, orbits are near-coplanar. We describe a method that has been chosen by CNES and KIAM to solve this class of problem. Example problems are presented to illustrate the results. For some Martian missions, very long range (few months) and non-coplanar rendezvous are envisaged. We depict some preliminary work that is undertaken at CNES and we give some results obtained for test cases.

Session 13 Neutral Density
0830 Wednesday, 1 Aug

Chair Frank Marcos
Air Force Research Laboratory

0830 AAS 01 - 394

NRLMSISE-00 EMPIRICAL ATMOSPHERIC MODEL: COMPARISONS TO DATA AND STANDARD MODELS

J. Picone – Naval Research Laboratory; A. Hedin – Universities Space Research Association; D. Drob, J. Lean – Naval Research Laboratory

This paper describes the new NRLMSISE-00 model of atmospheric composition, temperature, and total mass density and discusses performance relative to other standard models used by the scientific and operational communities. The NRLMSIS database underlying the new model now covers total mass density from satellite drag (Jacchia, Barlier) and accelerometers. A new species, "anomalous oxygen," for drag estimation, allows for appreciable O^+ or hot atomic oxygen contributions to the total mass density at high altitudes. Extensive tables present a statistical comparison of data to NRLMSISE-00, MSISE-90, and Jacchia-70. NRLMSISE-00 achieves an improvement over MSISE-90 and Jacchia-70, incorporating the advantages of each.

0850 AAS 01 - 393

PARAMETERIZATIONS OF SOLAR EUV IRRADIANCE VARIATIONS FOR USE IN UPPER ATMOSPHERE DENSITY MODELS

J. Lean, J. Picone, J. Mariska – Naval Research Laboratory; H. Warren – Harvard-Smithsonian Center for Astrophysics; S. Knowles – Raytheon Systems Company; J. Bishop, R. Meier – Naval Research Laboratory

Uncertainties in atmospheric density are the largest source of error in special perturbations orbital codes. Inadequate EUV radiation proxies used by the models are a primary cause of these uncertainties. The density models use the 10.7 cm coronal radio emission, but some of the strongest lines in the EUV spectrum are emitted from the solar chromosphere. A new version of NRLMSIS (an improved upper atmosphere density model) is being developed using both coronal and chromospheric solar radiation parameterizations, which we describe. Additional refinements may include height-dependent inputs from a new physics-based EUV irradiance variability model based on differential emission measures.

0910 AAS 01 - 395

ATMOSPHERIC DENSITY MODEL ERRORS AND VARIATIONS IN THE BALLISTIC COEFFICIENT

J. G. Miller – The MITRE Corporation

Atmospheric density model errors are absorbed into the ballistic coefficient or B term by the differential correction process. Unmodeled forces (e.g., geopotential terms) can

lead to variations in the B term. For satellites with small energy dissipation rates, observability problems can also contribute to variations in the B term. Monte Carlo simulation is used to determine the accuracy of the variations in ballistic coefficient in absorbing atmospheric density model errors. The standard deviation of the relative change in the B term from the least squares differential correction covariance matrix is shown to provide an estimate of the accuracy of the B term in absorbing atmospheric density model errors. The accuracy of the variation in the B term depends on the accuracy of the sensor measurement observations, the differential correction fit span, and the number of independent observations in the fit span. The length of the fit span is most critical for satellites with B term observability problems.

0930 AAS 01 - 396

MODELING AND SIMULATION TOOL FOR THE HIGH ACCURACY SATELLITE DRAG MODEL

M. Storz — Headquarters Space Warfare Center

This paper describes an atmospheric modeling and simulation 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 hydrostatic and diffusion equations. The tool is tested to demonstrate that density can be accurately recovered from energy dissipation rates. It is being used to optimize the set of density correction parameters and the set of calibration satellites used in the AF Space Battlelab's High Accuracy Satellite Drag Model initiative. The goal of this initiative is to significantly improve the accuracy of predicted trajectories for low perigee satellites.

0950 BREAK

1010 AAS 01 - 397

DYNAMIC CALIBRATION ATMOSPHERE TOOL FOR THE HIGH ACCURACY SATELLITE DRAG MODEL

S. Casali, W. Barker - OMITRON Inc.; M. Storz - Headquarters Space Warfare Center

This paper describes the Dynamic Calibration Atmosphere method proposed for the Astrodynamics Support Workstation and the AF Space Battlelab's High Accuracy Satellite Drag Model initiative. It uses an iterative, weighted least-squares differential correction technique applied across a number of atmospheric calibration satellites to estimate a near real-time correction to the model thermospheric density, as well as the individual satellite states. The density correction is expressed in terms of coefficients of spherical harmonic expansions of exospheric temperature and Jacchia inflection point temperature. Correcting these temperature parameters leads to a correction in the thermospheric density through the use of a modified Jacchia model. Metric satellite tracking observations are used directly, avoiding the intermediate step of fitting ballistic

coefficient histories. The goal of the Space Battlelab initiative is to significantly improve the accuracy of predicted trajectories for low perigee satellites.

1030 AAS 01 - 398

APPLYING NEW AND IMPROVED ATMOSPHERIC DENSITY DETERMINATION TECHNIQUES TO RESIDENT SPACE OBJECT POSITION PREDICTION

S. Knowles - Raytheon Technical Services Company; M. Picone, S. Thonnard, A. Nicholas, K. Dymond, S. Coffey - Naval Research Laboratory

Recent developments have made possible exciting new methods and algorithms for better predicting and determining the atmospheric density field in the altitude range of 200 to 1000 km., and thus drag on resident space objects (RSOs) in that altitude range. The Naval Research Laboratory is undertaking a program to apply its capabilities in the area of space physics, astrodynamics and computer science, in cooperation with Naval Space Command, to improve position prediction and determination for the USSPACECOM Space Object Catalog. As one of these developments, a method is being developed to determine thermospheric density in near real time from inversion of far ultraviolet airglow spectral lines observed by the LORAAS instrument of the ARGOS research satellite. This algorithm will become operational as the closely related SSULI instrument is launched on the next generation of DMSP payloads. This technique, when fully developed, will enable a better nowcasting of satellite drag. Preliminary results of this method will be presented, together with a discussion of present limitations to the technique and improvements planned. An alternate technique being developed is dynamic calibration of the atmosphere, presently being developed under the sponsorship of the Air Force Space Battlelab. NRL is participating in this by using its capability to compare to the MSIS model and use adjustable fit spans to produce an independent analysis of the High Accuracy Satellite Drag Model (HASDM) calibration data set. Results from this analysis will also be presented, as well as a data base of RSO ballistic coefficients determined in this analysis together with an analysis of the long-term time spectrum of thermospheric density fluctuations and its implications for thermospheric density models.

1050 AAS 01 - 399

ON THE MECHANISM OF ATMOSPHERIC DRAG PERTURBATIONS.

R. Broucke, J. Hacker – The University of Texas at Austin

In the present work, we study some fundamental properties of the atmospheric drag perturbations of a satellite, which seem never to have been clearly mentioned in the classical literature. In particular, we divide the evolution of the orbit in three distinct consecutive phases: 1. The circularization of the elliptic orbit, 2. The spiral orbit, and 3. The reentry. We study the principal properties of the orbit in each phase, as well as the transition between phases. We especially note the evolution of the eccentricity, which undergoes a single minimum, at the instant of transition between phases 1. and 2. This is important to know because the eccentricity is in the denominator of some of the equations.

1110 AAS 01 - 400

A PERSPECTIVE ON NEUTRAL DENSITY PROGRESS

F. Marcos – Air Force Research Laboratory; F. Hoots – GRC International

Satellite drag effects are the largest error source in determining and predicting orbits of low altitude satellites. Uncertainties in neutral density variations are the major source of satellite drag errors. After three decades of essentially no quantitative progress, the problem is being vigorously and fruitfully attacked on several fronts: data assimilation or "calibration" schemes, solar indices, space-borne measurements, and numerous relevant space weather studies. We review the operational impacts of satellite drag, the historical and forthcoming efforts of the astrodynamics community in dealing with them, and the promising future capability, when neutral density may no longer be the largest error source in determining orbits of low altitude satellites.

1130 AAS 01 - 481

ATMOSPHERIC DENSITY CORRECTION USING SPACE CATALOG DATA

S. Bergstrom – Massachusetts Institute of Technology; R. Proulx – The Charles Stark Draper Laboratory; P. Cefola – The MIT Lincoln Laboratory; A. Nazarenko – Center for Program Studies, Russia; V. Yurasov – Space Research Center "Kosmos", Russia

Inaccuracies in modeling the effects of atmospheric drag account for a large portion of errors in low-altitude satellite orbit prediction. By incorporating short-arc ballistic factor time history data from a significant portion of the space catalog of low-earth satellites, time-localized errors in the atmospheric density models, especially biases, can be reduced. This algorithm uses only data that is already available and is independent of the density model employed. The paper includes the mathematical details of the algorithm as well as its implementation. The algorithm also provides improved estimates of the ballistic factors for satellites with uncertain or slowly-varying ballistic factors. This algorithm has been implemented using the Goddard Trajectory Determination System (GTDS) for the orbital motion calculations, Matlab for the atmospheric density correction calculations, and Perl to coordinate the several processes. Validation of the code is in progress, and the performance and limitations of the algorithm are analyzed.

Session 14 Tethers
0830 Wednesday, 1 Aug

Chair **Craig McLaughlin**
Air Force Research Laboratory

0830 AAS 01 - 401

A COMPARISON OF ORBIT DETERMINATION AND LONG-TERM PREDICTION METHODS FOR TETHERED SATELLITE SYSTEMS
T. Lovell – Auburn University

This paper investigates the problem of orbit determination and prediction for a tethered satellite system, where a long arc of observational data is available. A standard batch filter algorithm is used, within which several different choices of dynamic models are considered. Each candidate model represents a different degree of complexity and detail. In one of the models, a neural network is used to emulate the tethered satellite dynamics. The performance of these candidate schemes is then compared in terms of orbit determination and prediction accuracy, computational speed, robustness to observation error, and overall ease of use.

0850 AAS 01 - 402

ATTITUDE DYNAMICS OF THE END-BODIES OF A TETHERED SATELLITE SYSTEM DURING SPIN-UP
A. Mazzoleni – Texas Christian University

The Human Exploration and Development of Space will involve prolonged exposure in humans to a microgravity environment; this can lead to significant loss of bone and muscle mass, particularly for missions requiring travel times of several months or more, such as on a trip to Mars. One possible remedy for this situation is to use a spent booster as a "counter-weight" and tether it to the crew cabin for the purpose of spinning up the counter-weight/cabin system about its common center of mass like a dumbbell, hence generating artificial gravity for the crew during long duration missions. This paper studies the attitude dynamics of the end-bodies of such a system during spin-up.

0910 AAS 01 - 403

ATTITUDE DETERMINATION OF A TETHER BY MEANS OF SIMPLE SENSORS
M.Parisse, F.Curti – University of Rome “La Sapienza”, Italy

This study investigates the possibility of using relatively simple, but reliable sensors, as linear accelerometers, and if necessary assisted by a strain gauge, in order to reconstruct the roll and pitch angles of the tether system. The dynamics modelization is based on the hypothesis of a straight wire and a very important role in the dynamics as a whole is played by the thermal dynamics which triggers off, due to the variation of the heat input along the orbit, the longitudinal elastic oscillations of the wire which, in turn, through the gyroscopic coupling, set the librations into motion. The estimation process is realized by means of an Extended Kalman Filter.

0930 AAS 01 - 404

POINTING DYNAMICS OF TETHER-CONTROLLED FORMATION FLYING FOR SPACE INTERFEROMETRY

C. Bombardelli – University of Padova, Italy; E. Lorenzini – Harvard-Smithsonian Center for Astrophysics; B. Quadrelli – Jet Propulsion Laboratory

The pointing dynamics of a three-body tethered interferometer orbiting in an Earth-trailing, heliocentric orbit is analyzed. The tether provides the control of the spacecraft formation by keeping two light collectors and one combiner aligned while spinning about the boresight of the interferometer. The tethered configuration also enables the reconfiguration of the interferometer by varying the baseline length. The range of allowable spin velocities is computed based on the light collection requirement and the mechanical characteristic of the tether. The analysis of the pointing dynamics acted upon the environmental perturbations indicates that the pointing stability of the tethered interferometer is well within the required value. Finally, the micrometeoroid environment is utilized to design a multi-line tether with a probability of survival greater than 99% after 5 years in orbit.

0950 BREAK

1010 AAS 01 - 405

MODAL ANALYSIS OF THE STABILITY OF PERIODIC SOLUTIONS IN ELECTRODYNAMIC TETHERS

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

Recent studies have shown the instability of the lower modes of oscillation of electrodynamic tethers. Simulations show the higher modes are also excited. A modal decomposition Lagrangian approach is used to study the stability of those modes. A periodic solution is found, and its stability is investigated through the eigenvalues of the monodromy matrix. Elasticity introduces much higher frequencies that render the method inpractical, but this can be circumvented by averaging, also keeping any effect of elasticity on the lateral modes

1030 AAS 01 - 406

CONTROL OF TETHER SYSTEM BY USING TRANSVERSE MOTION OF TETHER

H. Fujii, T. Fujiki, T. Watanabe, W. Taira, T. Murase – Tokyo Metropolitan Institute of Technology, Japan; P. Trivailo – Royal Melbourne Institute of Technology, Australia

Transverse motion of space tether is treated with taking flexibility and line density of tether in to consideration and a control method is studied to damp the pendulum motion of subsatellite by actuating the transverse motion of tether to propagate as traveling waves. Transverse motion of tether is described by the partial deferential equations, and

results of numerical analysis show that the present control method has satisfactory performance to damp the pendulum motion of tether system.

1050 AAS 01 - 407

EXPERIMENTAL ANALYSIS OF DEPLOYMENT /RETRIEVAL OF TETHER SYSTEM USING BALLOON TECHNIQUE

H. Fujii, W. Taira, T. Watanabe, T. Murase, T. Kusagaya – Tokyo Metropolitan Institute of Technology, Japan; P. Trivairo – Royal Melbourne Institute of Technology, Australia

This paper proposes a control method of attitude motion of a tethered subsatellite by the control of tether. A tension control is applied to increase or decrease energy of attitude and pendulum motion of the subsatellite. A mathematical model of the tethered system is studied in this paper by comparing the results of experiment and numerical simulation. The subsatellite model is designed with employing air ships technology and conditions are studied for validation of the on-ground experiment on the dynamics of the tethered subsatellite in order to simulate the on-orbit behavior of tethered system with very low tension in tether.

1110 AAS 01 - 408

DYNAMICS AND CONTROL OF A TETHERED SPACE ROBOT WITH TENSION

S. Hokamoto, N. Imamura – Kyushu University, Japan;V. Modi – University of British Columbia, Canada

Whereas most of the previous studies treat free-floating space robots, this study deals with a space robot subjected to a tether tension force. The system is composed of a main satellite in orbit, a tether, and a space robot with a manipulator consisting of two connected links. This study investigates the interaction of motions for the space robot, the tether, and the main satellite in a gravity-gradient field. Some of the typical dynamics and control are calculated numerically and compared with the results for a free-floating space robot.

Session 15 Mars Missions II
1330 Wednesday, 1 Aug

Chair Robert Melton
The Pennsylvania State University

1330 AAS 01 - 409

RECENT DEVELOPMENTS IN THE ORBIT LIFETIME ANALYSIS FOR THE PLANETARY PROTECTION REQUIREMENTS OF MARS ORBITERS

M. Vincent – Jet Propulsion Laboratory

As previously reported, a new probability analysis method, named the Trinomial Method, was created to reduce the orbit raise requirements for the planetary protection aspect of the Mars Global Surveyor mission. Follow-on activities included numerical tests of the method and comparisons to Monte Carlo. The method was also developed for other applications such as the cumulative effect of multiple natural disasters on the insurance industry. The Trinomial Method has a potential three-orders of magnitude savings over the Monte Carlo method. A generic curve was produced to allow the determination of planetary protection altitudes for all Mars orbiters. However it was subsequently learned that some of the models used in conjunction with this analysis were not representative of average conditions. The most significant of these was the modeling of the solar activity and its effect on the atmosphere. The new improved model produces much lower altitude requirements. This is very significant for MGS since it meant that a relatively small or perhaps even no maneuver would be required at the end of their extended mission. Likewise it will substantially improve the fuel budgets for the other two Mars orbiters considered, Mars Odyssey (2001) and Mars Reconnaissance Orbiter (2005).

1350 AAS 01 - 410

MARS GLOBAL SURVEYOR: MAPPING ORBIT EVOLUTION AND CONTROL THROUGHOUT ONE MARS YEAR

P. Esposito, E. Graat, S. Demcak, D. Baird, V. Alwar – Jet Propulsion Laboratory

This paper presents the evolution and control of Mars Global Surveyor's (MGS) mapping orbit throughout one Mars year of the primary mapping mission. MGS's orbit represents the first short period (117 minutes), low altitude (≈370 km at periapsis passage), circular (e=0.005), polar (I=93.0 deg), frozen-orbit (argument of periapsis =270 deg) and sun-synchronous (≈2:00 pm LMST at ascending equator crossing) orbiter of Mars. Topics to be presented include orbit evolution and control, perturbations especially due to the spacecraft's angular momentum desaturations, variation in the ground track walk pattern and the degree of non-uniformity in the ground tracks.

1410 AAS 01 - 411

MARS GLOBAL SURVEYOR ORBIT DETERMINATION UNCERTAINTIES USING HIGH RESOLUTION MARS GRAVITY MODELS

E. Carranza, D. Yuan, A. Konopliv – Jet Propulsion Laboratory

Orbit determination of the Mars Global Surveyor performed at the Jet Propulsion Laboratory was conducted for the purpose of refining the Mars gravity field, as part of the radio science investigation. The orbit determination was performed using X-band one-way, two-way, three-way Doppler data, collected primarily from the DSN 34m HEF tracking stations. A description of the mission and its trajectory will be provided, followed by a discussion of the orbit determination estimation procedure and models. Accuracies will be examined in terms of orbit-to-orbit solution differences, and are determined for the latest 75th degree gravity model for the nominal mission.

1430 AAS 01 - 412

IMPROVING MARS APPROACH NAVIGATION USING OPTICAL DATA

B. Rush, S. Bhaskaran, S. Synnott – Jet Propulsion Laboratory

An important objective of future Mars missions is to land with increasing accuracy at the surface. This requires precise targeting of the trajectory at entry. The navigation accuracies obtained with radio data can be improved with optical data, using satellite images against a star background to pinpoint the spacecraft's Mars-centered state. This paper presents covariance studies showing that these data can produce entry accuracies better than one km. Simulations validate these results, using a realistic Phobos model, and considering the effects on the solution of errors in spacecraft and Phobos ephemerides and in the shape and rotational dynamics of Phobos.

1450 BREAK

1510 AAS 01 - 414

SYNODIC PERIOD VARIATIONS FOR SHORT FLIGHT TIME LOW-THRUST MISSIONS

G. Rauwolf, M. Doyle, S. Hoffman - SAIC

Due to the recent success of Deep Space One and the continued on-orbit success of the commercial ion thrusters, the use of low-thrust propulsion technologies for interplanetary trajectories is becoming more common. A recent study examined the application of several solar-powered low-thrust technologies to short flight time (200-400 days) crewed and cargo Mars missions. Analysis performed in support of this study demonstrated a distinct performance variation of Solar Electric Propulsion (SEP) trajectories over the synodic period. In addition, the relative performance of Ion and Hall SEP technologies varied significantly as a function of the opportunity. This paper will document the primary influences that lead to performance variations over the synodic period and explore how these variations may impact propulsion technology selections for Mars transportation systems.

1530 AAS 01 - 415

RENDEZVOUS OPTIONS AND DYNAMICS FOR MARS SAMPLE RETURN MISSIONS

C. Ocampo, J. Breeden – The University of Texas at Austin; J. Guinn – Jet Propulsion Laboratory

The relative motion dynamics associated with a mission to rendezvous with a passive object, such as a canister containing a sample of Martian soil, is necessary to support NASA’s effort to collect and return to Earth such a sample for examination. The current mission profile assumes that the canister is in orbit about Mars and a rendezvous spacecraft dispatched from the Earth arrives at Mars, captures into a suitable orbit, searches, rendezvous with the orbiting sample, collects the sample, and returns to the Earth. An alternate profile places the canister in heliocentric orbit where the rendezvous spacecraft collects the sample and returns to Earth.

1550 AAS 01 - 416

TRAJECTORY DESIGN FOR MSR TERMINAL RENDEZVOUS PHASE

D. Geller, C. DíSouza, T. Brand – The Charles Stark Draper Laboratory; R. Lock – Jet Propulsion Laboratory

The Terminal Rendezvous Phase Mission Design Team at JPL has been developing and evaluating potential rendezvous trajectory profiles to effect the capture of an orbiting ëgrapefruití size canister containing a Martian soil sample. We have found that a co-elliptic flyby followed by insertion into a relative ëfootballí orbit that is based on the C-W Hillís equations results in a rendezvous trajectory profile that meets all mission requirements, including a no-impact requirement for passive aborts. In this paper, we will discuss the flyby/football orbit rendezvous trajectory profile, present navigation and dispersion analysis, and show how and why this rendezvous trajectory profile meets all mission requirements.

Session 16 Guidance, Navigation, & Control
1330 Wednesday, 1 Aug

Chair Jean de Lafontaine
Universite de Sherbrooke

1330 AAS 01 - 417

RELATIVE EQUILIBRIA OF A GYROSTAT WITH A DISCRETE DAMPER
R. Sandfry, C. Hall – Virginia Polytechnic and State University

We investigate the dynamics and stability of motion of a torque-free rigid gyrostat with a discrete damper. Equations of motion are developed using a Newton-Euler approach and non-dimensonalized. Numerical continuation is used to find branches of equilibria within the global state-space while varying the rotor absolute angular momentum. Changes in damper parameters or inertia properties significantly affect the structure of these bifurcation diagrams. Focusing on a gyrostat designed to spin about a minor axis, continuation results reveal the existence of stable equilibria near the desired spin configuration.

1350 AAS 01 - 418

ATTITUDE DYNAMICS AND CONTROL OF BIFOCAL RELAY MIRROR SPACECRAFT
B. Agrawal – Naval Postgraduate School

This paper presents attitude dynamics and control of Bifocal Relay Mirror Spacecraft. The spacecraft is composed of two optically coupled telescopes used to redirect the laser light from ground-based, aircraft-based or spacecraft based lasers to distant points on the earth or in space. The spacecraft has very challenging multi-body dynamics and fine pointing problems because the two large inertia telescopes that are gimbaled result in continual change in spacecraft dynamics and spacecraft inertia during operation and it has very tight jitter and pointing requirements to meet optical payload requirements. The attitude control system consists of reaction wheels, star trackers, gyros, course sun sensors, magnetometers and magnetic rods. Feed forward control is complex but critical to meet the performance during fast slewing and a major change in spacecraft dynamics. Based on the simulation results, it is concluded that fine tracking requirements can be achieved.

1410 AAS 01 - 419

MULTIPLE TARGET SELECTION AND OBSTACLE AVOIDANCE USING POTENTIAL FUNCTION GUIDANCE METHOD
G. Radice, C. McInnes – University of Glasgow, Scotland

This paper analyses a novel approach utilising potential functions to autonomously control constrained attitude slew manoeuvres. The method hinges on defining a potential function from the geometric configuration of the satellite's current attitude, the final target attitude and any pointing constraints which may be present. It will be demonstrated that complex path shaping and planning can be achieved using little computational effort. The method is mathematically validated using Lyapunov's theorem and so can be considered for safety critical applications.

1430 AAS 01 - 421

AUTONOMOUS NAVIGATION AND GUIDANCE ON-BOARD EARTH-OBSERVATION MINI-SATELLITES
J. de Lafontaine – Universite de Sherbrooke, Canada; P. Vuilleumier – ESA/ESTEC, The Netherlands; P. Van den Braembussche – Werhaert Design and Development nv, Belgium

In an attempt at reducing ground operation costs and ensuring a better management of on-board resources, Earth-observation mini-satellites are now relying on the autonomous on-board execution of functions that were normally performed by ground operators. The European Space Agency is currently developing technologies that will enable such on-board autonomous mission management. These technologies will be evaluated in a real scenario on-board the PROBA mini-satellite, to be launched in mid-2001. PROBA is a three-axis stabilised Earth-observation mini-satellite carrying a high-resolution imaging spectrometer that imposes stringent requirements on on-board navigation and guidance.

1450 BREAK

1510 AAS 01 – 422

AUTOMATED LANDMARK IDENTIFICATION FOR SPACECRAFT NAVIGATION
R. Gaskell – Jet Propulsion Laboratory

An integrated approach to surface relative optical landmark tracking for spacecraft is being developed. Landmarks are defined as full digital topography/albedo maps and are determined from previous imaging and navigation data. Initially, this technique will speed up ground based optical navigation. Ultimately, it will enable on-board trajectory determination during orbital and landing maneuvers.

1530 AAS 01 - 423

APPLICATIONS OF DRAG-FREE TECHNOLOGY TO PRECISION SATELLITE NAVIGATION
R. Nerem – University of Colorado; J. Ries – The University of Texas at Austin; P. Axelrad, P. Bender – University of Colorado; J. LaBrecque – NASA Headquarters

The last several decades have seen a steady improvement in precision satellite navigation due to advancements in the models for the Earth's gravity field. The models for the non-gravitational forces (atmospheric drag, solar radiation pressure, etc.), however, have resisted significant improvement. It is proposed that drag-free technology, initially explored with the Transit satellites in the 1970s, would essentially eliminate the problem of unpredictable non-gravitational forces. This paper will describe the advantages of drag-free systems for various Earth satellite applications, and present simulations of the orbit determination/prediction accuracy that could potentially be obtained with such a system. In addition, the state of the current technology in precision accelerometers and micro thrusters will be reviewed, and improvements required will be described.

1550 AAS 01 - 424

TOPEX/POSEIDON AND JASON-1 COORDINATED NAVIGATION
A. Salama – Jet Propulsion Laboratory; A. Soroosh, T. Martin-Mur, E. Paredes - Raytheon

This paper presents the results of the TOPEX/Poseidon and Jason-1 coordinated navigation effort performed by the TOPEX navigation team. Three mission phases are considered. First, coordinated navigation effort during Jason acquisition phase is presented. Formation flying during Jason cross calibration and validation phase is then discussed. Finally, the tandem mission is analyzed. It is the phase which follows calibration during which the two satellites repeat different ground track grid.

Session 17 Orbital Mechanics
1330 Wednesday, 1 Aug

Chair Felix Hoots
GRC International

1330 AAS 01 - 425

ACCELERATED STUMPFF FUNCTION EVALUATIONS ASSOCIATED WITH UNIVERSAL KEPLER'S EQUATION SOLUTIONS
D. Adamo – United Space Alliance

Use of transcendental, hypergeometric Stumpff functions in universal solutions to Kepler's Equation is reviewed. A recursive Stumpff function series evaluation technique from Goodyear (1966) is introduced, along with its truncation criterion. Extensive digital computer execution time comparisons are reported between Kepler's Equation solutions using the series method and those employing conventional IEEE math library Stumpff function evaluations. These comparisons demonstrate the series approach is typically 10% to 30% faster than equivalent solutions utilizing math library calls.

1350 AAS 01 - 426

IMPLEMENTATION OF GAUSS-JACKSON INTEGRATION FOR ORBIT PROPAGATION
M. Berry – Virginia Polytechnic and State University/Naval Research Laboratory; L. Healy – Naval Research Laboratory

The parallel special perturbation catalog maintenance software "SpecialK" being introduced at Naval Space Command's uses an 8th order Gauss-Jackson predictor-corrector for numerical integration. This integrator comes from legacy code which is not extensively documented. A study of the theory that the integrator is based on and the method that the integrator is implemented in the software is necessary to determine if speed or accuracy improvements can be made. This paper presents some results from the study, including a discussion of a variable step size method that had been implemented in the ancestor code that proves to be ineffective.

1410 AAS 01 - 427

VISUAL DEMONSTRATION OF THE INABILITY OF AN ANALYTICAL ORBIT PROPAGATOR TO PREDICT ATMOSPHERIC VARIABILITY
E. Lydick – Naval Space Command

The Naval Space Commands space surveillance radar, the Fence, takes 175000 observations a day. These observations consist mainly of the time of observation and a pair of direction cosines. These observations are automatically identified based on predicted observations generated with an analytical propagator using 3 to 10 day fit spans. Each identified observation generates residuals with the predicted values assumed to be truth. By stringing together a series of time ordered plots consisting of data taken from 2-hour segments for each day, a movie can be generated showing how the observation time residual and the North-South direction cosine residual vary from day to day as the atmosphere changes.

1430 AAS 01 - 428

EFFICIENT NUMERICAL INTEGRATION OF COUPLED ORBIT AND ATTITUDE TRAJECTORIES USING AN ENCKE TYPE CORRECTION ALGORITHM
J. Woodburn, S. Tanygin – Analytical Graphics, Inc.

The accurate computation of orbit and attitude trajectories may require their simultaneous numerical integration. The procedure employing two integrators for weakly coupled integration is proposed. The orbit state is numerically integrated at every step using full force model and attitude state known at the beginning of the step. The second integrator propagates attitude and uses reduced force model to propagate an Encke type correction to the orbit state. Once it catches up with the first integrator, the orbit state is rectified by the correction and the process is continued. The procedure seeks to retain accuracy of the fully coupled integration while reducing computation time.

1450 BREAK

1510 AAS 01 - 429

A SUMMARY OF ASTRODYNAMIC STANDARDS
D. Vallado – Raytheon

This paper provides status of the AIAA Committee on Standards. We describe the AIAA Recommended Practices Part II, Methods, Models, and Data formats. The committee felt it was important to provide a concise summary listing to encompass the findings and descriptions in the recommended practices, and the current tools and methods we consider as standards. The paper is a detailed listing with summary slides to introduce the reader to the available techniques, sources, practices, and data for astrodynamic applications. To broaden the scope, we structured the material along both functional and accuracy formats. We specify low, medium, and high accuracy to bound the accuracy section.

1530 AAS 01 - 430

A CURIOUSLY OUTLANDISH PROBLEM IN ORBITAL MECHANICS
I. M. Ross – The Charles Stark Draper Laboratory; H. Yan, F. Fahroo – Naval Postgraduate School

A somewhat outrageous problem in orbital mechanics is proposed. In this problem the planet gravitational model obeys the Newtonian inverse-square law but the atmosphere increases with altitude. A unique minimum-drag Forced Keplerian Trajectory is defined by a thrust-drag cancellation. The optimal control problem is to transfer a spacecraft from a point on this manifold to another point on it while minimizing a Mayer cost. We show by theory and numerical results that the spacecraft follows a non-minimum-drag trajectory to minimize fuel. The application of this result to real problems (i.e. strict adherence to hydrostatic laws) has surprising consequences.

1550 AAS 01 - 431

A COMPARISON OF LATITUDE TARGETING SCHEMES FOR MAINTAINING GROUND TRACKS AT HIGH LATITUDES

P. Demarest – a.i. solutions, Inc.

Two methods for calculating the out-of-plane maneuvers required to maintain the ICESat ground track at high latitudes have been developed. Both methods are based on the comparison of the perturbed ground track with a repeating reference at the apex of each orbit. The optimal set of maneuvers for the 5-year ICESat mission was determined by parameter optimization using the downhill simplex method. Comparison of the targeting schemes with the single-arc and global optimum set of maneuvers showed that the improved latitude targeting scheme is both an effective and efficient method for calculating the required maneuvers.

1610 AAS 01 - 433

SPACE MECHANICS TOOLS : RETHINKING FLIGHT DYNAMICS TOOLS WITH OPEN SOURCE SOFTWARE

V. Martinot, S. Herbiniere – Alcatel Space, France

In the very competitive environment of the space industry, the question of developing or buying flight dynamics tools is more up-to-date than ever before. Although not always based on cost, its answer can be influenced by the possibility of using open source software to develop more quickly the parts of the tools which are not specific to flight dynamics like graphical user interfaces, visualization tools..This article describes how open source software can ease the development of engineering Flight Dynamics Tools by presenting as example Space Mechanics Tools (SMT), a flight dynamics software used in the Mission Analysis Department of Alcatel Space. The rationale for the choice of open source software are presented in details with the hope that it can be of some help to Flight Dynamics Engineers, especially to those in the industry who may hesitate to use open source software in their engineering developments.

Session 18 Interplanetary I
0830 Thursday, 2 Aug

Chair Brian Barden
Jet Propulsion Laboratory

0830 AAS 01 - 434

INVESTIGATION ON THE USE OF ALTIMETER CROSSOVERS FOR THE NEAR ORBIT DETERMINATION

F. Pelletier – The University of Texas at Austin; R. Nerem – The University of Colorado; J. Bordi, J. Miller, B. Williams – Jet Propulsion Laboratory

The Near Earth Asteroid Rendezvous spacecraft carried a laser altimeter to measure distances from the asteroid 433 Eros' surface. Altimeter heights can be differentiated at points where the ground track intersects. Referred to as crossovers, the computation of these points and their use for orbit determination is investigated. Crossover measurements were formed using real altimeter data from NEAR and were processed, along with radio metric observations, through the NEAR operational orbit determination software in an attempt to improve the orbit solutions. A 20-day period beginning on April 30, 2000 was selected for this study and corresponds to a 50-km circular polar orbit. The orbit solutions are compared to reference orbits, obtained by processing radio metric and optical landmark tracking data. This study shows that the orbit differences and the residuals RMS were both reduced, proving that crossovers served as a good complementary information to the radio metric observations. Additionally, results were further improved by editing some crossovers with respect to their quality.

0850 AAS 01 - 435

ON THE HISTORY OF THE SLINGSHOT EFFECT AND OF COMETARY ORBITS.

R. Broucke – The University of Texas at Austin

In the present work, we study some aspects of the history of the gravity-assist or slingshot effect during the space era as well as previous to the space era in relation to comets. We comment on some of the initial work at JPL, especially in 1961 by Michael Minovitch. We also describe the basic principle very briefly and we reminisce on the first few important missions, such as Pioneers 10 and 11 as well as well as the Mariner 10 mission to Mercury.

0910 AAS 01 - 436

A STUDY OF THE CLOSE APPROACH BETWEEN A PLANET AND A CLOUD OF PARTICLES

A. Prado – Insituto Nacional de Pesquisas Espaciais (INPE), Brazil

We study the close approach between a planet and a cloud of particles. It is assumed that the dynamical system is formed by two main bodies in circular orbits and a cloud of particles in planar motion. The goal is to study the change of the orbit of this cloud after the close approach with the planet. It is assumed that all the particles have semi-

major axis a ± Da and eccentricity e ± De before the close approach with the planet. It is desired to known those values after the close approach.

0930 AAS 01 - 437

METHODS FOR THE DESIGN OF V_∞ LEVERAGING MANEUVERS

N. Strange, J.Sims – Jet Propulsion Laboratory

V_∞ leveraging maneuvers are intended to change the V_∞ of a spacecraft between flybys of a gravity-assist body. This paper considers these maneuvers in three categories: resonant, nonresonant, and pi-transfers. Methods are developed for the analysis of each type of maneuver. A Tisserand graphical method is presented for the analysis of nonresonant leveraging transfers. These methods have application to tour design at Saturn and Neptune, study of _V-EGA (_V Earth Gravity Assist) trajectories, and study of lunar gravity assist transfers.

0950 BREAK

1010 AAS 01 - 438

VARIABLE SPECIFIC IMPULSE INTERPLANETARY TRAJECTORY DESIGN AND OPTIMIZATION

K. Karavasilis , B. Ross, R. Sagdeev – University of Maryland; F. Chang-Diaz – NASA/Johnson Space Center; D. Jorjoliani – National Institute Learning Center, Georgia

In planetary missions long trip times and small payloads are major concerns and drawbacks when using conventional rockets. The Variable Specific Impulse Magnetoplasma Rocket (VASIMR) being developed at the Advanced Space Propulsion Laboratory (ASPL) at the Johnson Space Center (JSC) NASA could dramatically shorten transit times between planets. In this paper using software we developed at the East-West Space Science Center of the University of Maryland we demonstrate the benefits of using variable I_{sp} in Earth to Mars transits, resulting either in an increased payload mass or in a shorter transit time.

1030 AAS 01 - 439

WATCH OUT, IT'S HOT! EARTH CAPTURE AND ESCAPE SPIRALS USING SOLAR ELECTRIC PROPULSION

T. Sweetser, M. Cherng, P. Finlayson, P. Penzo – Jet Propulsion Laboratory

Solar electric propulsion may be used to escape from or capture into a low circular orbit at Earth. Radiation from the Van Allen belts, though, poses a significant hazard for such trajectories. This paper examines various strategies proposed to minimize radiation exposure, including varying the inclination and the eccentricity of the spirals. Analytic expressions are derived for the thrust direction which keeps periapse altitude constant and these control laws are used to generate elliptical spirals for comparison with the more familiar circular spirals. Radiation exposure estimates are given for the various trajectories. An inclined circular spiral may be the best.

Session 19 Trajectory Design and Optimization
0830 Thursday, 2 Aug

Chair Ron Proulx
Charles Stark Draper Laboratory

0830 AAS 01 - 441

LYAPUNOV FUNCTIONS FOR ELLIPTIC ORBIT TRANSFER
D. Chang, D. Chichka, J. Marsden – California Institute of Technology

We present a study of non-impulsive transfer between elliptic Keplerian Orbits using Lyapunov functions specific to this problem as our basic methodology. The Lyapunov functions are based on the constants of the motion for Keplerian orbits, the orbital energy, Laplace (-Runge-Lenz) vector, and the angular momentum vector. It can be shown that such a function based on the angular momentum and Laplace vectors can be used to derive a controller valid for any elliptic orbit transfer. Simulations indicate that this controller compares well with other controllers in the literature and with transfers computed using optimal transfer codes. Further, this method can guarantee that the transfer remains within a desired set of orbits during the transfer. However, this Lyapunov function is more restrictive than is necessary for many cases, such as transfer to a circular target orbit. For such cases, we consider simpler functions, and comment on their suitability.

0850 AAS 01 - 443

TRAJECTORY OPTIMIZATION WITH DUAL THRUST LIMITED PROPULSION SYSTEMS
C. Ocampo – The University of Texas at Austin

Necessary conditions are derived for the optimal orbit transfer problem for a spacecraft equipped with two distinct thrust limited, constant specific impulse propulsion systems. These conditions are required to optimize the transfer of a spacecraft launched on to the transfer orbit with a high thrust booster and the spacecraft, which is the booster's payload, itself has a dedicated propulsion system that is used for the final orbit insertion maneuvers. The propulsion system that makes the final maneuvers may be a low thrust constant specific impulse system and be more efficient than the one making the first injection maneuver.

0910 AAS 01 - 444

AMMO: AN AUTOMATED MULTIPLE MANEUVER OPTIMIZATION SYSTEM
C. Potts, J. Michel, B. Raofi – Jet Propulsion Laboratory

An automated maneuver design capability can provide significant benefits in cost, risk reduction, and science return for interplanetary spacecraft missions. Emphasis must be placed on a general and robust approach to accommodate the diversity of complex missions, both present and future. Maneuver optimization provides a highly desired sophisticated Δv solution, but also increases complexity and introduces significant automation challenges. An Automated Multiple Maneuver Optimization (AMMO) system is presented in this context. Additionally, the prototype system has proven to be extremely successful with Stardust operations support.

0930 AAS 01 - 445

A NEW COLLOCATION-BASED METHOD FOR SOLVING PURSUIT/EVASION (DIFFERENTIAL GAMES) PROBLEMS
B. Conway, K. Horie – University of Illinois

A new numerical method for solving zero-sum two-person differential games is developed. The method, which we call semi-direct collocation with nonlinear programming, incorporates necessary conditions for saddle-point trajectories into the direct collocation with nonlinear programming method, and finds saddle-point trajectories and associated control histories. An example problem of spacecraft interception of an optimally evasive target is solved to verify suitability of the method for a realistic dynamic problem. A second, more complex problem of air combat in three dimensions is also successfully solved.

0950 BREAK

1010 AAS 01 - 446

A NEW SCHEME FOR TRAJECTORY OPTIMIZATION
B. Neta – Naval Postgraduate School; Y. Lipowski – Ramat Aviv, Israel

In this paper we develop a method for the solution of the equations of motion of an object acted upon by several gravitational masses. In general the motion can be described by a special class (for which y' is missing) of second order initial value problems (IVPs) y''(x) = f(x, y(x)), y (0)=y0, y'(0)=y1 . The numerical integration methods for this can be divided into two distinct classes: (a) problems for which the solution period is known (even approximately) in advance; (b) problems for which the period is not known. Here we only consider some methods of the second class. Numerical methods of Runge-Kutta type as well as linear multistep methods can be found in the literature. Our idea here is to develop a new method that conserves the energy per unit mass in the case of perturbation-free flight and use the energy in other cases to approximate the angular variation. The generalization to cases were the energy is not conserved is given. We close with numerical experiments for both cases and compare the solution to well established methods.

1030 AAS 01 - 447

ALGEBRAIC ANALYSIS OF NONIMPULSIVE ORBITAL TRANSFERS UNDER THRUST ERRORS, 1.
A. de Jesus – Universidade Estadual de Feira de Santana (UEFS), Brazil; M. Souza, A. Prado – Instituto Nacional de Pesquisas Espaciais (INPE), Brazil

In this paper we present the first part of an algebraic analysis of nonimpulsive orbital transfers under thrust errors. This was done as part of an extensive study conducted in three phases. This paper emphasizes the first part of the third phase but mentions the other two phases. We found algebraic relations similar in shape but proportional in values, confirming the Monte-Carlo simulations conducted in the second phase. The numerical and algebraic results of the study suggest and partially characterizes the progressive deformation of the trajectory distribution along the propulsive arc. Its main results also characterize how close/far are Monte-Carlo analysis and covariance analysis for those examples.

1050 AAS 01 - 448

SYNTHESIS OF CONTROL OF THE ASCENT INTO THE ORBIT OF A MULTIMODE AEROSPACE SYSTEM

V. Gusynin – National Space Agency of Ukraine; V. Baranov – Institute of Modeling Problem in Power Engineering, Ukraine; A. Gusynin – National Technical University, Ukraine; T. Demyanchuk – Polytechnical Institute, Ukraine; I. Khomitskyy – Ternopol State Technical University, Ukraine

The method of synthesis of control of the multimode aerospace space system (ASS) ascent into orbit is offered. The method is based on mathematical tools of differential transforms of functions and equations, does not require of a numerical integration of differential equations and is permitted of analytical solution of the problem. The results of the computer simulation have shown, that the synthesized control algorithm is provided at the expense of optimization a fuel conservation in 0,7 % and a high accuracy of the ascent ASS with simultaneous essential reduction of computer costs on simulation in comparison with the conventional numerical methods.

Session 20 Formation Flying
0830 Thursday, 2 Aug

Chair David Folta
NASA/Goddard Space Flight Center

0830 AAS 01 - 449

EARTH OBSERVER-1 MISSION OVERVIEW
N. Speciale, B. Cramer, D. Schulz – NASA/Goddard Space Flight Center

In 1996 NASA started the New Millenium Program (NMP), designed to identify, develop and flight validate key instrument and spacecraft technologies than enable new or more cost-effective approaches to conducting science missions in the 21^{st} century.

The first of these NMP Earth Orbiting missions is the Earth Observing-1 (EO-1) mission, an advanced land-imaging mission that demonstrates new instruments and spacecraft systems. EO-1 is designed to validate technologies contributing to significant reduction in cost of follow-on Landsat missions. EO-1 was successfully launched on November 21, 2000.

0850 AAS 01 - 450

FOLLOW THAT SATELLITE: EO-1 MANEUVERS INTO CLOSE FORMATION WITH LANDSAT-7
R. De Fazio – NASA/Goddard Space Flight Center; S. Owens – a.i. solutions, Inc.

The EO-1 and Landsat-7 spacecrafts are flying in a close formation during a one year mission to validate the next generation of Landsat instruments aboard EO-1. To achieve the imaging goals of this mission, EO-1 has to operate within one minute + / - 6 seconds along track behind Landsat-7. Meeting this formation requirement depended heavily on a finely tuned launch window and an optimized formation acquisition profile which had to be uniquely computed for each possible launch date in a 16 day Landsat-7 repeat cycle. Special action taken to re-plan several EO-1 orbit maneuvers in flight permitted a safer close approach with Landsat-7.

0910 AAS 01 - 451

NASA'S FIRST AUTONOMOUS FORMATION FLYING EXPERIMENT: EARTH OBSERVER – 1 (EO-1) ENHANCED FORMATION FLYING
D. Folta – NASA/Goddard Space Flight Center; A. Hawkins – a.i. solutions, Inc.

With the launch of NASA's Earth Observer-1 (EO-1) satellite, the Goddard Space Flight Center is demonstrating NASA's first-ever autonomous formation flying mission. EO-1 has completed its primary goal of demonstrating enhanced formation flying, the capability of satellites to react to each other and maintain a close proximity without human intervention. This implemented formation flying algorithm is a 3-Dimensional autonomous open-loop flight code onboard the New Millennium Program (NMP) EO-1 spacecraft. This paper describes the mathematical background of the autonomous formation flying algorithm and presents the validation results of this unique system. Tests ranging from functionality assessment to full autonomous maneuver control are presented in comparison to simulations and EO-1 operational maneuvers. Use of an integrated autonomous control system called AutoCon™ for flight and ground operations is also discussed. This technology advancement allows spacecraft to autonomously react to required orbit changes quickly and efficiently.

0930 AAS 01 - 452

FLIGHT SOFTWARE IMPLEMENTATION OF ENHANCED FORMATION FLYING

J. Bristow – NASA/Goddard Space Flight Center; A. Hawkins, G. Dell – a.i. solutions, Inc.

This paper describes the interface for maneuver planning and execution to meet the formation flying constraints of the EO-1 mission. It provides details on how AutoCon was modified from a ground system to on-board maneuver planning and orbit maintenance. The paper also describes the methodology used to scale the AutoCon ground system to fit and execute on the flight hardware. Finally, it describes a significant component of the on-board system the GPS data smoother for accurate spacecraft estimated position states.

0950 BREAK

1010 AAS 01 - 453

A DECENTRALIZED KALMAN FILTER AND SMOOTHER FOR FORMATION FLYING CONTROL OF THE EARTH OBSERVING –1 (EO-1) SATELLITE

D. Rosenberg, A. Hawkins – a.i. solutions, Inc.; D. Folta – NASA/Goddard Space Flight Center

A requirement of the Enhanced Formation Flying (EFF) experiment aboard the New Millennium Program's Earth Observing-1 (EO-1) satellite is the determination autonomously of the spacecraft's orbital state. Orbital state data in the form of pseudorange and Doppler measurements are acquired by a GPS Tensor receiver and converted via the GPS Standard Positioning System (SPS) into states that are then processed by a primary Kalman filter. Preflight analysis suggested that the errors in these filtered states were too large to allow them to initialize the targeting algorithms utilized by the EFF system. A decentralized Kalman filter and smoother were thus incorporated within the software executive of the EFF experiment to provide an additional level of processing.

1030 AAS 01 - 454

THE ROLL OF SHORT-PERIODIC MOTION IN FORMATION FLYING OF SATELLITES WITH LARGE DIFFERENTIAL AREA TO MASS RATIO

R. Proulx, P. Cefola – Charles Stark Draper Laboratory; K. Luu – Air Force Research 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 have large area-to-mass differences, 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 affected by differential drag, while high altitude formations will be primarily affected 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 the differential 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.

1050 AAS 01 - 455

RELATIVE FORMATION KEEPING OF LEO SATELLITES SUBJECT TO SMALL DRAG DIFFERENCES

D. Mishne – Rafael, Israel

In this paper we develop a method to control the relative apparent position (the position as observed from the earth) of satellite formation in almost circular LEO. The orbit altitude is such that the major perturbing force that causes the in-plane drift of the satellites from their desired positions is the drag differences between the satellites. To compensate for the drag variation, periodic velocity corrections are applied such that each satellite moves along a trajectory that minimizes its deviations from the nominal trajectory, in the least-square sense. The difference between the ballistic coefficients of neighboring satellites is estimated from measurements of the relative position, and this estimate is used to compute the correction. The algorithms for the determination of the velocity correction are developed in the paper, and a numerical example is presented.

1110 AAS 01 - 457

MODELING RELATIVE POSITION, RELATIVE VELOCITY, AND RANGE RATE FOR FORMATION FLYING

C. McLaughlin, R. Burns, C. Sabol, K. Luu – Air Force Research Laboratory

The relative position, relative velocity, and range rate evolution is examined for a formation of satellites that projects a circle onto the along-track/cross-track plane. A simple analytical model including Earth oblateness effects for the equations of relative motion is presented. This model provides physical insight into the Earth oblateness

effects that are neglected by using Hill's equations. The accuracy of the relative position, relative velocity, and range rate predictions for using Hill's equations and the analytical model are compared to realistic force modeling obtained using the Draper Semianalytic Satellite Theory for formations of varying size, inclination, and altitude.

Session 21 Interplanetary II
1330 Thursday, 2 Aug

Chair Dennis Byrnes
Jet Propulsion Laboratory

1330 AAS 01 - 458

IMPROVEMENTS IN TRAJECTORY OPTIMIZATION FOR MESSENGER: THE FIRST MERCURY ORBITER MISSION

J. McAdams, R. Farquhar – JHU/Applied Physics Laboratory; C. Yen – Jet Propulsion Laboratory

MESSENGER (MErcury Surface, Space, ENvironment, GEochemistry, and Ranging), the seventh NASA Discovery Program mission, will utilize a carefully planned sequence of Venus and Mercury gravity assist flybys to deliver the 3-axis-stabilized, dual-mode-propulsion spacecraft into Mercury orbit. Two minimum-ΔV launch opportunities in March and May 2004 not only satisfy a wide array of science goals, but also meet engineering, operational, programmatic, and cost constraints. New baseline and backup trajectories provide substantial improvements for many aspects of MESSENGER's five-year journey to Mercury over the lowest-ΔV trajectories known at the start of Phase B studies.

1350 AAS 01 - 459

COMBINING LOW-THRUST AND GRAVITY ASSIST MANOEUVRES TO REACH PLANET MERCURY

M. Vasile, F. Bernelli-Zazzera – Politecnico di Milano, Italy; R. Jehn, M. Katzkowski – ESA/ESOC, Germany

A direct transfer to planet Mercury requires a considerable amount of propulsion, which translates into an excessive thrust time required from a state-of-the-art low-thrust engine (over 7000 h of operations). An interesting way to reduce such a requirement is to resort to Gravity Assist (GA) manoeuvres. In this paper a direct optimisation approach, based on a Finite Elements in Time discretisation technique, has been used to design an optimal trajectory to planet Mercury combining low-thrust propulsion with one or more swing-bys of Venus and Mercury itself. Swing-bys are modelled, at first, by a linked-conic approximation, in order to design a first optimal trajectory taking into account the dependency of low-thrust on the power provided by the solar panels, and then by a full numeric propagation of the swing-by hyperbola, in order to refine the solution previously obtained. Several cases corresponding to different launch opportunities or spacecraft configurations are proposed and analysed.

1410 AAS 01 - 460

ORBIT SYNTHESIS OF THE ISAS VENUS CLIMATE ORBITER MISSION

H. Yamakawa – Institute of Space and Astronautical Science (ISAS), Japan; M. Kimura – NEC Aerospace Systems, Ltd., Japan

This paper presents the preliminary orbit synthesis results of the ISAS VCO (Venus Climate Orbiter) mission, which were studied and proposed by the ISAS (Institute of

Space and Astronautical Science, Japan) Venus Exploration Working Group. The selection of the VCO will be determined in spring of 2001. The launch is scheduled in the 2007-2008 time frame. ISAS' three-staged M-V is postulated for the launch vehicle. The primary scientific objective of the VCO is to study the Venusian atmosphere. The VCO spacecraft is a three-axis stabilized spacecraft, which weighs around 650 kg. The phasing loop orbit, interplanetary parking orbit, Earth-Venus interplanetary transfer trajectory, as well as the orbit around Venus are depicted.

1430 AAS 01 - 461

AUTOMATED DETECTION OF POTENTIALLY HAZARDOUS NEAR-EARTH-OBJECT ENCOUNTERS
P. Chodas, S. Chesley, A. Chamberlin, D. Yeomans – Jet Propulsion Laboratory

Over the last two decades, there has been an increasing public and scientific awareness of the impact hazard posed by Near-Earth Objects (NEOs). We have implemented an automatic process for updating orbital solutions for NEOs and detecting those objects that have an Earth collision probability greater than about 1E-6. Since NEO orbits are often very uncertain, nonlinearites can be large, and Monte Carlo methods are therefore used for detecting possible Earth close encounters. Close approach data are collated and analyzed on the impact plane for each encounter. Automation using robust algorithms is essential because of the large number of objects and possible close approaches. This paper will discuss the techniques and algorithms used, and present several examples of asteroids which have been detected to have significantly non-zero probabilities of colliding with the Earth.

1450 BREAK

1510 AAS 01 - 462

REDUCING THE EARTH ENTRY VELOCITY FOR A COMET NUCLEUS SAMPLE RETURN MISSION
J. Sims – Jet Propulsion Laboratory

Methods for reducing the entry velocity at Earth for a sample return mission from a comet nucleus are presented. Both solar electric and chemical propulsion are considered for accomplishing the return. Additional thrusting on a direct return can be used to achieve relatively small changes in the entry velocity. Earth and Earth-Venus gravity assists can significantly reduce the entry velocity with a corresponding increase in flight time.

1530 AAS 01 - 463

TOUR DESIGN STRATEGIES FOR THE EUROPA ORBITER MISSION
M. Okutsu, T. Debban, J. Longuski - Purdue University

The Europa Orbiter will be launched to investigate the suspected liquid ocean beneath the icy surface of Jupiter's moon. In order to minimize propellant cost, the final Europa arrival speed is reduced via multiple gravity-assist flybys of the Galilean satellites, while meeting the mission constraints and requirements. This paper describes the design strategies and solution approaches to the satellite tours for the Europa orbiter mission and provides summaries of representative tours.

1550 AAS 01 - 464

THE FEASIBILITY OF A GALILEO-STYLE TOUR OF THE URANIAN SATELLITES

A. Heaton – NASA/Marshall Space Flight Center; J. Longuski – Purdue University

Gravity-assist trajectories have been a key to outer Solar System exploration. In particular, the gravity-assist tour of the Jovian satellites has contributed significantly to the success of the Galileo mission. A comparison of the Jovian system to the Uranian system reveals that the two possess similar planet/satellite mass ratios. Tisserand graphs of the Uranian system also indicate the potential for tours at Uranus. In this paper, we devise tour strategies and design sample tours of the Uranian satellites, thereby demonstrating the feasibility of such missions.

1610 AAS 01 - 465

ADVANCED PROPULSION OPTIONS FOR MISSIONS TO THE KUIPER BELT

T. Sweetser, C. Sauer – Jet Propulsion Laboratory

Ever since Kuiper Belt Objects (KBOs) were discovered in the distant reaches of the solar system, they have been objects of desire for planetary scientists. This paper examines different forms of advanced propulsion to see how useful they would be for fast flyby missions to KBOs. Only those unproven technologies that could be available within the next ten years or so are considered, and their performance is compared to chemical and solar electric propulsion. To sum up, solar sails look good, thermal desorption doesn't seem to help enough for this application to justify its development, and mini-magnetospheric plasma propulsion (M2P2) is a dark horse that might be a big winner.

Session 22 Low-Thrust Trajectory Optimization
1330 Thursday, 2 Aug

Chair Les Sackett
Charles Stark Draper Laboratory

1330 AAS 01 - 466

SUBOPTIMAL LOW-THRUST INTERPLANETARY TRAJECTORIES

S. Vadali, K. Aroonwiliroot – Texas A&M University; E. Braden – NASA/Johnson Space Center

This paper addresses the determination of suboptimal low-thrust trajectories for interplanetary missions. The formulations presented in the paper can be used for both constant and variable specific impulse (I_{sp}) propulsion. The problem formulations treat the spacecraft mass as a state variable, thus coupling the spacecraft design to the trajectory optimization. Gravitational effects of the sun, Earth, and Mars are included throughout an entire trajectory. To avoid numerical sensitivity, the trajectory dynamics is divided into segments, each written with respect to a different central body. These segments are patched at intermediate time points, with proper matching conditions of the variables. Various combinations of trajectory optimization methods are investigated in order to develop a fast and reliable algorithm for mission analysis.

1350 AAS 01 - 467

A SHAPE-BASED ALGORITHM FOR THE AUTOMATED DESIGN OF LOW-THRUST, GRAVITY-ASSIST TRAJECTORIES

A. Petropoulos, J. Longuski – Purdue University

Given the benefits of coupling low-thrust propulsion with gravity assists, techniques for easily identifying candidate trajectories would be extremely useful to mission designers. We describe the computational implementation of a shape-based method for the design of low-thrust, gravity-assist trajectories. We also augment the method by allowing coast arcs to be patched with thrust arcs on the transfers between bodies. This approach permits not only rapid, broad searches over the design space, but also provides initial guesses for trajectory optimization. Some numerical examples are presented.

1410 AAS 01 - 468

AN APPROACH TO DESIGN AND OPTIMIZATION OF LOW-THRUST TRAJECTORIES WITH GRAVITY ASSISTS

T. McConaghy, T. Debban, A. Petropoulos, J. Longuski – Purdue University

We present an approach for designing and optimizing low-thrust gravity-assist (LTGA) trajectories. The process consists of two steps, each using a different model. We begin by using a shape-based, patched-arc trajectory model. This model allows us to explore a broad region of the design space very quickly. The most promising regions of the design space are then explored more fully with a higher-fidelity model. We provide several examples of LTGA trajectories designed and optimized in this way.

1430 AAS 01 - 469

OPTIMAL CONTROL LAW FOR INTERPLANETARY TRAJECTORIES WITH SOLAR SAIL

G. Colasurdo, L. Casalino – Politecnico di Torino, Italy

An indirect method is applied to minimize the trip time of an interplanetary mission using a solar sail. The theory of optimal control provides the equation that gives the optimal orientation of the sail at each point of the trajectory. An analytical solution can be obtained in the case of unit reflectivity, whereas the equation is numerically solved for lower reflectivity. Once the reflectivity has been assumed, the optimal trajectory only depends on the acceleration which can be provided by the sail. The optimization procedure has been used to estimate the performance of different missions; in particular transfers to Mars and Mercury, and the escape from the solar system are considered and the influence of the sail reflectivity is pointed out.

1450 BREAK

1510 AAS 01 - 470

SOLAR SAIL HYBRID TRAJECTORY OPTIMIZATION.

G. Hughes, C. McInnes – University of Glasgow, Scotland

This paper details research conducted into the capability of Genetic Algorithms (GAs) and Sequential Quadratic Programming (SQP) algorithms to effectively optimise Solar Sail thrust vector orientation. A Direct-method Hybrid GA/SQP optimizer has been developed where a fixed time GA was used to conduct a global search of the solution space and then an SQP algorithm was employed as a 'fine-tuning' local optimizer to minimise transfer time and converge on the boundary conditions. A number of interplanetary trajectories and new transfers to Non-Keplerian Orbits have been discovered with acceptable transfer time penalties even with relatively few steering segments.

1530 AAS 01 - 471

OPTIMAL TRAJECTORIES FOR NON-IDEAL SOLAR SAILS

T. Cichan, R. Melton – The Pennsylvania State University

Typically, an ideal force model for solar sails, including perfect reflectivity of the sail surface, has been used to examine light pressure effects. For this analysis, an imperfect reflectivity model includes differences in the magnitude and direction of the force imparted by the light pressure. This paper examines some optimized interplanetary trajectories to compare the results from the two force models, and to evaluate the feasibility of a solar sail as propulsion for a mission. Feasible trajectories are found using the non-ideal force model, with a significant difference from the ideal sail trajectory.

1550 AAS 01 - 472

ANALYTIC CONTROL LAWS FOR NEAR-OPTIMAL GEOCENTRIC SOLAR SAIL ORBIT TRANSFERS

M. Macdonald, C. McInnes – University of Glasgow, Scotland

A set of analytic control laws for Solar Sail orbit transfers have been generated. These individual control laws allow for the optimal rate of change of any of the classical orbital elements. A guidance scheme has been developed to blend these individual steering laws and generates a near-optimal geocentric orbit transfer trajectory. The proposed guidance scheme is illustrated through trajectory calculations for the orbit-raising phase of the GeoSail mission and then for the scientific operational phase.

Session 23 Relative Motion and Rendezvous
1330 Thursday, 2 Aug

Chair **Rich Burns**
Air Force Research Laboratory

1330 AAS 01 - 473

MAINTAINING PERIODIC TRAJECTORIES WITH THE FIRST-ORDER NONLINEAR HILL'S EQUATIONS
J. Mitchell – Air Force Research Laboratory; D. Richardson – University of Cincinnati

An approach to provide control for the first-order nonlinear Hill's equations describing relative motion of two satellites about a spherical Earth using Baumgarte stabilization is presented. The linearized and nonlinear Hill's equations are stabilized with a modified Baumgarte technique using each system's Hamiltonian. We then show trajectories similar to the periodic trajectories of the linearized system can be obtained from the stabilized nonlinear system using a first integral of the linearized system as the desired invariant manifold. This approach provides a significant reduction in the along-track drift with the nonlinear Hill's equations as compared to the linearized equations.

1350 AAS 01 - 474

SECOND ORDER RELATIVE MOTION EQUATIONS
C. Karlgaard, F. Lutze – Virginia Polytechnic and State University

This paper presents an approximate solution of second order relative motion equations. The equations of motion for a Keplerian orbit in spherical coordinates are expanded in Taylor series form using reference conditions of a circular orbit. Only terms that are linear or quadratic in state variables are kept. A perturbation approach is employed to obtain an approximate solution of the resulting nonlinear differential equations. This solution is then compared with the previously known solution of the linear case to show improvement, and with numerical integration of the second order equations to understand the error incurred by the approximation.

1410 AAS 01 - 475

DRIFT ATTENUATION MANEUVERS AND OTHER RELATIVE MOTION ANALYSES FOR THE GRACE MISSION
R. Russell, W. Fowler – The University of Texas at Austin

GRACE is a unique mission that involves formation flying of two co-planar low-Earth-orbiting satellites. The nature of the mission requires a detailed understanding of the relative motion between the GRACE spacecraft. This paper overviews the development of a computer code written to model relative motion, and presents the analysis of several relative motion events that occur during the GRACE mission. These events include separation, drift attenuation, and de-orbit maneuvers. The code and optimization procedures developed can be easily configured for future use to perform further analyses for GRACE and/or any other relative motion application.

1430 AAS 01 - 476

RELATIVE MOTION ESTIMATION FOR CLUSTERED SATELLITES WITH VERY DIFFERENT AREA-TO-MASS RATIOS

S. Carlini – Telespazio S.p.A., Italy; C. Pastor - Dataspazio, S.p.A., Italy

The mass, number, and dimension of geostationary satellites could soon lead to overcome the current mission implementation capabilities. The co-location of smaller satellites inside a common dead-band could be a valid alternative. The control of co-located satellites may be complex if the area-to-mass ratios differ significantly, then the co-location possibilities for such satellites are evaluated through numerical simulations. The feasibility of the relative motion estimation using inter-satellite ranging is proved; moreover the full observability conditions of the state-vector are stated. Then relative trajectory estimations from inter-satellite ranging are simulated using a predictor model that include the Solar radiation pressure effect.

1450 BREAK

1510 AAS 01 - 477

OPTIMAL ORBITAL RENDEZVOUS USING GENETIC ALGORITHMS

D. B. Spencer, Y. Kim – The Pennsylvania State University

Optimal rendezvous between two orbiting spacecraft is a new application of genetic algorithms (GAs), and is presented in this paper. The optimal rendezvous problem contains multimodal and discontinuous parts. Conventional calculus-based optimization methods are not effective in these kinds of problems, and thus do not guarantee a globally optimal solution. Genetic algorithms are effective in domains of these types provide globally optimal solutions. The result of the GA optimal rendezvous yields a thrust time history (direction and magnitude), and the burn time of the maneuver(s). The boundary conditions are satisfied to an acceptable level and provide these solutions in a reasonable execution time.

1530 AAS 01 - 478

OPTIMAL FINITE THRUST RENDEZVOUS USING BENEFICIAL EFFECTS OF THE EARTH OBLATENESS

S. Tebbani, I. Queinnec, J. Bernussou – Laboratoire d'Analyse et d'Architecture des Systemes, France

The main purpose of this paper is to compute optimal or near optimal low-thrust low-Earth circular minimum-fuel orbital transfers with constrained final rendezvous and bounded transfer duration. The proposed transfer strategy consists in taking advantage of the Earth oblateness to provide some natural corrections, i.e., correction with no cost consumption. The satellite transfer is performed by a three-burn thrusting scenario, defining two intermediary drift orbits. A direct optimization method is used to optimize the trajectory, initialized by the multiple impulsive thrust solution . A Sequential Quadratic Programming algorithm is then used to solve the resulting NLP problem. Sub-optimality is tested by checking the necessary conditions of the maximum principle.

1550 AAS 01 - 479

AUTONOMOUS ORBITAL RENDEZVOUS USING ANGLES-ONLY NAVIGATION

R. Chari, T. Brand, D. Geller – The Charles Stark Draper Laboratory

This paper describes techniques for orbital rendezvous and close approach where navigation is accomplished with angles-only measurements. The ability to determine distance along the line-of-sight is enhanced by a combination of techniques. First, the relative trajectory between the chaser and target is designed to create changes in the line-of-sight, enhancing the observability of relative position. Second, the chaser executes maneuvers designed to further enhance the observability of the position component along the line-of-sight. The target vehicle is assumed to be non-maneuvering and in a near-circular orbit, but the basic techniques should extend to modestly elliptical orbits. The modeled system includes several representative mission scenarios.

1610 AAS 01 - 480

ON THE COMBINED OPTICAL AND RADIO NAVIGATION IN LOW THRUST RENDEZVOUS WITH AN ASTEROID

J. Kawaguchi, S. Sawai, T. Ohnishi, M. Uo, M. Kimura, M. Matsuoka, T. Kominato – The Institute of Space and Astronautical Science (ISAS)

The optical navigation has been utilized in interplanetary missions for many years. In an approach to a planet, since the spacecraft flies in uniform gravity field, the conventional radio metric navigation accuracy may not be sufficient for guiding the spacecraft to fly through capture corridor associated with the planet. It is very important, especially in case an aerocapture technique is introduced, when the corridor width is sometimes down to only several kilometers. A conventional radio metric navigation angular accuracy is about one micro to several hundreds nano radians and does never satisfy the aerocapture accuracy requirement. An optical navigation, whose angular resolution depends on the aperture diameter, can have an angular resolution of a few arc seconds (a few tens micro radians) easily. When it exposes a certain natural or an artificial landmark at the distance of around a few millions kilometers, when the spacecraft is approaching a few days prior to the closest encounter. With it, the above mentioned corridor accuracy is obtained via the optical technique. This is the essence of an optical navigation advantage. In case this is used for the planetary capture or flyby, since the approach direction is along an asymptote of a hyperbolic trajectory, the optical navigation well helps the lateral dispersion information straightforward. As well known, a conventional optical navigation has little sensitivity toward the line of sight direction and the longitudinal information needs to be supplemented by the other means such as a radio range information. That is why the technique shown is referred to as a hybrid navigation.

AUTHOR INDEX

AUTHOR INDEX

AUTHOR INDEX

AUTHOR INDEX

AUTHOR INDEX

RECORD OF MEETING EXPENSES

AAS/AIAA 2001 Astrodynamics Specialist Conference

Hilton Quebec
Quebec City, Quebec, Canada
29 July – 2 August 2001

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