# AAS/AIAA
# Space Flight Mechanics Meeting

**Embassy Suites on Monterey Bay**
**Monterey, California**

**February 9 – 11, 1998**

# PROGRAM

| | General Chairs | Technical Chairs |
|---|---|---|
| AAS | Louis A. D'Amario<br>Jet Propulsion Laboratory | Jay W. Middour<br>Naval Research Laboratory |
| AIAA | Dennis V. Byrnes<br>Jet Propulsion Laboratory | Lester L. Sackett<br>Charles Stark Draper Laboratory |

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# MEETING INFORMATION

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

| | |
|---|---|
| AAS or AIAA Members | $110 |
| Non-members | $130 |
| Students | $20 |
| Non-members* | $195 |

*Includes one-year AAS membership at special discounted rate and the Journal of the Astronautical Sciences.

The registration desk in the Conference Pre-convene Area will be open at the following times:

| | |
|---|---|
| Sunday | 4:00 PM - 7:00 PM |
| Monday and Tuesday | 7:00 AM - 4:00 PM |
| Wednesday | 8:00 AM - 11:30 AM |

**Please note that credit cards cannot be accepted for payment of any conference fees. A check payable to "1998 AAS/AIAA Space Flight Mechanics Meeting" is the preferred form of payment.**

**Conference Proceedings**
Based on current estimates, the proceedings will be available to attendees of the conference at a pre-publication cost of $135. This price may vary. Orders for the conference proceedings will be accepted at the time of registration.

**Social Events**
<u>Sunday</u> evening (6:00 - 7:30 PM), there will be an Early-Bird Reception in Laguna Ballroom C.

<u>Monday</u> evening (7:00 - 10:30 PM), the Conference Banquet will take place in the Outer Bay Wing of the Monterey Bay Aquarium. The cost of the banquet is $30 per person and includes admission to the aquarium and dinner. One motorcoach (capacity 47) will be provided for those who do not wish to drive. **Please note that a maximum of 100 people can be accommodated for the banquet, and we expect this event to be sold out.** To make a reservation, provide your name and the total number of banquet tickets desired to either of the conference General Chairs.

<u>Tuesday</u> after the technical sessions, there will be a guest lecture (5:00 - 6:00 PM) by Dr. Roger Bourke of the Jet Propulsion Laboratory on "Mars Exploration: Recent Results and Future Plans" in Laguna Ballroom D. The lecture will be followed by a reception (6:00 - 7:30 PM) in Laguna Ballroom C at which hot and cold hors d'oeuvres and beverages will be provided.

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

**<u>AAS General Chair</u>**
Dr. Louis A. D'Amario
Jet Propulsion Laboratory
MS 301-276
4800 Oak Grove Drive
Pasadena, CA 91109-8099
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818-393-5214 FAX
louis.damario@jpl.nasa.gov

**<u>AIAA General Chair</u>**
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dennis.v.byrnes@jpl.nasa.gov

## TECHNICAL PROGRAM

**Technical Sessions**
There are 18 technical sessions scheduled over a 3 day period with a total of 109 papers on the agenda. The technical sessions will run in parallel with 3 morning sessions and 3 afternoon sessions each day.

**Speakers' Briefings**
Authors who are presenting papers and session chairs will meet for a short briefing each morning at 8:00 AM in Laguna Ballroom A. Please attend only on the day of your presentation. Speakers staying at the Embassy Suites receive a free cooked to order breakfast available from 6:30 AM to 9:30 AM in the Hotel Breakfast Area (an amenity included in the cost of the room); off-site speakers will be provided complimentary tickets entitling them to a free breakfast on the day of their presentation.

**Presentations**
Morning technical sessions will start at 8:30 AM, and afternoon technical sessions will start at 1:30 PM each day. All presentations are scheduled for 25 minutes: 20 minutes for the presentation and 5 minutes for questions. This schedule will be strictly enforced so that attendees may schedule their time between parallel sessions. There will be a 20 minute break midway through each session. Please note that the **NO PAPER/NO PODIUM** rule will be strictly enforced - i.e., speakers will not be allowed to present their work if they have not provided 50 copies of their completed paper. Also, papers will be automatically withdrawn from the meeting and will not be eligible for inclusion in the proceedings if one of the stated authors is not in attendance to present the paper.

**Paper Sales**
Authors are required to bring 50 copies of their paper to the meeting. The preprints will be on sale for $1.00 per paper in the Del Mar Room. Bound copies of the proceedings of the conference may be ordered at the registration desk.

**Committee Meetings**
Committee meetings will be held in the Del Monte Room according to the following schedule:

| | | |
|---|---|---|
| AIAA Astrodynamics Technical Committee | Monday | 11:30 AM - 1:00 PM |
| AAS Space Flight Mechanics Technical Committee | Tuesday | 11:30 AM - 1:00 PM |
| AIAA Astrodynamics Standards Committee | Wednesday | 11:00 AM - 2:00 PM |

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

**AAS Technical Chair**
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**AIAA Technical Chair**
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## MONTEREY INFORMATION

### Location

Monterey (pop. 33,000) is located on the Monterey Peninsula in the southernmost curve of Monterey Bay. Also located on the Monterey Peninsula are the communities of Carmel and Pacific Grove. The scenic Big Sur coastline is 30 miles south of Monterey, and the city of Santa Cruz is 40 miles to the north. Founded in 1770 by Franciscan priest Junípero Serra and Spanish governor Gaspar de Portolá, Monterey served as California's first capital under Spanish, Mexican, and American flags. Originally fishing and then later tourism anchored the area’s economy. Monterey's historic character, natural beauty, and unique attractions have enabled it to become a quality residential community and one of the premier tourist destinations in the United States. The Monterey Peninsula enjoys a mild coastal weather pattern. In February, the average maximum and minimum temperatures are 61 degrees and 45 degrees, and the average rainfall is 2.7 inches.

### Embassy Suites Features

- 225 two-room suites with private bedroom, separate vanity/dressing area, separate living room with sofa bed and dining/work table, wet bar, microwave, refrigerator, coffee maker, two telephones (voice mail and computer jacks), AM/FM clock radio/alarm, two remote-control televisions, hair dryer, iron, and ironing board
- Heated indoor pool, outdoor sun deck, whirlpool, sauna, exercise facility, and game room
- Access to Waterfront Recreational Trail
- Nearby golf, tennis, scuba diving, and deep-sea fishing
- Free cooked-to-order breakfast (6:30 - 9:30 AM) and free hosted manager’s reception (5:30 - 7:30 PM) each day
- Pacifica Cafe serving steaks, seafood, and regional favorites
- Cypress Lounge with indoor and outdoor deck seating, piano music and micro-brewed beers
- Corporate business center, gift shop, laundry service, free parking, free newspaper (weekdays), and courtesy airport transportation
- Check-in after 4:00 PM, check-out by 12:00 noon, deposit required, major credit cards accepted, cancellation 48 hours prior to arrival, children under 12 free

### Local Attractions

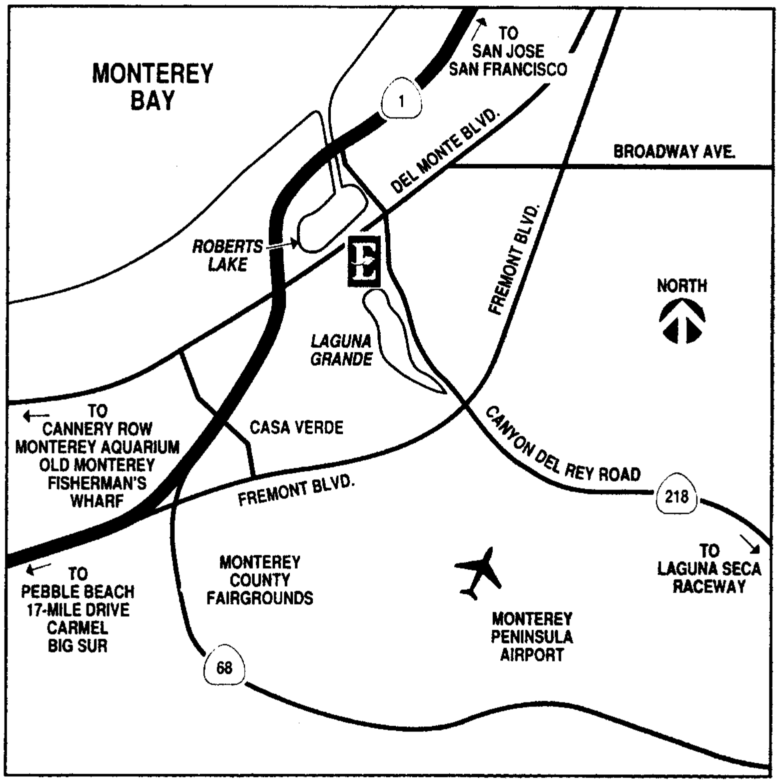
- Cannery Row
- Fisherman’s Wharf
- Maritime Museum of Monterey
- Carmel
- Point Lobos State Reserve
- Monterey Bay Aquarium
- Monterey State Historic Park
- 17-Mile Drive
- Pebble Beach
- Big Sur

### Transportation

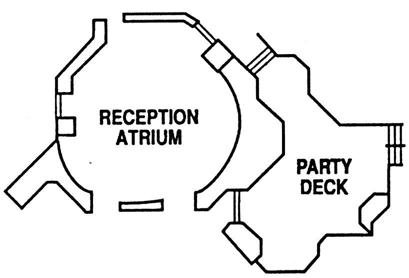
The Monterey Peninsula Airport is located about 5 minutes from the Embassy Suites, which provides a free airport shuttle. The airport is served by 11 airlines, including American, Continental, Delta, Northwest, United, and US Air, with more than 100 daily arrivals and departures to and from San Francisco, San Jose, Los Angeles, and Las Vegas. Rental cars are available at the airport from Avis, Budget, Hertz, and National.

Approximate driving times from nearby large cities are: 2 hours from San Francisco, 1.5 hours from San Jose, 3.5 hours from Sacramento, and 6 hours from Los Angeles. The approach to Monterey is on Highway 101, traveling south from San Francisco, San Jose, or Sacramento or traveling north from Los Angeles. Detailed directions to the Embassy Suites from Highway 101 are given at the conference home page site at: www.space-flight.org. Follow the links to “1998 AAS/AIAA Space Flight Mechanics Meeting” and then “Conference Information.”

## LOCAL AREA MAP

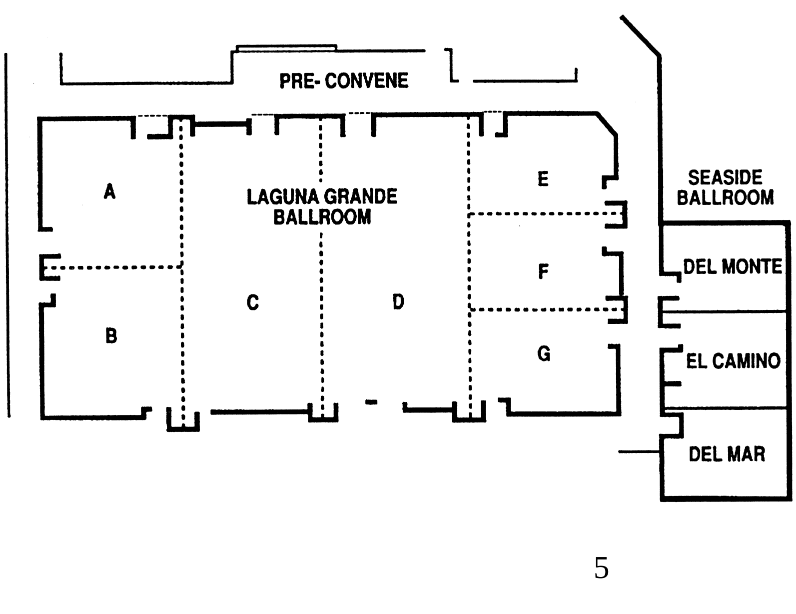



## HOTEL FLOOR PLAN




EMBASSY SUITES℠

HOTEL & CONFERENCE CENTER
ON MONTEREY BAY



# PROGRAM SUMMARY

| Date/Time | Event | Location |
|---|---|---|
| Sunday, February 8 | | |
| 4:00 - 7:00 PM | Conference Registration | Conference Pre-convene Area |
| 6:00 - 7:30 PM | Early-Bird Reception | Laguna Ballroom C |
| Monday, February 9 | | |
| 7:00 AM - 4:00 PM | Conference Registration | Conference Pre-convene Area |
| 8:00 AM - 5:00 PM | Paper Sales | Del Mar Room |
| 6:30 - 8:00 AM | Speakers' Breakfast | Hotel Breakfast Area |
| 8:00 - 8:30 AM | Speakers' Briefing | Laguna Ballroom A |
| 8:30 - 11:45 AM | Technical Sessions 1, 2, 3 | Laguna Ballroom E, F, G |
| 11:30 AM - 1:00 PM | AIAA Technical Committee Meeting | Del Monte Room |
| 11:45 AM - 1:30 PM | Lunch | |
| 1:30 - 4:45 PM | Technical Sessions 4, 5, 6 | Laguna Ballroom E, F, G |
| 7:00 - 10:30 PM | Conference Banquet | Monterey Bay Aquarium |
| Tuesday, February 10 | | |
| 7:00 AM - 4:00 PM | Conference Registration | Conference Pre-convene Area |
| 8:00 AM - 5:00 PM | Paper Sales | Del Mar Room |
| 6:30 - 8:00 AM | Speakers' Breakfast | Hotel Breakfast Area |
| 8:00 - 8:30 AM | Speakers' Briefing | Laguna Ballroom A |
| 8:30 - 11:20 AM | Technical Sessions 7, 8, 9 | Laguna Ballroom E, F, G |
| 11:30 AM - 1:00 PM | AAS Technical Committee Meeting | Del Monte Room |
| 11:45 AM - 1:30 PM | Lunch | |
| 1:30 - 4:45 PM | Technical Sessions 10, 11, 12 | Laguna Ballroom E, F, G |
| 5:00 - 6:00 PM | Guest Speaker: Dr. Roger Bourke "Mars Exploration: Recent Results and Future Plans" | Laguna Ballroom D |
| 6:00 - 7:30 PM | Reception | Laguna Ballroom C |
| Wednesday, February 11 | | |
| 8:00 - 11:30 AM | Conference Registration | Conference Pre-convene Area |
| 8:00 - 11:30 AM | Paper Sales | Del Mar Room |
| 6:30 - 8:00 AM | Speakers' Breakfast | Hotel Breakfast Area |
| 8:00 - 8:30 AM | Speakers' Briefing | Laguna Ballroom A |
| 8:30 - 11:45 AM | Technical Sessions 13, 14, 15 | Laguna Ballroom E, F, G |
| 11:00 AM - 2:00 PM | AIAA Standards Committee Meeting | Del Monte Room |
| 11:45 AM - 1:30 PM | Lunch | |
| 1:30 - 4:20 PM | Technical Sessions 16, 17, 18 | Laguna Ballroom E, F, G |

## Session 1 Tethered Systems

**8:30 AM Monday, February 9 Laguna Ballroom E**

**Chair: Dr. Arun K. Misra**
**McGill University**

**8:30 AM**
**AAS 98-100**

### Mission Analysis Of A Tethered System For LEO To GEO Orbital Transfers

E. C. Lorenzini, M. L. Cosmo - Harvard-Smithsonian Center for Astrophysics; M. Kaiser - Technische Universitat Munchen, Germany; M. Bangham, H. Dionne, D. Vonderwell - The Boeing Co.

The use of spaceborne tethers is investigated for designing a reusable system to transfer payloads up to 4000 kg from LEO to GEO. The study indicates that a two-stage tethered system is preferable to a single-stage tethered system, on a mass basis, with present-day tether materials. A first stage in LEO and a second stage in medium Earth orbit provide the required $\Delta$Vs for injecting the payload into geotransfer orbit. The orbits of the two stages and the payload released from the first stage are resonant in order to provide periodic encounters and capture opportunities. The ratios between orbital periods are optimized with the goal of reducing the overall system mass. The approach velocity and acceleration between the second stage and the payload released from the first stage are computed to demonstrate the salient features of this non-conventional rendezvous. The system requirement of one transfer per month for two years of operation without refueling is considered for computing the overall propellant needed for reboosting the stages. The study concludes that a two-stage tethered system is more competitive, on a mass basis, than a present-day chemical upper stage after only two transfers.

**8:55 AM**
**AAS 98-101**

### Identification And Orbit Determination Of Tethered Satellite System

S. Cho, J. E. Cochran, Jr. - Auburn University

Orbital motion of a tethered satellite system, composed of two satellites and the tether, is considered by using a perturbed two-body model. This approach is adopted so that the determination of the orbit of one of the satellites can be attempted without using observations of the motion of the other satellite in the system. A method of identification based on observations of only one of the bodies in the tethered satellite system is also described. The characteristics of the "tether perturbed" motion of the observed satellite are investigated.

**9:20 AM**
**AAS 98-102**

### Orbit Determination Of A Tethered Satellite System Using Laser And Radar Tracking

S. R. Vadali, H. Jung, K. T. Alfriend - Texas A&M University

The Tether Physics and Survivability satellite (TiPS) is comprised of two small subsatellites connected by a 4 km tether. Orbit and attitude estimation of TiPS was initially based on Satellite Laser Ranging (SLR). Unfortunately, reliable acquisition of TiPS could not be achieved with range data only. Although the accuracy of SLR is higher than radar tracking, a radar can provide azimuth and elevation information also, which the lasers could not provide. This paper investigates the advantages of radar tracking over SLR for acquiring TiPS on a more reliable basis using both simulated data as well as actual measurements.

**9:45 AM** **BREAK**

**10:05 AM** **Orientation Control Of A Platform Supporting A Tethered Payload**

**AAS 98-103**

V. J. Modi, G. Gilardi, S. Kalantzis - The University of British Columbia; A. K. Misra - McGill University

Using an O(N) Lagrangian formulation, the paper studies reorientation of a platform, supporting a tethered satellite, in three dimensions. Such a maneuver can provide better platform attitude for communication, on board experiments, solar power production, etc. thus enabling the system to undertake diverse missions. Two different schemes are used to this end : ( i ) energy intensive procedure governing rigid degrees of freedom using the FLT based CMG/Thruster control, with the flexible tether vibrations regulated through the LQG/LQR and the tether offset as actuator; ( ii ) the Liapunov method with the platform controlled through the tether offset while the other degrees of freedom are left uncontrolled. Both the procedures are quite effective. The choice will depend on mission demands and constraints.

**10:30 AM** **Analysis And Design Of The Aerobraking Tether For Stochastic Errors**

**AAS 98-104**

S. G. Tragesser, J. M. Longuski - Purdue University

As an alternative to conventional aerobraking spacecraft, we propose a system comprised of a probe and an orbiter connected by a long, thin tether. The probe provides the necessary drag while the orbiter remains high above the sensible atmosphere. A sensitivity analysis of the aerobraking tether is performed where we consider errors in knowledge of the atmosphere and in control of the initial conditions. A simple guidance algorithm is developed in order to minimize the effect of off-nominal conditions. The final design achieves a 99% probability of mission success for aerocapture at Mars.

**10:55 AM** **On The Deployment Of An Electrodynamic Tether From An Elliptical Orbit**

**AAS 98-105**

M. Ruiz, J. Pelaez - Universidad Politecnica de Madrid, Spain

A two-phase deployment scheme allows a long tether to be deployed from a circular LEO in less than one period. Through a perturbation method, PDE's become ODE's allowing phase-plane study to achieve a local vertical final figure. With two or even one term, the method is nearly as accurate as finite differences or lumped-mass methods, and much faster. In an elliptical orbit, the method allows a wide exploration of parameters: eccentricity, initial anomaly, ejection angle and exponential speed ratio. Ranges are identified to obtain the straight vertical figure, avoid slackness, rotation, resonances, and high sensitivity to initial conditions.

## Session 2 Interplanetary Missions 1

**8:30 AM Monday, February 9 Laguna Ballroom F**

**Chair: Dr. Lincoln J. Wood**
**Jet Propulsion Laboratory**

**8:30 AM** **Description Of Three Candidate Cassini Satellite Tours**

**AAS 98-106** J. C. Smith - Jet Propulsion Laboratory

In July of 2004, Cassini will become the first spacecraft to insert into orbit about Saturn. During the 4 year tour, the spacecraft trajectory is modified by gravity assists provided by the Saturnian satellites. This paper describes three candidate Cassini satellite tours which are indicative of tours currently under consideration. The first 1.2 years of the tour have been finalized; however, the remaining 2.8 years will not be selected until the year 2000 time frame. A comparison of these three tours illustrates the tradeoffs involved in the design process and provides a preview of the characteristics of the final tour.

**8:55 AM** **Incorporating Icy Satellite Flybys In The Cassini Orbital Tour**

**AAS 98-107** A. A. Wolf - Jet Propulsion Laboratory

The Cassini satellite tour is a series of orbits in which flybys of Titan are used to shape and control the trajectory. Achieving flybys of Saturn's less massive icy satellites is an important tour objective; however, icy satellite flybys must be achieved essentially "on the way" from one Titan flyby to another, because they can make only small changes in the spacecraft's orbit. This makes achieving close flybys of icy satellites a challenge requiring new methods in satellite tour design. Techniques developed to assist trajectory designers in maximizing the number of icy satellite flybys in Cassini tours are described here.

**9:20 AM** **Navigation Feasibility Studies For The Europa Orbiter Mission**

**AAS 98-108** M. D. Guman, D. C. Roth, B. G. Williams - Jet Propulsion Laboratory

This paper describes preliminary navigation analyses for the proposed Europa Orbiter mission. To quantify achievable navigation accuracies, orbit uncertainties are computed for simulated range and Doppler tracking coverage from NASA’s Deep Space Network stations. In addition, single-station optical communication range tracking is simulated to assess its capabilities against those of traditional radiometric tracking. Covariance analyses are performed for these scenarios to identify important model uncertainties. Emphasis is placed on the operational “orbit phase” of the mission for which additional navigation considerations are investigated; these include spacecraft safety shortly after Europa orbit insertion and sensitivity to various orbit configurations.

**9:45 AM** **BREAK**

**10:05 AM** **Mission Design Of The 2001 Mars Surveyor Program Orbiter And Lander**

**AAS 98-109**

B. M. Sutter - Lockheed Martin Flight Systems; S. E. Matousek, D. A. Spencer - Jet Propulsion Laboratory

The task to design and build the MSP'01 Orbiter and Lander has reached the completion of the Phase A effort. A mission design has been created that accommodates the many requirements of the science instruments while still enabling the construction of a spacecraft designed to be built faster, better, and cheaper. These missions will launch in the March and April of 2001 and perform a number of technologically challenging mission firsts. The MSP'01 Orbiter will be the first demonstration of a guided aerocapture in which the spacecraft directly enters the atmosphere from the incoming hyperbola and uses the atmosphere to decelerate in a single aeropass into a low altitude science orbit. From this orbit, two science instruments with widely differing lighting requirements will perform data collection in a phased use approach that takes full advantage of the eccentricity of Mars' heliocentric orbit. The MSP'01 Lander will soft land and deploy a long range/long lived rover and perform scientific studies for at least 100 sols from the surface. The nominal mission scenarios, requirements, and contingency planning are discussed. The missions consist of 5 distinct phases for the Orbiter/Lander: Launch, Cruise, Aerocapture/Direct Entry, Transfer to Mapping/Terminal Descent, Science Orbit/Surface Operations. Each of these phases will be discussed in detail for both the Orbiter and Lander. Additionally, a discussion of the alternatives and the rational for selecting the baseline scenario instead of the alternatives will be provided. Finally a discussion of the support this spacecraft will provide for subsequent missions to Mars will be included.

**10:30 AM** **Mars Aerocapture Studies For The Design Reference Mission**

**AAS 98-110**

J. E. Lyne - University of Tennessee; P. Wercinski, J. Arnold - NASA Ames Research Center; G. Walberg, R. Jits - North Carolina State University

NASA is developing plans for the first human Mars landing to occur in 2014 after cargo flights deliver surface components and the Earth return vehicle two years before the crew's arrival. The mission design calls for rapid crew transits and aerocapture for both the manned and robotic vehicles at Mars. To minimize on-orbit assembly, a triconic aerobrake has been selected which can be launched as a single piece and also will serve as the launch shroud during Earth lift-off. The current paper presents the results of aerocapture studies for this configuration, for both fast-transit, crew vehicles and minimum-energy cargo flights.

**10:55 AM** **Non-Typical Trajectory Alternatives For Mars Cargo Missions**

**AAS 98-111**

B. M. Portock - University of Tennessee Space Institute; J. E. Lyne - University of Tennessee; G. A. Flandro - University of Tennessee Space Institute

The design reference mission set forth by NASA MSFC HMM Preliminary Design Study plans for two cargo flights for the 2011 launch opportunity. This paper studies the alternatives of Solar Electric propulsion and Solar Sail propulsion in place of the impulsive options used in the design reference cargo missions. The relaxation of the short time of flight restriction for the cargo missions causes low thrust propulsion to become an attractive alternative. Solar Sail and Solar Electric missions are directly compared with the design reference cargo missions. The Solar Sail and Solar Electric propulsion options both have substantial improvements of initial mass in low Earth orbit with little change in overall mission architecture.

**11:20 AM** **Mars Global Surveyor Aerobraking At Mars**

**AAS 98-112**

M. D. Johnson, P. B. Esposito, V. Alwar, S. W. Demcak, E. J. Graat, R. A. Mase - Jet Propulsion Laboratory

On September 12, 1997, the Mars Global Surveyor (MGS) spacecraft was successfully inserted into a highly elliptical capture orbit about Mars. To establish the required mapping orbit, the MGS spacecraft must supplement its propulsive capabilities by aerobraking. This paper describes the baseline aerobraking strategy in place for the MGS mission following the capture in September 1997. This description includes the aerobraking constraints imposed on the trajectory design, the trajectory control methodology, key aerobraking metrics, and the operational implementation. This paper also describes the current aerobraking flight profile and contrasts the initial results achieved to date against that profile.

## Session 3 Tracking and Navigation

**8:30 AM Monday, February 9 Laguna Ballroom G**

**Chair: Dr. Catherine L. Thornton**
**Jet Propulsion Laboratory**

**8:30 AM**
**AAS 98-113**

### An Operational Special-Perturbations-Based Catalog

S. L. Coffey - Naval Research Laboratory; H. L. Neal - GRC International

During the Fall of 1997, a special perturbations system, called SPeCIAL-K, will be installed at Naval Space Command. This system runs on a group of computers that comprise a virtual parallel processing system, layered on top of the PVM environment. With this system we hope to demonstrate the following: that it is feasible to maintain the space object catalog with special perturbations, to determine the amount of operator intervention necessary to process the objects that fail to converge normally, determine the computer resources required to maintain the catalog with SP, determine the robustness of the SP vectors, and gain information concerning improved accuracy of special perturbations vectors for all objects in the general catalog with standard tasking of the SSN sensors. SPeCIAL-K can be easily scaled to maintain a catalog of 50,000 or more objects with special perturbations, the only modifications necessary would be the addition of more computers, not modification of the software. The next generation of radars being designed for Naval Space Command may generate observations on such a large catalog, necessitating a parallel processing approach to processing the data.

**8:55 AM**
**AAS 98-114**

### Object Oriented Ephemeris Generation In A Distributed Computing Environment With Java

J. G. Kasalo - Santa Clara, CA

This paper examines the ability of object orientated technology to expand the solution space for astrodynamic software. The well-known SGP4 propagator is re-coded in Java to utilize an object orientated architecture; performance data for several platforms is reported. This code is used to satisfy two use cases with network connections - a mobile observer and a remote tracking sensor - which illustrate the types of problems object technology can address and its benefits. Software patterns and UML (Unified Modeling Language) are employed to high light their contribution to the manageability and robustness of this technology.

**9:20 AM**
**AAS 98-115**

### Single Track Covariance For Space Surveillance Network Sensors

K. T. Alfriend - Texas A&M University; F. Hoots, R. A. Glover - GRC International

When USSPACECOM updates the orbital elements of objects in the space catalog, a covariance at epoch is also obtained. This covariance does not provide an accurate estimate of the position error at times beyond epoch. In this paper a study is made of the accuracy and distribution of the covariance resulting from single tracks of SSN sensors. A total 31,119 tracks of 31 satellites in altitudes from 500-1000 kilometers were used in the analysis. The prediction intervals were 0.25 - 2.0 orbits. The results show that the orbit errors are approximately Gaussian and the covariance for single tracks is a good estimator of orbit error.

**9:45 AM** **BREAK**

**10:05 AM**

**AAS 98-116**

### Design For Operational Metric Calibration Of The Naval Space Surveillance System

P. W. Schumacher, Jr. - Naval Space Command; G. C. Gilbreath - Naval Research Laboratory; M. A. Davis - Allied Signal Technical Services Corp.; E. D. Lydick, S. G. Walters - Naval Space Command

This paper describes a Concept of Operations for incorporating SLR-based calibration into routine operation of the Naval Space Surveillance System. This sensor system, known as “the Fence”, is unique in the current inventory of space tracking assets and presents special opportunities and challenges in the area of calibration. We describe the basic fence system operation, the interferometric processing method, the different fence data types, such as direction cosines, direction cosine rates, and bi-static Doppler, and the SLR data type proposed as the basis for calibration. The Concept of Operations involves description of the data flow from the Fence sensor suite to NAVSPACECOM, generation and quality assessment of accurate reference orbits at Naval Research Laboratory, and the derivation of weights and biases for use in Catalog maintenance operation.

**10:30 AM**

**AAS 98-117**

### Estimation Of Radar Orientation, Location And Other Calibration Parameters Using Regularized Residuals

M. F. Storz - Falcon AFB Space Warfare Center

Calibration of space surveillance radars to remove systematic biases is a cost-effective way to improve metric observation accuracy, leading to more accurate satellite orbit determination. Radar calibration can be performed more effectively today because of the many available reference orbits with sub-meter accuracy. CALIBRE, described in this paper, is a new software program that simultaneously estimates the values and covariances for the following bias parameters: sensor location, sensor clock bias, sensor orientation, isotropic range and range rate biases, and an ionospheric bias. CALIBRE transforms look angle (azimuth/elevation) residuals and look angle rate residuals into a localized angular coordinate frame that removes the geometric distortions that arise near the zenith. These regularized residuals lead to better least squares estimates. Range (and its rate and acceleration) observations are also used as input. Look angle biases are estimated as a single rigid-body rotation of the sensor axes, a method more physically realistic than the common practice of estimating a bias in azimuth and a bias in elevation as decoupled parameters. Operational application of CALIBRE promises to provide significant improvements in the metric calibration of space surveillance radars and the resulting orbital accuracy.

**10:55 AM**

**AAS 98-118**

### Analysis Of The Telstar-401/GOES-10 Close Approach Using The Raven Telescope

C. Sabol - University of Colorado; R. Burns, S. Wallace - Kirkland AFB

On August 26, 1997, Telstar 401, an uncontrolled satellite, and GOES-10, the latest in the series of GOES weather satellites, had a close approach in geosynchronous orbit. This paper describes analysis of the close approach utilizing tracking data from Raven telescopes and the Space Surveillance Network. This was the first orbit determination application of the Raven telescopes located at the Air Force Research Lab sites in Albuquerque, NM, and Maui, HI. An effort is made to gauge the minimum distance between the two satellites and to evaluate the performance and benefits of the Raven telescope in orbit determination. This work represents a collaborative effort between the Air Force Research Lab, the NASA Goddard Space Flight Center, and U.S. Space Command.

## Session 4 Control Theory and Applications

**1:30 PM Monday, February 9 Laguna Ballroom E**

**Chair: Dr. Thomas E. Carter**
**Eastern Connecticut State University**

**1:30 PM**

**AAS 98-119**

### Repetitive Control Using Basis Functions

Hao-Ping Wen, R. W. Longman - Columbia University

The field of repetitive control develops control algorithms that learn to eliminate repetitive errors in a feedback controller's response to a periodic command or in its response to a constant command with a periodic disturbance. The typical objective is to attempt to eliminate all tracking error as time progresses for each time step of the period. It is often difficult to obtain this convergence based on the nominal system model, and even when convergence is guaranteed based on the nominal model, phase errors at high frequencies, for example due to unmodeled low amplitude high frequency dynamics, can destroy the convergence. This paper studies the use of projections of the error histories on chosen basis functions sets as a means to obtain improved robustness of repetitive control. The first set of basis function addressed comes from Fourier series, and has the advantage that the understanding of the stability boundary based on frequency response can be applied. Then other sets of basis functions including the use of wavelets are considered, and the potential advantages and disadvantages are investigated.

**1:55 PM**

**AAS 98-120**

### Implementing Time Optimal Robot Maneuvers Using Realistic Actuator Constraints And Learning Control

Ju Li, R. W. Longman - Columbia University; V. H. Schulz - University of Stuttgart, Germany; H. G. Bock - University of Heidelberg, Germany

This paper is one in a series of papers on time optimal control of robots, aiming to bridge the gap between theoretical/numerical results and routine application of time-optimal robot path planning in a factory environment. The research is building toward a demonstration of increased productivity on a Mercedes Benz press chain, where one robot is the slowest to accomplish its task and hence determines the cycle time of the chain -- we aim to speed up that robot and thus make the chain operate faster. In this paper, we develop a set of realistic inequality constraints that must be satisfied by the optimized trajectory. These constraints are far more complicated than the typical torque limits appearing in the literature. The physical constraints are related to lifetime or wear considerations in the drive systems, lubrication in the bearings, contact stresses, ratcheting limits, etc., and result in a mixture of pointwise speed and torque limits as well as limits on weighted speed and torque, as well as speed and torque alone, averaged over a cycle. Once the limits are formulated, the issue of how to command the commercial robot feedback controllers so that they actually execute the desired trajectory. Here we suggest the use of learning control.

**2:20 PM**

**AAS 98-121**

### Model Reference Adaptive Control In The Presence Of Bounded Unknown Disturbances

M. R. Akella, J. L. Junkins - Texas A&M University

We present a novel method to formulate and implement model reference adaptive control of poorly determined systems (for example, imprecise knowledge of the plant matrices) that are subject to bounded unknown disturbances. The disturbance dynamics are imposed on the system by augmenting its states to those of a nonlinear Markov process. Linearly contained coefficients in the generally nonlinear Markov process may be poorly known. Robust adaptive feedback control laws are then derived which ensure stability (bounded tracking errors) even in the presence of unknown model parameters, so long as the external disturbances belong to the class modeled by the nonlinear Markov process. We will demonstrate the practical implications of these results through numerical simulation of example problems.

**2:45 PM** **BREAK**

**3:05 PM**

**AAS 98-122**

### State Observability During Unpowered Hypersonic Entry At Mars

R. Carpenter, R. H. Bishop, and B. Hutchison - University of Texas at Austin

The choice of state variables in a guidance law can be viewed as a nonlinear state transformation of the standard longitudinal equations of motion of a point mass in atmospheric flight over a spherical, non-rotating planet. One common state variable is the atmospheric scale height which may not be known to sufficient accuracy for entry in planetary atmospheres. Therefore, it is of interest to consider the problem of the observability of the scale height along with other common state variables. Using only measurements of drag acceleration, such as might be derived from an inertial measurement unit onboard the entry vehicle, an observability analysis for a representative entry profile for a low L/D vehicle at Mars is presented. In this paper we implement the Apollo entry guidance law in the Mars environment and study the observability of the states along a baseline guided entry trajectory. The (nonlinear) observability for a particular choice of phase variables describing unpowered hypersonic aeroentry are derived.

**3:30 PM**

**AAS 98-123**

### Integration Of Comet Centroiding, Attitude Disturbance Rejection And Steering Mirror Control For The Stardust Mission

L. Sachi, P. Good - Lockheed Martin Astronautics; S. Bhaskaran - Jet Propulsion Laboratory

STARDUST is a mission to fly by the comet Wild-2 in early 2004 and return samples of the coma to Earth. During its flyby of the comet nucleus, an onboard navigation camera will take images of the comet for both science data and for navigation information. A nucleus tracking algorithm closes the navigation loop for attitude determination and camera tracking control. Spacecraft control is designed to reject particle disturbances in the pitch and yaw axes such that the spacecraft stays behind its protective shields. This paper discusses the nucleus tracking, camera tracking control and attitude control used during the encounter.

**3:55 PM**

**AAS 98-124**

## The High Accuracy Digital Servo Control And Data Processing System Of The Antenna Platform In The Satellite Orbit Simulation Laboratory

Yan, Jie; Chen, Liyi - Northwestern Polytechnical University, P. R. China

The transmit and receive antenna on the satellite should be tested before launching to determine its performances. The earth-base satellite space orbit survey and control laboratory (SSOSCL) is designed to deal with the antenna performances tests, which is generally composed of an isolated microwave room, antenna platform, control system, 3-D orbit system and a computer system by which we can design and control the test. In this paper, we discuss the composition of the SSOSCL (size: 4 m , 4 m, 10m) control system at first, then give the block diagram for the system. A PID type control algorithm is developed, which is different from the general PID algorithm. The main controlled variable in the suggested algorithm is the speed, and the position variable is introduced to correct the orbit error. The suggested PID algorithm has the advantage that it makes running orbits more smooth and accurate. The paper describes the design of the new PID control algorithm in detail, discusses its real-time calculate problems in the computer, and shows some results obtained with the suggested control algorithm.

## Session 5 Orbital Dynamics

**1:30 PM Monday, February 9 Laguna Ballroom F**

**Chair: Dr. Shannon L. Coffey**
**Naval Research Laboratory**

**1:30 PM** **Paper withdrawn.**

**1:55 PM**

**AAS 98-126**

### Harmonic Oscillator Solutions To Linearizable Perturbations Of Two-Body Problems

I. Aparicio, L. Floria - Universidad de Valladolid, Spain

In extended phase-space formulation, we analyze the exact linearization (say, reduction to second-order differential equations with constant coefficients governing a set of harmonic oscillators) of the equations of motion derived from a class of perturbed Keplerian Hamiltonian systems, and solve the resulting set of second-order equations. The said exact linearization is studied in terms of the so-called BF-, DEF- and D-variables, originally devised to regularize and exactly linearize unperturbed Keplerian Hamiltonian systems. We characterize perturbing potentials admitting exact linearization in these variables, and obtain the respective solutions corresponding to harmonic oscillators.

**2:20 PM**

**AAS 98-127**

### An Analytical Theory For Tesseral Harmonic Perturbations

A. M. Segerman - GRC International; S. L. Coffey - Naval Research Laboratory

An analytical method has been developed for the treatment of tesseral harmonic perturbations. The procedure is an iterative Lie transformation technique which avoids the typical eccentricity expansions as well as the numerical singularities normally associated with resonance conditions. At each iteration, terms of the perturbing potential become multiplied by the ratio of the satellite's orbital period to the earth's rotational period. Following a suitable number of iterations, the potential is deemed to be sufficiently small that it may be ignored, with the tesseral effects captured in the transformation.

**2:45 PM** **BREAK**

**3:05 PM** **AAS 98-128**

### Satellite Constellation Design For Zonal Coverage Using Genetic Algorithms

T. A. Ely, W. A. Crossley, E. A. Williams - Purdue University

Traditional satellite constellation design strategies typically address the problem of global coverage, however for many applications this is not necessary; coverage over a zonal region between specified latitudes is sufficient. This is often the case with satellite communication systems that focus coverage over the most populous regions of the Earth's Northern Hemisphere. To make the design problem analytically tractable, previous methodologies have imposed circular orbits as a constraint. The present study does not apply this constraint, it includes elliptical orbits in the design space for finding 'efficient' (minimal number of satellites and altitude guaranteeing complete coverage over a zonal region) satellite constellations. However, including elliptical orbits greatly complicates the design problem, yielding one that is not analytically tractable. Design selection must utilize a numerical search technique, a multiobjective design strategy using genetic algorithms appears to be well suited for this problem. The algorithm is capable of arriving at efficient designs that have varied, often competing, design goals in a complex design space (such as with the present problem).

**3:30 PM** **AAS 98-129**

### An Algorithm For Simulation Of Motions Of 'Variable Mass' Systems

S. Djerassi - Haifa, Israel

This paper deals with two kinds of 'variable mass' systems, namely, 'continuously' particle-ejecting (capturing) systems, such as rockets; and 'discretely' particle-ejecting (capturing) systems, such as automatic weapons (that fire rounds, one at a time). A new algorithm for the simulation of motions of such systems is introduced. Accordingly, the effect of the expulsion and/or capture of particles on the motion of the system is presented as *changes* in the integration variables, evaluated, in connection with numerical solutions of the motion equations, at each integration step.

**3:55 PM** **AAS 98-130**

### Searching For Repeating Ground Track Orbits: A Systematic Approach

M. Lara - Real Instituto y Observatorio de la Armada, Spain

For the zonal part of the earth artificial satellite problem, families of periodic orbits are computed in a synodic reference frame. A systematic procedure for finding periodic orbits at any inclination is described. The solutions found in this way repeat exactly their ground track on the surface of the earth and are a very good start for further refinements including other perturbations. A practical application is provided.

**4:20 PM** **AAS 98-131**

### Non-Integrability And Chaos In Satellite Orbital Dynamics

M. E. Sansaturio - E.T.S de Ingenieros Industriales, Spain; M. I. Vigo-Aguiar, J. M. Ferrandiz - Universidat de Alicante, Spain

Non-integrability and chaos are phenomena which appear in satellite dynamics and can affect the predictability of the solutions to a greater or lesser degree. In this paper, we first give a summary of the results so far obtained on the non-integrability resulting from different gravitational perturbations acting on a satellite, putting the stress on the auxiliary particular solutions used in the proofs and on their interpretation from the orbital dynamics point of view. Later on, we present some numerical experiments relative to some of the aforementioned problems. In particular, for the J22 problem, the corresponding Poincare sections for different values of the parameter J22 are built, showing the appearance of chaos.

## Session 6 Mission Analysis

**1:30 PM Monday, February 9 Laguna Ballroom G**

**Chair: Dr. C. David Eakman**
**Boeing Company**

**1:30 PM**
**AAS 98-132**

### Exact Analytical Solution To A Three-Dimensional Interception Of A Maneuvering Target

N. X. Vinh, P. T. Kabamba, T. Takehira - The University of Michigan

The 3-dimensional guidance problem has been extensively discussed in the open literature. However, because of the non-linearity of the equations of relative motion, its analytical solution is generally expressed in the form of non-integrable quadratures. In this paper, we generalize a guidance law, first studied by Cochran, to include a component of the relative commanded acceleration along the line-of-sight as well as its orthogonal component. For this more general guidance law, exact analytical solution to the 3-dimensional guidance problem is obtained explicitly in closed-form with two arbitrary control parameters. Application to the interception of a satellite in circular orbit is presented.

**1:55 PM**
**AAS 98-133**

### Greater Titan-Centaur Payloads Utilizing Space Shuttle Rendezvous

W. S. Vaning - San Rafael, CA

The concept of increasing the payload of the Titan-Centaur by rendezvous with the Space Shuttle in Low Earth Orbit, is examined. For Shuttle safety, the shuttle carries only the payload and other inerts. The Titan-Centaur carries the entire propulsion system, and several configurations are considered. This includes the options of a bare Centaur, extended tank Centaurs, one or more Agenas and/or Burner II's, and an auto refueling Centaur. Exponential rocket equations predict good results, up to 244% times the payload of just one Titan-Centaur.

**2:20 PM**
**AAS 98-134**

### Determination Of Close Approaches For Earth-Fixed Launch Trajectories

J. Woodburn - Analytical Graphics, Inc.

This work focuses on the determination of close approaches just after launch for cases where the trajectory is known in the Earth-Fixed reference frame but uncertainty exists in the time of launch. An algorithm is presented to determine all possible close approaches based on a launch time contained anywhere within a specified launch window in a single run. The corresponding blackout times during the launch window are also computed. This new algorithm requires substantially less computation time and is more robust than the simple technique of computing close approaches based on sampling throughout the launch window.

**2:45 PM** **BREAK**

**3:05 PM**

**AAS 98-135**

### Human Mars Exploration: Student-Designed Missions And The Current NASA Reference Mission

C. C. Seybold, W.T. Fowler - The University of Texas at Austin

The Advanced Design Program (ADP) was a NASA-funded project, administered by the Universities Space Research Association (USRA), to encourage upper-level undergraduates to develop high quality aerospace design projects and share them with their peers nationwide. Currently, the focus on Mars has revived an interest in having students participate in developing mission and vehicle designs, particularly through the Human Exploration and Development in Space-University Partners (HEDS-UP) program. This paper reviews the student ADP projects which focused on Mars missions and facilities. Each project is summarized, and the projects are compared with respect to types of assumptions, vehicle sizes, crew complements, propulsion systems, etc. The goal of the paper is to provide a quick and concise reference to ten years of innovative student work focusing on Mars.

**3:30 PM**

**AAS 98-136**

### Low Energy Interplanetary Transfers Using The Invariant Manifolds Of L1, L2, And Halo Orbits

M. W. Lo, S. D. Ross - Jet Propulsion Laboratory

The invariant manifolds associated with the outer planets are extremely large objects in phase space. They are trajectories in the ecliptic which intersect one another. This enables a low energy single impulse transfer between the planets which requires several orbital periods. Since the periods of the outer planets are large, this time factor precludes its use in mission design. However, if we consider the Jovian satellites where the same dynamics occurs but with very short orbital periods, this approach may be used for tour design requiring minimal Delta-V. The existence of this transfer is an indication of the instability of the region of space between the satellites. It may explain some of the difficulties encountered in traditional satellite tour designs using conic approximations.

**3:55 PM**

**AAS 98-137**

### Uranus L4/L5 Origin For Pluto?

W. S. Vaning - San Rafael, CA

Pluto may have originated at Uranus Lagrangian 4 or 5, 60˚ ahead or behind Uranus in its orbit. Gravitational perturbations eventually maneuvered Pluto/Charon into one or more far Flybys of Neptune, deflecting Pluto/Charon outwards to its present chaotic orbit. Computer simulations show about 5% of Uranus L4 & L5 planetoids will end up as trans-Neptunian objects. The relative velocities at Neptune match Pluto's speed to 10% presently. An exact match occurs within normal orbital variations. The Pluto/Charon synchronous orbit is not disrupted by this scenario.

**4:20 PM**

**AAS 98-138**

### Challenges Posed By Hyper-Light Trajectories

P. A. Murad - Vienna, VA

A candidate hyper-light drive is postulated that benefits from increasing electro-magnetic effects when a spaceship moves at, or faster than light speed. Details of the propulsor are briefly described and the trajectory from such a spacecraft is analytically derived using potential theory concepts for changing the trajectory equations from a time-spatial sense to a purely spatial scheme. There is an essential need for an embedded mathematical switch that alters the canonical form of the equations to account for changes near the speed of light. This is examined for both the *General* and *Special Relativity* cases and the issue of detecting such a trajectory is also discussed.

## Session 7 Attitude Control

**8:30 AM Tuesday, February 10 Laguna Ballroom E**

**Chair: Mr. Alfred J. Treder**
**Boeing Defense and Space Group**

**8:30 AM**

**AAS 98-139**

**Attitude Control Issues Associated With Flexible And Loosely Connected Appendages**

S. Tanygin, T. Williams - University of Cincinnati

Flexibility and slop of the connections may in practice greatly affect performance of the closed-loop attitude control system and become especially hazardous for a crewmember performing extra-vehicular activity. At the same time, they can be exceedingly difficult to measure on the ground. The general effect and potentially most damaging ranges of flexibility and slop are studied in this paper. Attitude control modifications leading to a better closed-loop performance are also of interest.

**8:55 AM**

**AAS 98-140**

**Feedback Control Law For Variable Speed Control Moment Gyros**

H. Schaub, S. R. Vadali, J. L. Junkins - Texas A&M University

Variable speed control moment gyroscopes are currently being considered to control spacecraft attitude. They combine the features of the classical reaction wheels and control moment gyroscopes. They can also be thought of as reaction wheels on single-axis gimbals. We present the equations of motion of a generic rigid body with several such gimbaled reaction wheels attached. The formulation is such that it can easily accommodate the classical cases of having either control moment gyros or reaction wheels to control spacecraft attitude. A globally asymptotically stabilizing nonlinear feedback control law is presented. For a redundant control system, a weighted minimum norm inverse will be used to determine the actual control vector. This weighted approach allows the variable speed control moment gyroscopes to behave more like classical reaction wheels or control moment gyroscopes depending on what the systems calls for.

**9:20 AM**

**AAS 98-141**

**Optimal Design Of A Passive Coning Attenuator For Spinning Spacecraft Under Thrust**

D. M. Halsmer, A. R. Fetter - Oral Roberts University

A procedure for designing a one-dimensional passive coning attenuator for a symmetric, spinning spacecraft under thrust is described. General expressions for the optimal stiffness and damping constants are derived, as well as an expression for the relative stability. General expressions for the optimal particle mass and attenuator location are derived from a simplified expression for the relative stability. These results provide a quantitative measure of the maximum "strength" of a passive coning attenuator. This is useful in designing such a device to overcome destabilizing effects.

**9:45 AM** **BREAK**

**10:05 AM** **Stardust TCM And Despin In The Presence Of Complex Fuel Dynamics**

**AAS 98-142**

P. Good, A. Carpenter, T. Gardner - Lockheed Martin Astronautics

STARDUST is a mission to fly by the comet Wild-2 in early 2004 and return samples of the coma to Earth. Two critical issues in the design of the Stardust attitude control system were driven by the interaction of spacecraft and fuel dynamics: controller stability during delta-velocity burns and possible recontact with the launch vehicle upper stage during controlled despin of the spacecraft after separation. This paper discusses the analytical methods used to model the fuel and spacecraft dynamics and to resolve the control and recontact issues.

**10:30 AM** **An Analysis Of Shuttle-Based Performance Of MEMS Sensors**

**AAS 98-143**

R. H. Smith - The Aerospace Corp.

The use of micro/nanotechnology (MNT) devices in space applications has the potential of revolutionizing some basic spacecraft subsystems. Their low cost, weight and volume, and mass producibility make them ideal for an era of spaceflight that concentrates on smaller and less expensive spacecraft. This paper introduces the reader to a Shuttle-based testbed program and some of its basic objectives. One of the core demonstrations of the STS-95 flight of the testbed will involve a suite of microaccelerometers and gyros. A pre-flight prediction of their performance will be given. Furthermore, a review of their basic operating features and potential applications will also be presented.

**10:55 AM** **Exponential-Of-Integral Design Synthesis Method For Satellite Attitude Control Under Structured Parameter Uncertainties**

**AAS 98-144**

Chang-Hee Won - Electronics and Telecommunications Research Institute, Korea

In this paper we introduce the Exponential-of-Integral control method as a generalization of the classical linear quadratic method. Furthermore, we develop the parameter robust Exponential-of-Integral control synthesis method to deal with parameter uncertainties. To determine the performance of this method, the steady state mean square regulation errors are calculated by finding the covariance matrices. Moreover, the performance and stability robustness of parameter robust Exponential-of-Integral control is compared with the classical linear quadratic Gaussian control. Finally, as an application of this parameter robust Exponential-of-Integral control, we use Korea Multi-Purpose Satellite model equipped with the reaction wheels and the thrusters as the attitude controller.

## Session 8 Interplanetary Missions 2

**8:30 AM Tuesday, February 10 Laguna Ballroom F**

**Chair: Dr. Richard Holdaway**
**Rutherford Appleton Laboratory**

**8:30 AM** **Navigation Flight Operations For Mars Pathfinder**

**AAS 98-145**

R. M. Vaughan, P. Kallemeyn, D. A. Spencer - Jet Propulsion Laboratory; R. D. Braun - NASA Langley Research Center

This paper describes the navigation flight experience for the Mars Pathfinder interplanetary cruise from launch in December 1996 to arrival at Mars on July 4, 1997. First, force modeling and the successful application of an enhanced filter technique for spacecraft orbit determination are discussed. Next, maneuver design and execution results for the 4 Trajectory Correction Maneuvers (TCMs) are presented. Finally, the navigation role in the days and hours leading up to and including the Entry, Descent, and Landing (EDL) is explained.

**8:55 AM** **Mars Pathfinder Atmospheric Entry Reconstruction**

**AAS 98-146**

D. A. Spencer - Jet Propulsion Laboratory; R. C. Blanchard, R. D. Braun - NASA Langley Research Center; S. W. Thurman - Jet Propulsion Laboratory

Five minutes after entering the Martian atmosphere, the Mars Pathfinder spacecraft impacted the surface of the Red Planet, and bounced and rolled to a stop. This paper presents the results of an effort to reconstruct the Pathfinder atmospheric entry trajectory, and assess the performance of the Entry, Descent and Landing (EDL) system. In addition, a reconstruction of the Mars atmosphere profile encountered by the Pathfinder entry vehicle will be presented.

**9:20 AM** **Entry Trajectory Dispersions Due To Uncertainties In The Mars Atmosphere**

**AAS 98-147**

G. E. Peterson - The Aerospace Corp.; R. H. Bishop - University of Texas at Austin

As greater accuracies become required for manned missions to Mars, it is necessary to identify those areas of atmospheric error that drive the total error for entry trajectories. To accomplish this task, the current study examines the dispersions for a proposed Mars 2001 ballistic entry profile using the Mars Global Reference Atmosphere Model developed by the Marshall Space Flight Center to accomplish this task. Error sources surveyed include: thermosphere errors, atmospheric waves, dust storms, global climatic change, and a new wind error model based upon the Dryden aerodynamic model modified for the martian atmosphere. Comparison with the usual COSPAR standard deviations is also examined.

**9:45 AM** **BREAK**

**10:05 AM** **Minimum-Fuel Escape From Two-Body Earth-Sun System**

**AAS 98-148**

G. Colasurdo, L. Casalino, S. Cassotto, E. Fantino - Politecnico di Torino, Italy

The analysis of interplanetary trajectories is a complex task due to the possibility of obtaining gravity assists from the planets; these assists can, in turn, be improved by deep-space impulses and multiple solutions exist to achieve, for instance, the escape from the solar system. If the two-body (Sun-Earth) system is considered, the number of potential trajectories is reduced and easier insight into the problem features is possible. Under this assumption, an elementary procedure, which uses the two-body problem equations and the patched-conic approximation, provides near-optimal trajectories using multiple Earth flybys. The most interesting missions are then improved by means of an indirect optimization procedure.

**10:30 AM** **Launch Period Analysis For The Jupiter Gravity Assist Opportunities To Pluto**

**AAS 98-149**

M. D. Reyes - Naval Postgraduate School; S. E. Matousek - Jet Propulsion Laboratory; I. M. Ross - Naval Postgraduate School

NASA Jet Propulsion Laboratory is designing a mission, called the Pluto/Kuiper Express, that will conduct reconnaissance of the Pluto/Charon system, determining the composition, atmosphere, and geological characteristics of each. To reach Pluto in a reasonable time frame at lowest cost, several trajectory options must be considered. Two nominal launch dates are determined, using JPL mission design software, and launch periods are built around them. By comparing the launch energy required by the spacecraft on each day of the period to the performance capabilities of several medium-lift launch vehicles, launch strategies for each day are compiled.

**10:55 AM** **Auto Aero-Assist For Comet Rendezvous And/Or Return**

**AAS 98-150**

W. S. Vaning - San Rafael, CA

When a comet is near perihelion, its gaseous exhalations can theoretically be used by Aero-Assisted spacecraft. If this maneuver properly reduces the spacecraft velocity, relative to the comet, Comet rendezvous can occur near comet aphelion, 1/2 orbit later with about 3 times the payload of a direct flight from Earth. This is called a comet (self, or) auto-assist. Aero conditions are comparable to reentry to Earth from Earth orbits. If this technique is used in reverse, to return samples from a comet, the payload increase is about 60%, slightly more than a Mars swingby. Specimen trajectories are presented.

## Session 9 Reference Systems and Simulation

**8:30 AM Tuesday, February 10 Laguna Ballroom G**

**Chair: Dr. Bruce J. Haines**
**Jet Propulsion Laboratory**

**8:30 AM** **The International Celestial Reference System**

**AAS 98-151** P. K. Seidelmann - U.S. Naval Observatory

The International Astronomical Union (IAU) has adopted a new and much more accurate International Celestial Reference System (ICRS) based on extragalactic radio sources. The reference frame is essentially fixed in space and not tied to the dynamics of the solar system. The use of the new reference frame does involve the kinematics of the Earth rotation. The ICRS, its realization as an optical reference frame, and as a reference frame for dynamical applications are described. The differences from the FK5 reference frame, how to get from there to the new system, the magnitude of the transformations, and the internal accuracies of the past and new systems are provided.

**8:55 AM** **The New Star Catalogs**

**AAS 98-152** P. K. Seidelmann - U.S. Naval Observatory

The Hipparcos Astrometric Satellite star catalog was released with 118,000 star positions, accurate to one milliarcsecond (mas) in 1991. There is an Astrographic Catalog/Tycho (ACT) catalog of about 1 million stars accurate to about 40 mas. This is based on the Astrographic Catalog from the beginning of the 20th century and the Tycho observational catalog from Hipparcos and goes as faint as 12th magnitude. There is the Washington Select Star List of the most accurate positions of bright, non-double, and non-variable stars that are recommended for navigation and guidance. A Washington Fundamental Catalog is in preparation that will provide the best reference catalog on J2000.0 for stars down to 12th magnitude. New catalogs in the 12-16th magnitude range accurate to 20-50 mas are in preparation. There is an Infrared Catalog currently available.

**9:20 AM** **The 488,006,860 Stars In The USNO-A1.0 Catalog**

**AAS 98-153** D. G. Monet - U.S. Naval Observatory Flagstaff Station

USNO-A1.0 (the largest star catalog ever compiled) is particularly useful for (a) computing the celestial coordinates of unknown or uncorrelated targets, and (b) removing star clutter so that such targets can be identified from a single image. By adopting catalog rather than mount-model astrometry, the accuracy of routine observations approaches that of the USNO-A1.0 catalog, about 0.25 arcsec. The density and completeness of USNO-A1.0 means that many catalog objects will be visible in images taken with most combinations of telescopes and image sensors. The spatially culled version (USNO-SA1.0) may be adequate for applications needing fewer reference objects.

**9:45 AM** **BREAK**

**10:05 AM** **Fizeau Astrometric Mapping Explorer (FAME) Satellite**

**AAS 98-154** P. K. Seidelmann - U.S. Naval Observatory

FAME is a small, inexpensive astrometric satellite that would give a star catalog of 10,000,000 stars of accuracy better than 50 microarcseconds to 9th magnitude and 1 milliarcsecond for stars down to 15th magnitude. The astrometric catalog will provide a precise optical reference frame for navigation, guidance, and autonomous space navigation. The excellent science which can be done with the resulting data includes calibration of the "standard candles" for measuring cosmological distances, calibration of absolute luminosities of hundreds of solar-neighborhood stars, and kinematic studies to assess the abundance of dark matter in the Galactic disk. Also, FAME would be a precursor for future space interferometers. It would identify candidate grid stars for SIM and stars for searches for planetary systems and brown dwarfs.

**10:30 AM** **An Analysis Of The Behavior Of The J2000 Reduction Matrices**

**AAS 98-155** D. A. Vallado - Phillips Laboratory

Accurate orbit determination relies on dense observational data and numerical processing. As existing analytical methods are replaced with highly accurate numerical techniques, a need exists to permit numerical integration methods to efficiently implement reduction calculations. The theory for FK5(J2000) is well known, as well as numerical integration methods. The desirability to integrate and produce state vectors in varying frames requires efficient methods to convert between frames. In addition, the numerical integration is often performed in the "inertial" mean-of-date frame, while the measurements and force model accelerations are found in the true-of-date frames. In particular, this paper investigates the behavior of the reduction matrices for precession, nutation, sidereal time, and polar motion as applied to numerical propagation. It finds that the time required to determine the complete reduction matrices isn't always beneficial, depending on the accuracy requirements. It also shows graphical and timing analyses that show the approximations can save significant amount of time while maintaining modest accuracy. The new ICRS system should nullify many of the concerns of the different frames, but this analysis should prove useful until the ICRS is fully implemented. The overall conclusion is that the complete matrices should be used for all highly accurate calculations, and the reduction matrices need only be updated every week or more, depending on the desired accuracy.

## Session 10 Estimation

**1:30 PM Tuesday, February 10 Laguna Ballroom E**

**Chair: Dr. Christopher D. Hall**
**Virginia Polytechnic Institute and State University**

**1:30 PM**

**AAS 98-156**

### TOPEX/Posidon "Quick-Look" Precision Orbit Determination Improvement And Performance

A. H. Salama, B. Kennedy - Jet Propulsion Laboratory

The Topex/Poseidon satellite is now in its sixth year of operations and third year of extended mission. The last couple of years have been characterized by a flight team operating with minimal resources, two major satellite anomalies, reduction in Satellite Laser Ranging (SLR) tracking data, and some Global Positioning System Development Receiver (GPSDR) problems. Despite these shortcomings, the Precision orbit determination and Verification Team (PVT) has improved the processing of its Medium precision Orbit Ephemerides (MOE). The MOEs are now provided to the science community 3 days after-the-track instead of the 4-day baseline without loss of precision. The paper presents a performance summary of the "quick-look" orbit determination using GPS and SLR tracking data. The main feature of this process is that MOEs are produced with small radial position error (<5 cm RMS). The quick-look orbits are used in support of the Interim Geophysical Data Record (IGDR) production.

**1:55 PM**

**AAS 98-157**

### Nonlinear Adaptive State Estimator Approach To Attitude And Orbit Determination Using Only A Magnetometer

F. Curti - University of Rome "La Sapienza", Italy

In the present paper the Nonlinear Adaptive State Estimator (NASE) technique is applied to the attitude and orbit determination of the Italian San Marco 5 satellite, which was a spinning satellite (flown in 1988) with a three-axis magnetometer along the principal inertia axes. The technique is based on an adaptive scheme for directly building the estimator gain by using the magnetometer outputs. The NASE is functioning as an optimal filter with respect to a suitable Lyapunov function, which is selected for studying the stability of the estimator. Besides the optimality characteristics, the estimator is adapting with the disturbances arising from the noise and the high order terms of the linearization process. Moreover, thanks to the adaptation behaviour of the filter, the mismatching between the actual geomagnetic field and the Earth magnetic model is also balanced. The paper contributes to optimizing the values of the NASE parameters and sets up an automatic procedure for finding them.

**2:20 PM** **AAS 98-158**

### Wavelets, Smoothers, And Filters - Application To Satellite Attitude Determination Problems

D. L. Mackison - University of Colorado

Satellite attitude determination is dependent upon the choice of attitude sensors, geometrics, algorithms, dynamic and measurement models, and the appropriate use and combination of these resources. Even low noise systems including star sensors and inertial grade gyros have limits on their ultimate resolution. Approaches to reducing the effects of noise include the use of recursive Kalman filters, and the Extended Kalman Filter, and smoothing the data a priori or through the use of a forward-backward Kalman filter such as the Rauch-Tung-Striebel smoother. Here we apply smoothing techniques, wavelet denoising, and wavelet power spectra to satellite attitude data and demonstrate the comparative advantage and relative merits to problems in satellite attitude determination.

**2:45 PM** **BREAK**

**3:05 PM** **AAS 98-159**

### Toward The Most Precise Attitude Determination System Using Star Trackers

D. Mortari - Universita degli Studi "La Sapienza" di Roma, Italy; T. C. Pollock, J. L. Junkins - Texas A&M University

An application of the Attitude Error Estimator Algorithm (AEEA), here fully developed, to evaluate the gain in attitude accuracy obtainable by a new star sensor idea, is here presented. The AEEA, which is based on the right definition of the attitude error and on the spatial displacement of the observed directions, allows an accurate estimation of the attitude accuracy obtainable with a given attitude data set (sensors' error and observed directions). The attitude error statistical parameters, such as the expectation, the standard deviation and the variance, are shown to be related to the maximum value only. The application shows that, with respect to the classical star sensors, the proposed new star sensor achieves a substantial gain in the obtainable attitude accuracy, which is also shown to be almost independent of both the number of observed stars and the sensor field of view. In general, the AEEA can be applied to establish which attitude determination system, among a given set of attitude sensor allocations, is the most accurate.

**3:30 PM** **AAS 98-161**

### Application Of Average Contamination Sources For The Prediction Of Space Debris Environment

A. I. Nazarenko - Center for Program Studies, Russia

The conventional approach to prediction of technogeneous space contamination is based on modeling space debris (SD) generation as a result of satellite launches, technological operations and spacecraft breakups. The technique of SD environment prediction, developed in Russia, uses the averaged description of contamination sources: the average number of annually generated objects of different size on orbits with various altitudes, eccentricities and inclinations. The advantages and limitations of two above-mentioned approaches are considered in the report. The averaged description of contamination sources was used in the computer model for Space Debris Prediction and Analysis developed in Russia (the SDPA-model).

## Session 11 Optimization Theory and Applications

**1:30 PM Tuesday, February 10 Laguna Ballroom F**

**Chair: Dr. Craig A. Kluever**
**University of Missouri - Columbia/Kansas City**

**1:30 PM** **An Optimal Analytic Solution For Mayer's Variation Problem**

**AAS 98-162** D. M. Azimov - Tashkent State University and Uzbek State Space Research Agency, Uzbekistan

Mayer's variational problem of determining the optimum trajectories of a rocket moving with constant relative exhaust velocity and bounded mass flow rate in a newtonian field is considered. A new analytical solution, which represent certain spherical trajectories for three-dimensional intermediate thrust arcs are obtained. They may be optimal or non-optimal in depending on a sign of radial component of the primer-vector. The problem of minimization of characteristic velocity of active turning the plane of given elliptic orbit is considered. Also a new analytical solutions vector has been assumed to be a linear function of radius vector. Estimations of errors of using this approximation are given. It is shown that the $\lambda$-trajectory is a straight line and the direction of thrust force remain constant relative to the horizon. The problem of optimal free time minimum fuel transfer between given circular orbits by two maximum thrust arcs is discussed.

**1:55 PM** **Necessary And Sufficient Conditions For Optimal Control Problems With Scalar Terminal Constraint**

**AAS 98-163** Jang-Won Jo, J. E. Prussing - University of Illinois at Urbana-Champaign

A recent advance in sufficient conditions for a weak local minimum in the Bolza optimal control problem is used to develop a procedure for applying second-order necessary and sufficient conditions. This improved procedure provides routine testing of second-order conditions in optimal control problems. Two example problems are analyzed, including a spacecraft trajectory with a low-thrust power-limited rocket engine. A solution for a multi-objective performance index that depends on final orbit energy and propellant consumption is found. It satisfies the usual first-order necessary conditions, but is found to be non-optimal.

**2:20 PM** **Necessary And Sufficient Conditions For Optimal Control Problems With Multiple Terminal Constraints**

**AAS 98-164** Jang-Won Jo, J. E. Prussing - University of Illinois at Urbana-Champaign

A recent advance in sufficient conditions for a weak local minimum in the Bolza optimal control problem is used to develop a procedure for applying second-order necessary and sufficient conditions to problems with multiple terminal constraints. Three example problems are analyzed: a minimum-time problem, the shortest path between two points on a sphere, and an application of Hamilton's Principle to a circular orbit in an inverse-square gravitational field. When the circular orbit violates the second-order conditions, a genetic algorithm is used to determine an alternate path of lower cost.

**2:45 PM** **BREAK**

**3:05 PM** **Optimization Of Solar-Perturbed Double Lunar Swingby Escape Trajectories**

**AAS 98-165**

C. R. Cassell - University of California, San Diego

Double lunar swingby (DLS) escape trajectories employing a multi-month Solar-Perturbed Loop (SPL) between swingbys can be very beneficial for performance to lower energy objectives, such as near-Earth asteroids. Trajectory constraints negating these benefits can be offset with a propulsive impulse during the SPL. A "primer vector" approach is used to develop conditions for introduction and movement of this impulse in the time-fixed problem. The cost function uses a simplified model of the swingby delta-V facilitating this development and decoupling, to some extent, SPL optimization from the rest of the trajectory. The space of SPL reference trajectories is characterized and optimization of selected trajectories demonstrated.

**3:30 PM** **Application Of Periodic Optimal Control Theory To The Orbit Reboost Problem**

**AAS 98-166**

K. E. Jensen, F. Fahroo, I. M. Ross - Naval Postgraduate School

In a previous paper, it was shown that a forced Keplerian trajectory (FKT) obtained by thrust-drag cancellation is not Mayer-optimal. Application of this result to the fuel-optimal orbit maintenance problem implies that periodic reboosts must be more efficient than a thrust-drag cancellation. A linear analysis indicates that the performance of periodic Hohmann reboosts is the same as that of an FKT. To determine the optimal reboost strategy, we formulate an optimal periodic control problem. This problem is numerically solved by a spectral collocation method. Initial analysis indicates that fuel savings of at least 8% is possible for the international space station.

**3:55 PM** **Optimizing Boost Phase Of Rocket Using Lyapunov Optimal Feedback Control**

**AAS 98-167**

F. A. Lohar - University of Malaysia; T. Masood - National University of Sciences and Technology, Pakistan

The paper addresses the problem of optimizing boost phase of a rocket using Lyapunov optimal feedback control when liquid propellant is used. The same technique has already been used successfully for aeroassisted maneuvering. The decent function or Lyapunov function and necessary conditions are derived, and Lyapunov optimal feedback control problem is solved numerically. The results show the robustness of the technique that in the presence and absence of the atmospheric density fluctuations the final conditions are satisfied. Lyapunov optimal feedback controller is not only useful for its on board application but also more useful for preliminary trajectory analysis than the conventional methods.

## Session 12 Near Earth Mission Design

**1:30 PM Tuesday, February 10 Laguna Ballroom G**

**Chair: Dr. David B. Spencer**
**USAF Phillips Laboratory**

### 1:30 PM — Station-Keeping Strategies For Translunar Libration Point Orbits

**AAS 98-168**

G. Gomez - Universitat de Barcelona, Spain; K. C. Howell - Purdue University; J. Masdemont - Universitat Politecnica de Catalunya, Spain; C. Simo - Universitat de Barcelona, Spain

Spacecraft in orbits near the collinear libration points are excellent platforms for scientific investigations of various phenomena. Since such libration point trajectories are generally unstable, spacecraft moving on such paths must use some form of trajectory control to remain close to the nominal orbit. The primary goal of this effort is the study of two particular stationkeeping approaches applied to the maintenance of a spacecraft in a quasiperiodic Earth-Moon L2 halo orbit. The Target Point station-keeping method computes corrective maneuvers by minimizing a weighted cost function. The cost function is defined in terms of a corrective maneuver as well as position and velocity deviations from the nominal orbit at a number of specified future times; these state vectors are denoted as "target points." The target points are selected along the trajectory at discrete time intervals that are downstream of the maneuver. In contrast, the Floquet Mode approach incorporates invariant manifold theory and Floquet modes to compute the maneuvers. Floquet modes associated with the monodromy matrix are used to determine the unstable component corresponding to the local error vector. The maneuver is then computed such that it eradicates the dominant unstable component of the error. It is noted that both approaches have been demonstrated in a complex model, but neither of these methods has previously been applied in the Earth-Moon system.

### 1:55 PM — Formation Flying In The Vicinity Of Libration Point Orbits

**AAS 98-169**

B. T. Barden, K. C. Howell - Purdue University

Recent theoretical and numerical advances in trajectory design in the three-body problem have provided several new mission possibilities. Many of the advances have come from the application of dynamical systems theory. However, the majority of the design issues are based solely on the stable and unstable manifold of libration point orbits. This study seeks to utilize the center manifold in trajectory design in two different ways. First, the center manifold will be used as a means to include the size of the halo orbit as a design parameter in transfer trajectory design. Second, new mission options will be investigated (via the center manifold) that include flying multiple spacecraft in a controlled formation near a libration point. As part of the development, a discussion will be presented on the types of motions that exist near libration points and the transitions from one type of motion to another.

**2:20 PM**

**AAS 98-170**

### Eclipses By The Earth And By The Moon As Constraints On The AXAF Mission

S. W. Evans - Marshall Space Flight Center

The Advanced X-ray Astrophysics Facility (AXAF) is scheduled for launch on September 1, 1998, on a mission lasting ten years. During this time AXAF will be subject to eclipses by the Earth and the Moon. Eclipses by the Earth will occur during regular 'seasons' six months apart. AXAF requires that none last longer than 120 minutes, and this constrains the orbit orientation. Eclipses by the Moon occur infrequently, but may pose serious operational problems. The AXAF perigee altitude can be chosen, once the other initial conditions are known, so that objectionable Moon-eclipses can be avoided by targeting the final burn.

**2:45 PM** **BREAK**

**3:05 PM**

**AAS 98-171**

### On-Orbit Engineering Tests Of AERCam Sprint Robotic Camera Vehicle

T. Williams, S. Tanygin - University of Cincinnati

AERCam Sprint, a prototype "camera pod" vehicle developed by NASA Johnson, was tested on-orbit in December 1997 during the STS-87 mission. Sprint is a 35 lbm, 14 inch diameter sphere equipped with two television cameras, a 6 DOF cold-gas propulsion system, and an automatic attitude hold capability which maintains a fixed inertial orientation. After Sprint was released manually by EVA astronaut Winston Scott, it was tele-operated through a 70 minute test sequence by astronaut Steve Lindsey. This paper describes the maneuver sequence that was developed for the Sprint mission, and the actual flight test results obtained.

**3:30 PM**

**AAS 98-172**

### Continuous Global Earth Coverage By Means Of Multistationary Orbits

M. M. Castronuovo, A. Bardone, M. Di Ruscio - Universita degli Studi di Roma "La Sapienza", Italy

The traditional way to obtain a continuous global Earth coverage is to use three geostationary satellites at 120° of longitude from each other. An alternative and more cost-effective solution consists in using a constellation of four satellites on multistationary orbits rotated 90° one from the other. Such orbits are equatorial highly elliptic orbits with a revolution period of about 8 hours. For about 6 hours, around the apogee, the satellite is almost stationary with respect to a given meridian. In this paper we present a detailed analysis of the dynamics of such constellation, considering the effect of the major perturbations on the evolution of the orbital parameters and on the ground station visibility pattern. The visibility characteristics of the constellation have been computed for the CRPSM Ground Station of Malindi (Kenya) and the global Earth coverage has been evaluated.

**3:55 PM** **The 1997.0 CNUCE Orbital Debris Reference Model**

**AAS 98-173**

C. Pardini, L. Anselmo, A. Rossi - CNUCE/CNR, Italy; A. Cordelli - Consorzio Pisa Ricerche, Italy; P. Farinella - Universitai di Pisa, Italy

Today earth mission planning and operations must deal with a problem mostly ignored just twenty years ago: non-catalogued space debris. In order to understand the origin and distribution of the artificial debris in the 0.1-10 cm size range, we carried out a massive effort to estimate the contribution of the historical events able to produce a large number of particles. The sources considered were 140 spacecraft and upper stages breakups and the liquid sodium-potassium coolant leaked from 16 Soviet radar ocean reconnaissance satellites. The resulting 1997.O CNUCE Orbital Debris Reference Model (CODRM-97) includes more than 52 millions of particles heavier than 1 mg.

**4:20 PM** **The Realities Of Reentry Disposal**

**AAS 98-174**

W. Ailor, R. Patera - The Aerospace Corp.

Reentry and reentry breakup of space hardware are receiving increasing attention as spacecraft owners and operators plan for deorbiting space hardware at end of mission as a way of reducing the orbital debris hazard to other spacecraft. While many believe that hardware will be effectively burned-up during reentry into the Earth's atmosphere, and reentry is considered an effective and safe disposal method for spacecraft and stages at end of mission, there is evidence that significant pieces of debris may survive reentry and pose a hazard to people and property on the ground. This paper describes knowledge gained from several well-known reentries, including the Cosmos 954, Skylab, and the recent Delta II second stage reentry into Texas. These examples show that significant pieces of hardware can and do survive the reentry environment, and give notice that mission planners should include mitigation of the potential hazard such hardware might pose as part of their overall mission design. These reentries also provide information on the adequacy of current models for predicting the consequences of reentry. The paper outlines areas where additional research is required to refine our ability to model such events and suggests strategies spacecraft owners and operators can use to minimize hazards to people and property.

## Session 13 Space Structures

**8:30 AM Wednesday, February 11 Laguna Ballroom E**

**Chair: Dr. Peter M. Bainum**
**Howard University**

**8:30 AM**

**AAS 98-175**

### Effect Of Nonlinearity On The Dynamics Of Spinning Spacecraft Appendages With An Offset

A. K. Misra, M. J. Sadigh - McGill University; G. Tyc - Bristol Aerospace Ltd.

The paper considers a spinning system consisting of a central rigid body and a set of appendages, each of which is connected with an offset from the centre of mass of the rigid body. It is observed that when the quadratic terms involving the small elastic generalized coordinates are neglected in the final equations, which is the common practice, the system behaviour for some spin rates depends strongly on the sign of the offset. On the other hand, if the quadratic terms are retained in the equations of motion, the dynamics of the system does not depend on the sign of the offset. The paper explains why neglecting the quadratic elastic terms leads to incorrect stability prediction.

**8:55 AM**

**AAS 98-176**

### Vibration Suppression: Reduced Order Model/Residual Mode Filter Control Using Smart Structures

J. G. Stuart, B. N. Agrawal - Naval Postgraduate School

In general, active control of large flexible structures can be used to improve performance, e.g., shape fidelity, line-of-sight pointing accuracy, and vibration and disturbance suppression. Large-scale models of such structures (e.g., finite element models) are appropriate for dynamic simulation but cannot be used as a basis for control algorithms, which must be implemented via computer in real-time. Therefore, control algorithms are often based on Reduced-Order Models (ROM) of the structure dynamics. Whenever such a controller operates in closed-loop with the actual structure, unwanted Controller-Structure Interaction (CSI) occurs due to un-modeled dynamics. CSI can cause performance degradation and even instability. These instabilities can easily be relieved by the use of low-order Residual Mode Filters (RMF). These filters can be added on after the original ROM controller has been designed, and they produce very little degradation of designed performance while yielding an acceptable stability margin for closed-loop operation. The research presented in this paper integrates smart structure control technologies with the Reduced-Order Model (ROM)(ROM-RMF) control technique for active vibration control of a flexible spacecraft structure. This smart structure control technique is applied to a model of the U.S. Naval Postgraduate School's Flexible Spacecraft Simulator (FSS). The FSS simulates motion about the pitch axis of a spacecraft, and is comprised of a rigid central body and a reflector supported by a two-link flexible antenna support structure. The flexible arm representing the antenna support structure has two sets of piezoceramic sensors and actuators, which are used for active vibration control.

**9:20 AM**

**AAS 98-177**

### Deployable Antenna Test Facility With Magnetically Suspended Sliders (MagSus Sliders)

Y. Horiuchi, T. Sugimoto - Mitsubishi Electric Corp., Japan; H. Tsunoda, Y. Kawakami - Advanced Space Communication Research Laboratory, Japan

This paper describes an original deployable antenna test facility which provides precise on-ground evaluation of the antenna deployability using magnetically suspended sliders (MagSus Sliders). The MagSus Sliders system produces virtual micro-gravity environment and compensates the antenna weight without disturbing its 3-dimensional deployment motion. This system can be applied to the test facility for most of all deployable space structures, and enables us to evaluate their high precision deployability easily and repeatedly. Several deployment experiments on a mesh antenna partial model (real scale, 7m in diameter) show that this system is practical enough.

**9:45 AM** **BREAK**

**10:05 AM** **Paper withdrawn.**

**10:30 AM**

**AAS 98-179**

### Study Of Sensor Redundancy And Effect Of Accelerometer For Flexible Expendable Launch Vehicles (ELV)

Zhaozhi Tan, P. M. Bainum - Howard University

A simplified mathematical model of an expendable launch vehicle system suitable for subsequent control design has been established. It was requested by our grant sponsor that we consider an accelerometer collocated with the position gyro to be added to the system as an additional sensor. According to requirements of the grant sponsor the problem of sensor redundancy is also studied. The simulation results are given for comparison of the situations where: (1) none of the gyros, (2) one, or (3) two gyros fail. The effect of including (or deleting) the accelerometer as an additional sensor is also studied.

**10:55 AM**

**AAS 98-180**

### Three-Dimensional Attitude Maneuvers Of Flexible Spacecrafts With Viscoelastic Arms

S. H. Pourtakdoust, M. A. Jalali - Sharif University of Technology, Iran

Abstract unavailable.

**11:20 AM**

**AAS 98-181**

## Stability And Coupling Characteristics Of Flight Vehicle Consider With Elastic Freedom

Tang, Shuo; Li, Xiaolong - Northwestern Polytechnical University, P. R. China

In this paper, we establish the dynamic modeling of elastic vehicle acting with unsteady aerodynamic forces expressed by rational function matrices. When attitude dynamics is taken into account, the indicial lift functions are applied to describe unsteady aerodynamics for arbitrary motion. Stability of the coupling elastic vehicle system is studied through analysis of return difference matrix and multivariable Nyquist locus. By the response error analysis, a coupling measure is derived to indicate interactions between rigid-body motion variables, elastic variables, control variables and observation variables in frequency domain under open/closed-loop control. At the end, a practical example is given and a digital example is studied. The investigated vehicle dynamic model consists of longitudinal short period motion, first three modes of elastic freedoms and two exponential terms in the indicial functions. A single input/ single output constant gain feedback flight control system with pitching velocity gyro is investigated.

## Session 14 Comet and Asteroid Missions

**8:30 AM Wednesday, February 11 Laguna Ballroom F**

**Chair: Dr. I. Michael Ross**
**Naval Postgraduate School**

**8:30 AM**

**AAS 98-182**

### Planning A Faster, Cheaper Asteroid Mission

A. Hope - Naval Research Laboratory

Future space missions are being planned to satisfy the faster, cheaper and better philosophy. This paper is a how-to-guide for planning an asteroid mission which requires low energy (cheaper) and returns a maximum amount of science (better). Short term planning and execution of a mission is crucial to satisfy the cheaper aspect of a mission. Mission design methodology for constructing a low cost multiple asteroid flyby mission is given and example missions are presented.

**8:55 AM**

**AAS 98-183**

### Asteroid Selection And Mission Design For SpaceDev Corporation's Near-Earth Asteroid Prospector

C. R. Cassell - UCSD and Lockheed-Martin Missiles and Space Corp.; A. M. Schneider, R. Gulman, R. Lee, E. Estey - University of California at San Diego

Near-Earth Asteroid Prospector will be the first privately financed deep-space mission; the first of a series from SpaceDev Corporation. The requirement to make a profit on the science data set dictates formidable challenges for the preliminary design team of students and mentors at CalSpace/UCSD. Nevertheless, a number of rendezvous opportunities exist within these constraints of cost, timeline, delta-V, weight, power, etc. This paper focuses on criteria and modeling tools for asteroid selection, on launch vehicle selection and escape trajectory planning, and on the rendezvous and station-keeping strategy.

**9:20 AM**

**AAS 98-184**

### Mission Design And Navigation Of NEAR's Encounter With Asteroid 253 Mathilde

D. J. Scheeres - Iowa State University; D. W. Dunham, R. W. Farquhar - Applied Physics Laboratory; C. E. Helfrich - Jet Propulsion Laboratory; J. V. McAdams - APL; J. K. Miller, W. M. Owen, Jr., S. P. Synnott, B. G. Williams, P. J. Wolff, D. K. Yeomans - JPL

On June 27, 1997 the NEAR spacecraft had a successful close encounter with minor planet 253 Mathilde, flying by the asteroid at a distance of 1225 km and a speed of 9.93 km/s. The flyby was a complete success: all the planned science images were captured, the mass of Mathilde was determined and the spacecraft was delivered to its target point well within the predicted 1-sigma delivery accuracy in the B-plane and in time-of-flight. This paper reviews the mission design and navigation plans and operations leading up to the flyby and analyzes their performance in light of the post-flyby analysis. Topics covered in this paper are: trajectory design and characteristics; pre-flyby radio metric orbit determination of NEAR; pre-flyby ephemeris estimation of Mathilde using ground-based observations; optical navigation detection and reduction prior to the flyby; combining radio metric, ground-based ephemeris and spacecraft-based optical data into a joint solution for the spacecraft and for Mathilde; post-flyby optical navigation images, reconstruction of the actual flyby conditions and estimation of the Mathilde mass.

**9:45 AM** **BREAK**

**10:05 AM**

**AAS 98-185**

### Autonomous Controlled Landing On Cometary Bodies

S. Dawson, L. Early, H. Konigsmann, C. W. Potterveld - Microcosm Inc.

Control laws for autonomously guiding a spacecraft through a series of waypoints in inertial space were applied to the problem of autonomously landing on a cometary body. The cometary body used was based largely on models of comet 46 P/Wirtanen. Waypoints were generated by solving Lambert's Problem in universal variables. Initial simulations resulted in soft touchdowns (< 1 m/s) within a few meters of the intended target, demonstrating the feasibility of this approach.

**10:30 AM**

**AAS 98-186**

### Gravitational Effects Of Earth In Optimizing Delta-V For Deflecting Earth Crossing Asteroids

Sang-Young Park, I. M. Ross - Naval Postgraduate School

The gravitational effects of Earth to calculate optimal impulses for deflecting Earth-crossing asteroids are presented in this paper. The patched conic method is used to formulate the constrained optimization problem. The constraints at Earth are pulled back to constraints at the edge of the sphere-of-influence. The result is a heliocentric three-body optimization problem with first-order constraints. Numerical solution to the approximate three-body problem indicate that the delta-V requirements are considerably more than the two-body approximation.

**10:55 AM**

**AAS 98-187**

### Mission Design For The Deep Space 4/Champollion Comet Sample Return Mission

G. H. Tan-Wang, J. A. Sims - Jet Propulsion Laboratory

The Deep Space 4/Champollion mission will be the first to land a spacecraft on the surface of a comet, collect a subsurface sample, and return the sample to Earth for analysis. This paper describes the trade studies resulting in the current reference mission, which uses solar electric propulsion to rendezvous with the comet Tempel 1 in December 2005 after launching in April 2003. An option which uses a chemical propulsion system to return to Earth is discussed.

## Session 15 Orbit Determination

**8:30 AM Wednesday, February 11 Laguna Ballroom G**

**Chair: Dr. Paul J. Cefola**

**The Charles Stark Draper Laboratory**

**8:30 AM**

**AAS 98-188**

### On The Program Ensuring On Classical And Intermediate Orbit Determination By Observations

E. R. Mirmakhmudov - Astronomical Institute of Academy of Sciences, Uzbekistan; D. M Azimov - Taskent State University and Uzbekkosmos, Uzbekistan; T. I. Samusenko - Astronomical Institute of Academy of Sciences, Uzbekistan

The aim of the present work is program ensuring elaboration of unit methods of direct and indirect solutions of preliminary orbit determination problem on corner measurement of objects on basis of observations of small bodies in frame of the Gauss method. The choice of these methods is conditioned by the known opinions about deep reconsidering the Gauss algorithm on basis of latest achievements in the field of computational technologies. For computation of the preliminary orbit of celestial body one may use the fictition attracting center. The method based on idea of intermediate orbit determination is described. Such intermediate orbits are useful to use at approachment of the small body with the big planets, where the perturbations are great and classical method is less useful to preliminary orbit determination. It is shown that elements obtained on modified method are not worse in comparison with classical ones.

**8:55 AM**

**AAS 98-189**

### Modeling Catastrophic Decay Orbits Through Perigee

J. D. Fisher - USAF, Massachusetts Institute of Technology; P. J. Cefola, R. J. Proulx - C. S. Draper Laboratory

As highly eccentric orbits decay, their passage through perigee acts as a major perturbation due to highly dynamic atmospheric effects. In order to better model decay, the authors will do a brief analysis of the modeling errors for various atmospheric effects. Using data from an upper stage SL-6 Molniya rocket body, the errors identified in these analyses will be used to define a functional representation of the process noise. The results of incorporating this function into a Kalman Filter are presented.

**9:20 AM**

**AAS 98-190**

### Estimating Atmosphere Density Variations To Improve LEO Orbit Prediction Accuracy

A. I. Nazarenko - Center for Program Studies, Russia; P. J. Cefola - C. S. Draper Laboratory

Atmosphere density models such as Jacchia or MSIS provide insufficient accuracy for short-arc orbit determination applications involving strongly drag-perturbed orbits. Therefore, operational orbit determination procedures for these orbits employ a "solve-for" vector which consists of an element set (or the six equivalent components of position and velocity) and a ballistic coefficient or related drag factor. The drag factor adjusts the density model to better represent the real conditions experienced by the satellite. Thus, the observed ballistic coefficient associated with a particular fit span reflects the "average" solar activity and geomagnetic disturbance. When an orbit prediction into the future is made, the most recent element set and ballistic coefficient are employed. Significant orbit prediction errors occur because the "average" solar activity and geomagnetic disturbance in the predict interval is not identical to that in the fit interval. In this work, an atmosphere density tracking process that operates in parallel to the orbit determination process is introduced. The atmosphere tracking process employs data from multiple satellites. The atmosphere tracking process includes separate procedures for constructing the atmosphere density variations and for estimating the true ballistic coefficient of the satellites employed. The process also includes procedures for forecasting the atmosphere density at future times. Practical implementation of this process allows construction of a unique system for the upper atmosphere state monitoring. This work was supported by a purchase order issued to the Scientific-Industrial Firm “NUCLON” under the Draper Laboratory IR&D Program during DFY 97.

**9:45 AM** **BREAK**

**10:05 AM**

**AAS 98-191**

### Determination And Prediction Of Orbits With Due Account Of Disturbances As A <<Color>> Noise

A. I. Nazarenko - Center for Program Studies, Russia

The convenient-for-adaptation method of orbit determination with due account of a «color» noise is presented in this report. This technique has some common features with the Kalman filter. The difference consists in the fact, that, except two recurrent equations (for the state vector and for its correlation matrix), three additional functional recurrent equations were constructed: for noise estimations, for an a posteriori correlation function of noise, and also for a matrix of cross correlation of noise and state vector errors. Some examples of considered algorithm application are presented in the report.

**10:30 AM**

**AAS 98-192**

### Simultaneous Orbit Determination Of Large Satellite Constellations

M. T. Soyka, J. W. Middour - Naval Research Laboratory; J. Fein - Computer Sciences Corp.

The techniques of performing simultaneous orbit determination on a large telecommunications satellite constellation are demonstrated. Using the orbit determination program OCEAN, simulated radiometric two-way ranging is used as the baseline tracking type. Intersatellite ranging is used as an additional tracking type and for comparison to the two-way ranging solution. The addition of three-way ranging provides information necessary to determine the relative and absolute system timing. When satellite states are estimated in a simultaneous solution, intersatellite range and three-way range can provide cross-correlation and full covariance information between satellites.

**10:55 AM**

**AAS 98-193**

### Orbit Determination Performance Evaluation Of The Deep Space 1 Spacecraft's Onboard Navigation System

S. Bhaskaran, J. E. Riedel, S. D. Desai, P. J. Dumont, G. W. Null, W. M. Owen, S. P. Synnott, R. A. Werner - Jet Propulsion Laboratory

The first test of a fully autonomous onboard navigation systems will be performed as part of the technology validation for the New Millennium Program's Deep Space 1 mission. The mission goal is to flyby an asteroid, Mars, and a comet. The navigation system uses images of asteroids as beacons with which to triangulate the spacecraft position. The onboard orbit determination system then filters these observations to obtain the full spacecraft state, after which maneuvers are performed to achieve the desired flyby targets. This paper evaluates the performance of the orbit determination system in terms of its ability to deliver the spacecraft to the asteroid given the expected errors in the dynamics and data.

## Session 16 GPS Applications

**1:30 PM Wednesday, February 11 Laguna Ballroom E**

**Chair: Dr. Bobby G. Williams**
**Jet Propulsion Laboratory**

**1:30 PM** **Results Of STS-80 Relative GPS Navigation Flight Experiment**

**AAS 98-194** E. R. Schiesser, J. P. Brazzel, Jr. - The Boeing Company; J. R. Carpenter, H. D. Hinkel, G. L. Condon - NASA Johnson Space Center

NASA and the European Space Agency jointly conducted a relative GPS experiment during Space Transportation System flight 80 (STS-80), in December, 1996. The experiment included GPS receivers on the Orbiter and a deployable free-flyer. Data from four or five common GPS satellites were available during almost all of the final portion of rendezvous. A real-time Kalman filter was used to asynchronously process coarse/acquisition code pseudo-range measurements and IMU data. The resulting one sigma accuracy was on the order of 10 m for relative position, 0.15 m/s for relative velocity, and 100 m for relative semi-major axis, in comparison with laser tracking data.

**1:55 PM** **LEO Orbit Determination With Differential GPS**

**AAS 98-195** P. J. Melvin - Naval Research Laboratory

The purpose of this paper is to describe the use of GPS double differences for low Earth orbit determination in a Kalman filter. This filter is first described in AAS 96-145 which is available for download from http://tid.nrl.navy.mil/MELVIN/index.html or http://ssdd.nrl.navy.mil/melvin/. The chief advantage of combining ground station pseudoranges with those measured on-board a low Earth orbit (LEO) satellite is that clock errors are eliminated assuming synchronization to USNO. This prototype orbit determination software is for a new global network of seven GPS ground stations using Ashtech Z-12 continuous geodetic remote station (CGRS) receivers. Routines from the prototype will eventually migrate into the batch least squares orbit determination program OCEAN. The orbital accuracy is proven by use of data gathered on TOPEX with comparison to the precise orbit.

**2:20 PM** **Satellite To Satellite Relative Navigation Using GPS Signal Simulators**

**AAS 98-196** P. W. Binning - Naval Research Laboratory

The Naval Research Laboratory's orbit determination software OCEAN processes GPS pseudoranges for relative satellite to satellite navigation. A number of algorithms are developed which are used to quantify relative position errors. The software consists of an extended Kalman filter and a backwards discrete smoother. A Northern Telecom GPS signal simulator and an Allan Osborne Associates TurboRogue receiver are used to simulate a number of relative orbit conditions.

**2:45 PM** **BREAK**

**3:05 PM**

**AAS 98-197**

### Precise Orbit Determination For The MOMS/Priroda Camera Experiment Based On DGPS Carrier-Phase And Pseudo-Range Measurements

D. Kuijper, M. Schmidhuber - German Space Operations Center (GSOC), Germany

This paper deals with the precise orbit determination of the German Modular Optoelectronic Multispectral Scanner (MOMS), mounted on the PRIRODA module of MIR, based on differential GPS carrier-phase and pseudo-range measurements. The collected GPS measurements have been combined with ground station data to double difference GPS observables. The problem of ionospheric effects and cycle ambiguities for a single frequency receiver is addressed. Several orbit determination strategies are discussed and orbit determination results are presented. The orbit accuracy is assessed by analysis of the data residuals, formal errors, internal orbit overlaps, and comparisons with external sources.

**3:30 PM**

**AAS 98-198**

### Control Of Space Station And Its Adjoint Orbiter Using Relative DGPS

Jianping Yuan, Jianjun Luo, Xiaomu Dou, Zhongyuan Tian - Northwestern Polytechnical University, P. R. China

The control of space station and its adjoint orbiter is theoretically the control of relative motion of two or more space vehicles, including relative dynamics, relative kinematics, and relative attitude. Relative GPS can be used for navigating a vehicle in the vicinity of its target or destination. In this paper, GPS/DGPS are introduced and relative motion of space vehicles are modeled. Relative position, relative velocity and relative attitude are represented and solved by GPS/DGPS measurements. Use of multi-antenna and carrier phase signal of GPS satellites, with relative differential GPS technique, the attitude of space station with respect to the adjoint satellite can be accurately calculated in real-time. Analysis and results are given.

**3:55 PM**

**AAS 98-199**

### GPS Attitude Determination By Kalman Filtering: Simulation And Receiver Test Results

F. Bernelli-Zazzera - Politecnico di Milano, Italy; R. Campana, F. Gottifredi, L. Marradi - LABEN S.p.A., Italy; P. Mazza - Politecnico di Milano, Italy

This paper presents the results of the design of a high accuracy attitude determination solution, based on the design of a Kalman filter attitude solution using differential phase measurements. The Kalman filter designed includes as system states the quaternions and the angular velocities. Results show that the filtering process is able to significantly reduce the effects of measurements noise and also the effects of colored noise (multipath) when aided with an accurate model of the spacecraft dynamics and of the main angular perturbations. Numerical results indicate that the error in the attitude estimate, expressed in terms of Euler angles referred to an orbiting frame, are dependent on the multipath effects. In the case of a “good” geometry, i.e. low multipath, the standard deviation of the attitude error is in the order of 0.1 degrees, while with a high level of multipath it is in the order of 1 to 2 degrees, depending on the particular situation simulated.

## Session 17 Low Thrust Missions and Analysis

**1:30 PM Wednesday, February 11 Laguna Ballroom F**

**Chair: Dr. Robert G. Melton**
**Pennsylvania State University**

**1:30 PM**
**AAS 98-200**

### Optimal Low-Thrust Trajectories Using Flyby

D. Pastrone, L. Casalino, G. Colasurdo - Politecnico di Torino, Italy

The combined use of electric propulsion and gravity assist will probably be used in near-future deep-space exploration. Electric propulsion offers steering capabilities that can be used to approach the planet with the best direction for the gravity assist. The paper introduces the necessary boundary conditions for the trajectory which makes an optimal use of both propellant and gravity assist. Numerical examples concern low-thrust escape trajectories exploiting Venus or Jupiter flybys.

**1:55 PM**
**AAS 98-201**

### Navigation Considerations For Low-Thrust Planetary Missions

P. J. Wolff, F. Pinto, B. G. Williams, R. M. Vaughan - Jet Propulsion Laboratory

Motivated by the upcoming launch of the solar electric propulsion mission New Millennium Deep Space 1 and future SEP missions such as Pluto Express, an analysis of the operational strategies affecting ground based, deep space navigation of low-thrust missions is addressed. Simulations are performed to compare strategies for radiometric doppler based calibration of the SEP engine. Covariance analysis studies are conducted for the cruise phase of the Deep Space 1 trajectory to assess different orbit determination strategies for a spacecraft whose dynamics are corrupted by a relatively large continuous stochastic perturbation.

**2:20 PM**
**AAS 98-202**

### Optimal Interplanetary Spacecraft Trajectories Via A Pareto Genetic Algorithm

J. W. Hartmann, V. L. Coverstone-Carroll - University of Illinois at Urbana-Champaign; S. N. Williams - Jet Propulsion Laboratory; W. J. Mason - University of Illinois at Urbana-Champaign

A Pareto genetic algorithm is applied to the optimization of low-thrust interplanetary spacecraft trajectories. A multi-objective, nondominated sorting algorithm is developed following existing methodologies. A hybridized scheme is designed integrating the Pareto genetic algorithm with a calculus-of-variations-based trajectory optimization algorithm. “Families” of Pareto optimal trajectories are generated for the cases of Earth-Mars flyby, Earth-Mars rendezvous, and Earth-Mercury rendezvous trajectories.

**2:45 PM** **BREAK**

**3:05 PM** **Simple Control Laws For Low-Thrust Orbit Transfers**

**AAS 98-203**

C. A. Kluever - University of Missouri-Columbia/Kansas City

The maturation and successful demonstration of solar electric propulsion (SEP) technology will enhance the need for practical guidance and control laws for long-duration SEP orbit transfers. This paper presents several simple control laws for performing a variety of orbit transfers for SEP spacecraft. The control laws are developed by investigating the nature of the governing equations of motion. The result is a set of control laws that are simple functions of the spacecraft's current state. Numerical examples for a variety of orbit transfers are presented.

**3:30 PM** **Applying Flywheel Energy Storage To Solar Electric Orbital Transfers**

**AAS 98-204**

M. W. Marasch - Air Force Institute of Technology; C. D. Hall - Virginia Polytechnic Institute and State University

This paper investigates the application of flywheel energy storage to minimum-time, constant-thrust orbital transfers using electric propulsion. The advantages of using stored energy to continue electric thruster operations while in eclipse are explored. Results of simulations utilizing energy storage are compared to results without energy storage. Schemes incorporating energy storage are found to have advantages in terms of propellant mass used, time spent in transit, and deliverable payload.

**3:55 PM** **Optimal Low-Thrust Transfers To Halo Orbits About The L2 Libration Point In The Earth-Moon System (Elliptical Problem)**

**AAS 98-205**

T. F. Starchville, Jr. - The Aerospace Corporation; R. G. Melton - Pennsylvania State University

This paper develops a systematic procedure for generating optimal low-thrust transfers from one of the primaries in the elliptic restricted three-body problem (ER3BP) to a halo orbit in the three-body system. The examples all involve transfers from Earth to halo orbits about the L2 point in the Earth-Moon system. Using a transformation to the pulsating coordinate system (distances scaled by the time-varying range between primaries), it is possible to employ the method of stable manifolds to determine low-thrust trajectories that correctly inject into a specified halo orbit. The paper includes examples of both circular and elliptical halo orbits.

## Session 18 Numerical Analysis

**1:30 PM Wednesday, February 11 Laguna Ballroom G**

**Chair: Dr. Donald L. Mackison**
**University of Colorado**

**1:30 PM**
**AAS 98-206**

### Optimal Best Fitting Of Numerical Data

D. Mortari - Universita degli Studi "La Sapienza" di Roma, Italy

A new method, which optimizes the best fitting of numerical data, is here presented as applied to an m-degree polynomial. Optimization, which is obtained through a linear variable change representing an expansion/contraction of the abscissas axis, is defined as that which minimizes the condition number of the matrix to be inverted. As a function of the polynomial degree and the number of data, an optimal size of the abscissas data range is computed. Closed-form solutions are provided for first and second order polynomials. The improvement with respect to the existing method is substantial and it is shown by meaningful examples. Optimal Best Fitting is not restricted to a polynomial function but it can be applied to other different fitting functions such as at least: the Legendre orthogonal polynomials, trigonometric and exponential functions.

**1:55 PM**
**AAS 98-207**

### Compression Ephemerides In Attitude Dynamics

R. Barrio, A. Elipe - Universidad de Zaragoza, Spain; M. Vallejo - Real Observatorio de la Armada, Spain

In describing the attitude dynamics of rigid bodies with three different moments of inertia, elliptic functions play an essential role Most of asteroids have a clear non spherical shape. For instance, the asteroid Eros (target of the NEAR mission) is a tri-axial body with estimated dimensions of 40.5 by 14.5 by 14.1 kilometers. Hence, for computing the ephemerides of the rotation of such a body, the evaluation of elliptic functions at the desired instants is necessary, which computationally speaking, is very expensive. In order to save computing time and to have a fast transmission of data, we propose to compress the ephemerides. In the present communication, the compression technique is based on the use of Chebyshev polynomials of the first kind. These polynomials have special features that make them suitable for the approximation of functions. The optimization process is performed in the norm L-infinity or the Chebyshev norm in order to have a near minimax approximation and a uniform behavior of the compression error. By using this method, we are able to compress the attitude elements corresponding to the several revolutions, by using only 80 coefficients to reach a precision of more than 10 digits. Finally, we make several tests for an Eros-like body to show the behavior of the compressed ephemerides.

**2:20 PM**
**AAS 98-208**

### Improved First-Order Chebyshev Methods For The Numerical Integration Of First-Order Differential Equations

D. L. Richardson, D. Schmidt, J. Mitchell - University of Cincinnati

An improved version for Chebyshev integration of first-order differential equations has been developed. The paper describes the mathematical aspects of the improved procedures and their application to a selected set of Astrodynamics equations. The new procedures include automatic stepsize adjustment and a minimal iteration scheme for intra-nodal point values. The paper also discusses the A-stable character of the methods. The analysis demonstrates that these first-order Chebychev methods are quite suitable for integration of stiff systems.

**2:45 PM** **BREAK**

**3:05 PM** **A New Methodology For Simulation Validation And Model Modification**

**AAS 98-209**

Li, Xiaolong; Tang, Shuo; Guan, Xiaodong - Northwestern Polytechnical University, P. R. China

In this paper a new method to combine the matching measured flight response, simulation validation and model modification is introduced. The differences between the test data of the system and simulation results are considered. The simulation model error are supposed to be reflected through the control variable. The concept of Error Data Base (EDB) is introduced. The optimal method is used to obtain the EDB. The criterion of validation for the simulation model is introduced and the model modification is made through the EDB. The numerical example is made to verify the method.

**3:30 PM** **Trajectory Propagation Using High-Order Numerical Integrators**

**AAS 98-210**

G. Der - TRW

This paper compares the efficiency of four high-order numerical integrators (Shank's Runge-Kutta eighth-order, Nystrom fourth-order, Adams Bashforth Moulton eighth-order predictor corrector, Gauss-Jackson 9/11-order predictor-corrector) for Earth satellite trajectory propagation over long time spans. These integrators are formulated specifically for first and second order differential equations as well as the special perturbations methods of Cowell and Variation-of-Parameters. Efficiency is concerned with computational timing, accuracy, stability and ease of use. By long time spans we mean a few hours or days. Several Runge-Kutta integrators are used to generate reference trajectories. Depending on the order of the differential equations of motion and the special perturbations methods, the specialized integrators have markedly different performances.

**3:55 PM** **Error Covariance Matrix Propagation Over Very Short Time Spans**

**AAS 98-211**

G. Der - TRW

Error covariance matrix propagation has been treated extensively in the literature, few, if any, have compared the efficiency of analytic and numerical methods over very short time spans. Efficiency is concerned with computational accuracy and timing. By very short time spans we mean ten seconds or less, or, in some cases, as little as a few milliseconds. This paper uses the launch and impact point prediction problems of a short range (less than 20 km) ground launch rocket to illustrate the computational efficiency of state and error covariance matrix propagation.

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## RECORD OF MEETING EXPENSES

**1998 AAS/AIAA Space Flight Mechanics Meeting**

**Embassy Suites on Monterey Bay**
**Monterey, California**

**February 9 – 11, 1998**

Name ______________________________________________

Organization ________________________________________

| | | |
|---|---|---|
| Registration Fee: | Member @ $110 | ____________ |
| | Non-Member @$130 | ____________ |
| | Student @ $20 | ____________ |
| | Non-members @ $195 (Includes one-year AAS membership and the Journal of the Astronautical Sciences.) | ____________ |
| Conference Proceedings @ $135 | | ____________ |
| Conference Banquet @ $30 | | ____________ |
| Technical Paper Sales @ $1/paper | | ____________ |
| | **TOTAL:** | ____________ |

| Technical Paper Purchases: | No. Papers | Cost | Date |
|---|---|---|---|
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