AAS/AIAA
Space Flight Mechanics Meeting

Belleview Biltmore Resort & Spa
Clearwater, Florida

January 23–26, 2000

PROGRAM

	General Chairs	Technical Chairs
AAS	Dr. Chris Hall Aerospace and Ocean Engineering Virginia Tech Blacksburg, VA 24061 (540) 231-2314 Voice (540) 231-9632 Fax chall@aoe.vt.edu	Dr. Craig Kluever Mechanical and Aerospace Engineer- ing Department University of Missouri-Columbia Columbia, MO 65211 (573) 882-6764 Voice (573) 884-5090 Fax KlueverC@missouri.edu
AIAA	Dr. John Hanson NASA Marshall Space Flight Center Code TD54 Huntsville, AL 35812 (256) 544-2239 Voice (256) 544-5416 Fax john.hanson@msfc.nasa.gov	Dr. Beny Neta Department of Mathematics Naval Postgraduate School Monterey, CA (831) 656-2235 Voice (831) 656-2355 Fax bneta@nps.navy.mil

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Meeting Information

Registration

The following registration fees will be in effect for the meeting:

AAS or AIAA Members	$175
Nonmembers	$200
Students	$25
Nonmembers*	$260

*(this rate includes 1 year membership in AAS, including renewals)

Please note that credit cards cannot be accepted for payment of any fees.
Checks payable to the American Astronautical Society are the preferred form of payment.

The registration desk will be open:

Sunday evening	4:00 PM – 7:00 PM
Monday and Tuesday	7:00 AM – 4:00 PM
Wednesday	7:00 AM – 11:00 AM

Social Events

Sunday Evening	Cocktail party for early registrants	6:00 PM – 8:00 PM
Monday Evening	Reception	7:00 PM – 9:00 PM
Tuesday Evening	Mystery Dinner Theatre Show and Banquet	7:00 PM – 10:00 PM
Wednesday Evening	Nothing currently planned	

Mystery Dinner Theatre Show and Banquet

This special event features *The Blue Swank*, a Play in Five Acts including Mystery, Comedy, and Music, performed during four-course dinner. The banquet hall will be the stage as the players move through the audience, offering to "sell" clues and answer questions about the mystery. Whoever solves the mystery of *The Blue Swank* will win a bottle of champagne and a Mystery Dinner Theatre souvenir. The ticket price of $35 includes the four-course banquet and performance.

Questions or Comments

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

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Technical Program

Speakers Briefing

Session chairs and authors who are presenting papers will meet for a short briefing each morning from 7:00 – 8:00 AM. Please attend only on the day of your session. A continental breakfast will be provided.

Presentations

Each paper will be allotted 20 minutes (including introduction and question and answer period). Please note that a "no paper –no podium" rule will be strictly enforced for all presentations. An author will not be permitted to present his or her paper if a written paper has not been prepared and made available at the conference. Also, papers will be automatically withdrawn and will not be eligible for inclusion in the proceedings if one of the stated authors is not in attendance to present the paper.

Special Sessions

Two special sessions have been organized for the conference: **Session 2**: ***Formation Flying***, and **Session 9**: ***Mission Analysis for Earth-Observing Satellites***.

Paper Sales

Authors have been requested to bring 50 copies of their paper to the meeting. These preprints will be on sale for $1 per paper in the St Andrews Pub. Bound copies of the proceedings may be ordered at the registration desk.

Committee Meetings

Committee meetings will be held in the Magnolia Room according to the following schedule:

AIAA Astrodynamics TC	Monday 1/24	11:30 PM – 1:30 PM
AAS Spaceflight Mechanics TC	Tuesday 1/25	11:30 PM – 1:30 PM
AIAA Astrodynamics Standards Committee	Wednesday 1/26	11:30 PM – 1:30 PM

Coffee Breaks

There will be morning and afternoon coffee breaks in the St Andrews Pub.

Questions or Comments

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

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Clearwater, Florida

Location

Clearwater is located in Pinellas County on the west coast of Florida in the US. It is on the Pinellas Peninsula between the Gulf of Mexico on the west and Tampa Bay on the east. Clearwater's geographic location is latitude 27.57 N and longitude 82.48 W. The City of Clearwater was incorporated on 27 May 1915. In square miles, Clearwater's land area is 24.88 and the water area is 12.37, for a total of 37.25.

Here are the last 5 U.S. Census counts and the latest estimate:

1950: 15,581	**1960:** 34,653	**1970:** 52,074
1980: 85,170	**1990:** 98,784	**1995 (est.):** 101,162

Climate

The average high temperature for January is about 70°F, and the average low is 50°F. The record high is 86°F and the record low is 21°F. The average precipitation is 1.99 inches, with an average of 7 rain days in January.

History

When this area was known only to the native Timucuan, Calusa and Apalachee tribes, clear springs gurgled from the banks into the bay. The springs, long since gone, were located along the high bluffs upon which City Hall and downtown Clearwater are now situated. Early settlers called it Clear Water Harbor, which became simply "Clearwater" by 1906. When the first narrow gauge railroad was built in 1888, the Clear Water Harbor community had about 18 families. Henry Plant, the foremost Central and West Florida developer of the time, later built a standard gauge railroad through Pinellas County. To boost his passenger business, he built several grand resort hotels, including the Belleview Biltmore in 1897. Clearwater grew steadily as tourists and settlers were attracted by the climate. Morton F. Plant, the son of the illustrious Henry Plant, donated and raised money for the first hospital in 1914. The population continued to steadily climb. After World War II, a number of soldiers who had trained here returned to live. The Philadelphia Phillies professional baseball team began spring training in the 1940s. From 1950, with 15,000 citizens, the population burgeoned. The population today is around 102,000, with another 20,000 winter residents.

Outdoor Activities

There are two locations for parasailing. One is at the Marina, and the other is at the Hamden boat docks. Bikes, roller blades, and scooters can be rented at Transportation Station located at 652 S Gulfview Blvd on Clearwater Beach across from the International House of Pancakes. One moped is available for rental.

Bars

Some nightclubs on Clearwater Beach include the Beach Bar, Palm Pavillion, and Jamminz. Also, the Doubletree, Adam's Mark, Quality Inn, and the Clearwater Beach Hotel have dance clubs or outdoor bars.

Restaurants

Beef' O' Brady's, a “sports bar” at 1500 McMullen Booth Rd, (727) 725-4023
Carrabba’s Italian Grill, at 19919 U.S. Hwy 19 North, (727) 712-0844
Durango Steak House, 2571 Drew Street, (727) 712-0844
Johnny Leverock’s Seafood House, 551 Gulf Blvd, (727) 446-5884
Mugs ‘n’ Jugs Karaoke Sports Bar & Grill, 14400 U.S. Hwy 19 North, (727) 535-5847
Sweetwater’s Seafood and Steaks, 2400 Gulf-To-Bay Blvd, (813) 799-0818

Clearwater Beach Quick Facts

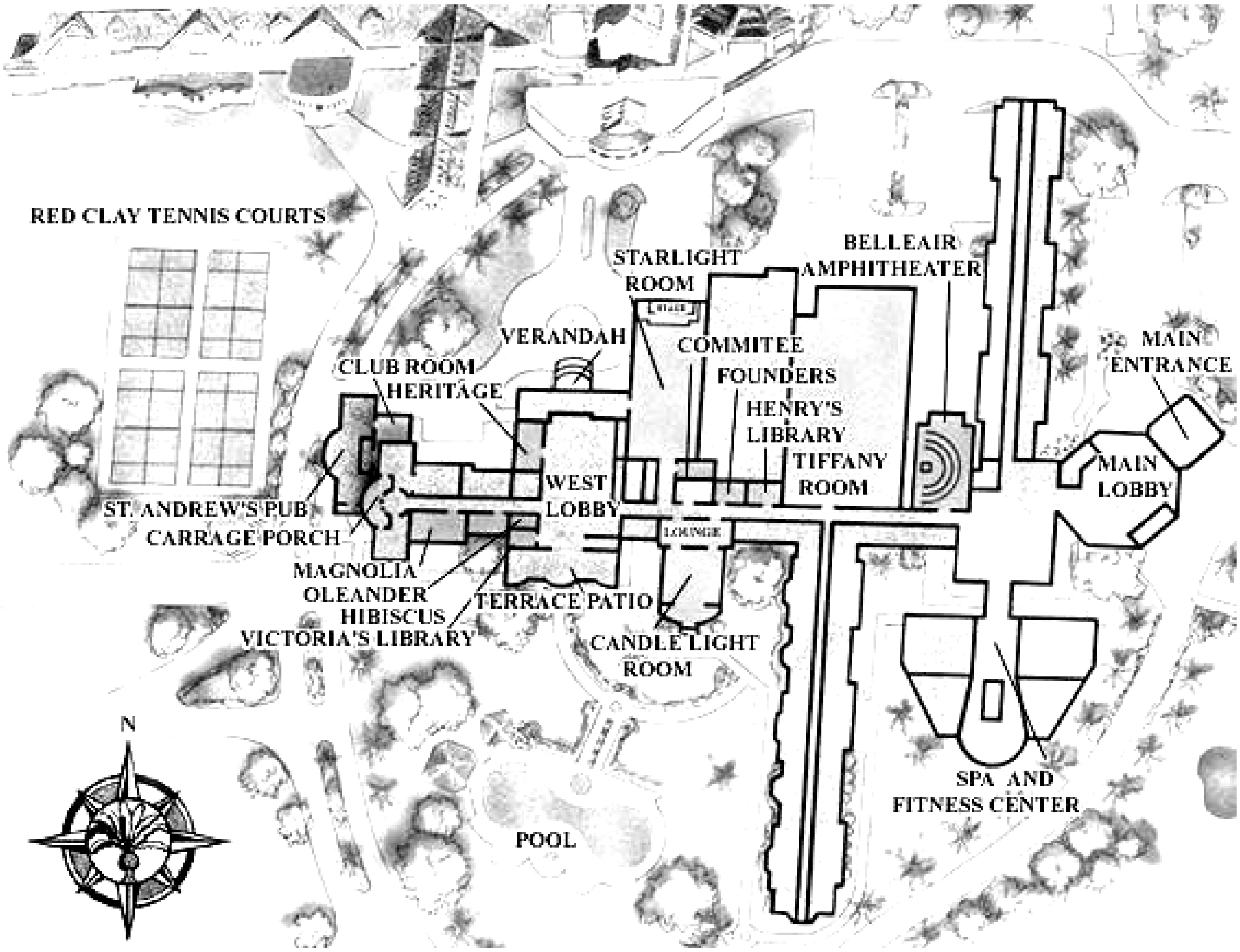
- Approximately 5 miles of waterfront
- Permanent resident population of 6,000
- Seasonal population of approximately 15,000
- Host to 1.4 million visitors each year
- Visitors spend nearly $3.7 million EACH DAY
- Visitor economic impact to Clearwater is $1.3 billion annually
- Average length of stay for visitors is 8 days
- Approximately 130 hotels/motels accounting for nearly 4,000 sleeping rooms
- Top domestic visitor origins are New York, Chicago, Boston, Philadelphia, Detroit
- Top international visitor origin is the United Kingdom
- Major beach volleyball tournaments may include Miller AVP, Cuervo Gold, and Bud Lite ProAm.
- The Clearwater Beach Visitors Center is located in the lobby of the Marina and is open 9 am to 5 pm daily except Christmas, Thanksgiving and New Year's Day.
- The Marina has over 50 commercial boats for leisure activities including sailing, diving, fishing, parasailing, sightseeing, dolphin watching and more.
- Sunsets at Pier 60 Society is a festival on Pier 60 from 2 hours before to 2 hours after sunset seven days a week. The festival includes artisans, crafters and entertainers.

The Jolley Trolley runs 10 am to 10 pm Sunday through Thursday, and 10 am to 12 pm on Friday and Saturday. The Trolley serves Clearwater Beach, Memorial Causeway, and Cleveland Street to Park Street. $.50 fare. The Clearwater Beach terminal is located at 40 Causeway Blvd. (727) 443-3655.

The Empress Cruise boat leaves from the Seminole Boat dock off of N. Fort Harrison.

Clearwater Marine Aquarium is on Island Estates. Take a left off of Island Way onto Windward Passage. It's approximately two blocks on the left.

Belleview Biltmore Resort & Spa Floor Plan



- Registration is in the area between the Main Lobby and the Tiffany Room.
- Technical Sessions are in the Club, Heritage, and Founders Rooms.
- Paper Sales are in the St Andrews Pub.
- Coffee Breaks are in the St Andrews Pub.
- Technical Committee Meetings are in the Magnolia Room.
- Speaker practice will be available in the Committee Room.

Monday Morning Sessions

Session 1:	***Topics In Control Theory***
8:30am – 11:10am	**Club Room**
Chair:	**I. Michael Ross**

00-100 **Structured Output Feedback for Uncertain Dynamical Systems**
0830am Maruthi R. Akella

For a class of systems that possess the structure of exact kinematics and uncertain dynamics, we establish output feedback stabilization. The resulting control is adaptive (in terms of the unknown parameters) and guarantees bounded stability of tracking errors even in the presence of bounded but unknown disturbances. The formulation assumes knowledge of only outputs and not the state vector. We present sufficiency conditions under which any system belonging to this class can be stabilized with adaptive output feedback. Example simulations illustrate adaptive output feedback control of MIMO, non-minimum phase nonlinear systems.

00-101 **A Signal Transmission Technique for Stability Analysis of Multivariable Non-linear Control Systems**
0850am Mark Jackson, Doug Zimpfer, Neil Adams

Among the difficulties associated with multivariabe, non-linear control systems is the problem of assessing closed-loop stability. Of particular interest is the class of non-linear systems controlled with on/off actuators, such as spacecraft thrusters or electrical relays. With such systems, standard describing function techniques are typically too conservative, and time-domain simulation analysis is prohibitively extensive. This paper presents an open-loop analysis technique for this class of non-linear systems. The technique is centered around an innovative use of multivariable signal transmission theory to quantify the plant response to worst case control commands. The technique has been applied to assess stability of thruster controlled flexible space structures. Examples are provided for Space Shuttle attitude control with attached flexible payloads.

00-102 **Low Order Closed Loop Compensators for Satellite Attitude Control/ Determination using Linear Quadratic Gaussian/Loop Transmission Recover (LQG/LTR) Methods**
0910am Donald L. Mackison

State space methods are readily applicable to the design of controllers for satellite attitude control systems. Modifications to the usual linear quadratic method solving Riccati equations for the control and observer gain included frequency shaped cost functionals, H-inf methods, and mu methods. Mackison has previously presented a method of modal weighting of the state in the LQ problem, which is equivalent to adding notch filters and lead/lag compensators, without raising the order of the dynamics to be considered. In fact, the resultant closed loop compensators have near pole/zero cancellation for some of the recovered observer modes, and other modes in the compensator are shown to be sufficiently fast that they can be neglected. This gives an orderly process for generating classical compensators for MIMO system, combining the modal weighting method with LQG/LTR. Design examples including flexible body satellites are presented, and comparisons are made with full order compensators, and with the usual classically obtained compensators.

00-103 **Basis Function Batch Process Repetitive Control**
0930am Raphael Akogyeram, Richard W. Longman, Andrew Hutton, Jer-Nan Juang

In many control applications there are disturbances that are repetitive in nature, whose source is known, for example, vibrations of a telescope or other fine pointing instrument caused by rotation of momentum wheels or gyros on a spacecraft. The example that inspires the current paper is fine pointing errors in an electron beam accelerator at the Jefferson National Accelerator Facility, caused by imperfect rectification of the AC current driving the magnets. Feedback control can never do a perfect job of correcting such repeating disturbances, and repetitive control concepts are used to converge to the correct command/feedforward signal to cancel the disturbance effects. In this paper a number of issues are addressed concerning the best way to make such corrections at 60Hz and harmonics. A major issue is the development of a condition giving the true stability boundary. This is compared to a much simpler sufficient condition based on steady state frequency response modeling.

0950am-1010am Coffee Break

00-104 **Numerical Determination of Optimal Feedback Control in Nonlinear Problems with State/Control Constraints**
1010am Peter Kramer-Eis, H. Georg Bock, Richard W. Longman, Johannes Schloder

Relatively recent developments in numerical methods are making it possible to obtain optimal control time functions for realistic models of physical systems, including complex and nonlinear models, inequality constraints on control variables, inequality constraints on state variables, and realistic optimization criteria. Unfortunately, optimal control normally results in open loop control functions, rather than closed loop control laws. We consider indirect methods based on the Pontryagin maximum principle and obtain solutions by multiple shooting involving both switching conditions and jumps. The multiple shooting formulation is exploited to obtain sensitivity information, which is then used to produce a feedback control for the neighborhood of the optimal solution. Some of the intricacies of defining a linearization in such nonlinear problems are discussed. Examples are given, including optimal descent of a space shuttle through the atmosphere with radiative heating constraints, and energy optimal control of an R-42 subway train in the New York City Subway System, showing the wide range of effectiveness of the resulting feedback control laws.

00-105 **FFT-Based Clear Box Disturbance Rejection -- Development and Demonstration on an Ultra-Quiet Platform**

1030am Hong-Jen Chen, Brij N. Agrawal, Richard W. Longman, Minh Q. Phan

A paper at the 1999 Astrodyanmics Conference reported on experiments in disturbance rejection on an Ultra Quiet Platform, using the Clear Box method that allows one to make intelligent decisions about what signals to control when the control authority is limited. The platform is to actively isolate a sensitive instrument from spacecraft vibration sources such as gyros and momentum wheels. The methods of that paper are based on time domain mathematics. Since the disturbances to be rejected are periodic, it is natural to ask if there can be advantages to developing analogous methods based on the frequency domain. Such methods are reported here, and the various pros and cons are summarized. Experimental results on the Ultra Quiet Platform are given, demonstrating the properties of the methods.

00-106 **A Unified Formulation of Iterative Learning Control**

1050am M. Q. Phan, R. W. Longman, K. L. Moore

Learning control develops controllers that learn to produce zero tracking error during repetitions of the command. With the exception of some precursors, this field started in 1984 motivated by eliminating deterministic errors in robots repeatedly executing a command. The emphasis has been on direct methods that iteratively decrease the tracking error toward zero, without requiring a precise model of the system, each time the control task is executed. By now a large number of iterative learning control (ILC) laws have been developed, taking different forms. Some involve only the past repetition; others involve the current repetition, or more past repetitions, etc. Some involve only one point in the last repetition; others involve many points, sometimes using non-causal filters on the previous repetition. It is the purpose of this paper to develop an overall framework to encompass these various possibilities, and to make conclusions on the benefits or lack of benefits of different classes of learning law structures.

Session 2:	***Special Session: Formation Flying***
8:30am – 11:10am	**Heritage Room**
Chair and Organizer:	**Dave Folta**

00-107 **Design and Implementation of Synchronized Autonomous Orbit and Attitude Control for Multiple Spacecraft Formation Flying Using GPS**
0830am Guang Xing, Shabbir Parvez, David Folta

Orbit control for spacecraft flying in formation require attitude information and attitude control, and the attitude control system needs to capture and track a moving object. The design presented in this paper uses GPS for this synchronized autonomous orbit and attitude control. The head of fleet is selected as the target reference for the formation, all member spacecraft in the formation pattern are described with respect to it. The relative attitude, angular velocity, relative kinematics and dynamics are developed. Nonlinear Lyapunov control method and the variable-structure control method for large attitude angle capture and tracking are also discussed.

00-108 **The ION-F Formation Flying Experiments**
0850am M. Campbell, R. Fullmer, C. Hall

The Ionospheric Observation Nanosatellite Formation (ION-F) comprises three small spacecraft that will cooperate to make measurements of the ionosphere's electron density and its effects on GPS signal propagation. A novel feature of the mission is the planned suite of formation flying experiments involving the three satellites. The uniqueness of these experiments is enhanced by the dissimilar nature of the sensors and actuators used by the three spacecraft, including micro-pulsed plasma thrusters, hydroxylammonium nitrate monopropellant thrusters, and differential drag control. In this paper, we describe the ION-F mission, the designs of the three satellites, and the proposed suite of formation flying experiments.

00-109 **Precise Formation Flying Control of Multiple Spacecraft Using Carrier-Phase Differential GPS**
0910am Gokhan Inalhan, Franz D. Buzze, and Jonathan P. How,

Formation flying is a key technology for deep space and orbital applications which involve multiple spacecraft operations. Imaging and remote sensing systems based on radio interferometry and SAR require very precise (sub-wavelength) aperture knowledge and control for accurate relative data collection and processing. Closely tied with the Orion and TechSat21 projects, this work describes the ongoing research to investigate precise relative sensing and control via differential GPS for multiple spacecraft formation flying. Specifically, we present an autonomous control architecture for formation flying that integrates low-level satellite control algorithms (formation keeping and relative error correction) with high-level fuel/time optimal formation co-ordination and planning. This architecture is implemented on a nonlinear orbital simulation of Orion vehicles with disturbances and a realistic differential GPS measurement model. Also, we generalize closed form solutions of passive apertures for constellations with mean formation eccentricity.

00-110 **SPHERES: A Testbed for Long Duration Satellite Formation Flying In Micro-Gravity Conditions.**
0930am Dave W. Miller

The MIT Space Systems Laboratory is developing the SPHERES formation flying testbed for operation on the KC-135 and International Space Station. The hardware consists of three 23 centimeter diameter, three kilogram spheres which can control their relative orientations. Each sphere consists of all of the sub-systems typical of a conventional satellite. The purpose of SPHERES is to provide the Air Force and NASA with a long term, replenishable, and upgradable testbed for validating high risk metrology, control, and autonomy technologies needed for operating distributed satellites as a part of sparse aperture missions such as TechSat21, ST3, TPF, etc. SPHERES draws upon the MODE family of dynamics and controls laboratories (STS-40, 42, 48, 62, MIR) by providing a cost-effective laboratory with direct astronaut interaction which exploits the micro-gravity conditions of space. This paper will present the SPHERES objective, design, and hardware status as well as the status of the technologies to be validated using the testbed.

0950am – 1010am Coffee Break

00-111 **Cooperative Multi-impulse Fuel-Optimal Control for Formation Flying of Satellites**
1010am S. R. Vadali and S. Vaddi

This paper deals with the control of a formation of satellites in a cooperative manner. The focus is on establishment of a formation. The mathematical model for the satellite dynamics includes the effect of J_2 perturbation. Unlike the master-slave or chief-deputy concepts, all the satellites forming a cluster are given the freedom to maneuver. It is assumed that all the satellites are identical in shape and size. The only physical property that is allowed to vary among the satellites is the amount of fuel left in each satellite. A variety of performance indices are explored to minimize the deviation in the fuel remaining in the satellites with respect to the mean.

00-112 **Modern Software Architecture for Satellite Formation Flight Dynamics Automation**
1030am P. Noonan, and F. Perkins

Only integrated satellite formations can satisfy the demands of certain advanced science and communications needs. Use of modern software architectures, specifically, formation constellation software objects as implemented in FreeFlyer®, provide heretofore unavailable capabilities for mission design, formation control, maneuver and operations optimization. Full implementation of these tools allows the user(s) to close the loop on flight dynamics automation, reducing control software cost and risk, as well as dramatically reducing demands on operators and program cost. Implementation examples for current and upcoming flight programs, including NASA's Earth Observer - 1 (EO-1) (formation flying with Landsat-7), AMM (four satellites in polar orbit), MMS (five satellites in highly elliptical polar orbits), and Discoverer II (a two-satellite distributed aperture) are discussed.

00-113 **Impulsive Formation Flying Control to Establish Mean Orbital Elements**
1050am Hanspeter Schaub and Terry Alfriend

An impulsive firing sequence is established which corrects for orbit errors between two formation flying spacecraft. The impulsive thrust calculations are developed using Gauss' variational equations for the osculating orbit elements. Specific orbit elements are corrected at their most efficient points in the orbit and in a manner which minimally impacts the remaining osculating orbit elements. The algorithm is then used to establish relative orbits expressed in terms of mean orbit elements. Due to the complex, yet near identity transformation between mean and osculating orbit elements, the computed impulsive thrusts will not precisely achieve the desired mean orbit element corrections, and they might have a small impact on the remaining mean orbit elements. A firing sequence is established which takes these deviations into account and establishes the desired relative orbit in an efficient manner.

Session 3:	***Orbit Determination and Navigation***
8:30am – 11:10am	**Founders Room**
Chair:	**Bobby Williams**

00-114 **Comparison of GPS-based Precision Orbit Determination (POD) Approaches for ICESat POD**

0830am Hyung-Jin Rim, Charles Webb, Sung Byun, Bob E. Schutz

The EOS ICESat (Ice, Cloud and land Elevation Satellite) mission is scheduled for launch on July 2001. The spacecraft features the Geoscience Laser Altimeter System (GLAS) to measure the Greenland and Antarctic ice-sheet topography and associated long-term changes, as well as the cloud and atmospheric properties. To achieve the science objectives, especially for measuring the ice-sheet topography, the position of the GLAS instrument should be known with an accuracy of 5 and 20 cm in radial and horizontal components, respectively. This position will be determined by POD using data collected by the on-board GPS receiver and ground GPS receivers. Several GPS-based POD approaches are compared for ICESat POD. Kinematic approach uses measurement information only without requiring any dynamic description. Geometric factors, such as number of the on-board GPS receiver channels, the direction of GPS signals, and GPS orbit accuracy, are limiting factors for kinematic approach. Dynamic approach fully utilizes the dynamic information, and therefore this approach is limited by the dynamic model accuracy. With the continuous, global, and high precision GPS tracking data, dynamic model parameters, especially geopotential parameters, can be tuned effectively to reduce the effects of dynamic model errors in the context of dynamic approach. The dense tracking data also allows for the frequent estimation of empirical parameters to absorb the effects of unmodeled or mismodeled dynamic errors. Reduced-dynamic approach uses both geometric and dynamic information and weighs their relative strength by solving for local geometric position corrections using a process noise model to absorb dynamic model errors.

00-115 **An Assessment of the Benefits of Including Glonass Data in GPS Based Precise Orbit Determination**

0850am S. Casotto, A. Zin

The present paper will address the performance of an orbit restitution system based on the use of combined GPS and GLONASS dual-frequency carrier phase data. The investigation is carried out by simulating realistic error sources including transmitter and receiver clock errors. Special attention is given to simulating the S/A $\boldsymbol{\delta}$-process in the GPS carrier phase data and the assessment of its impact on the restitution accuracy when observation time tagging to the transmission epoch is not adopted in the POD processing scheme. The effects of the S/A $\boldsymbol{\delta}$-process in the GPS carrier can be of the order of one centimeter in the double difference data type. The study is carried out in covariance mode wherever possible, and by adopting realizations of the error time histories when the analytical expressions of the covariance approach are impractical.

00-116 **Optical Tracker and S Band Ranging Utility for Accurate Orbit Determination and Prediction**
0910am John Cox, Chia-Chun Chao, Peter W Stephens, Lori F Warner

A study has been performed which addresses the efficacy of optical tracking of artificial Earth satellites. In particular the optical tracking is shown to reduce the load on resources that are capable of ranging to those satellites. It also demonstrates improved orbit estimation and ephemeris prediction accuracy. The orbits studied are geosynchronous (GEO) orbits and a geosynchronous transfer orbit (GTO). The GEOs are distributed about the Earth with a 30-degree longitude separation. Their orbits have low eccentricities and inclinations below 10 degrees. Only one GTO is studied. The S-band ranging system is nominally that of the Air Force (US) Satellite Control Network (AFSCN). Both covariance analysis and Monte Carlo simulations were used to demonstrate that a precision optical tracker as an augmentation to a ranging tracker can reduce the ranging needed to maintain an accurate orbit estimate. It was further shown that optical measurements improve the estimation accuracy if the optical tracker accuracy is at least one arc second at the one standard deviation level. Significant orbit accuracy improvement is achieved if the optical angle measurement accuracy is better than 0.5 arc seconds.

00-117 **Orbit Determination Applications with the Space-Based Visible Space Surveillance Sensor**
0930am Jayant Sharma

The Midcourse Space Experiment satellite, launched 24 April 1996, carries the Space-Based Visible sensor package designed for conducting Space Surveillance from an orbiting platform. The SBV consists of a visible imaging charged couple device sensor that generates observations of resident space objects. This paper will discuss space surveillance applications of data generated by the Space-Based Visible sensor. The Space-Based Visible sensor primarily observes objects in the geosynchronous belts and is capable of observing the entire belt. Initial orbit determination and precise orbit determination of geosynchronous satellites will be discussed.

0950am – 1010am Coffee Break

00-118 **Numerical Studies in the Vicinity of GPS Deep Resonance**
1010am B. E. Schutz

Numerical experiments have been performed to investigate the long term behavior of GPS satellites in the vicinity of deep resonance. The paper describes the general characteristics of GPS orbit evolution based on analysis of global ground based data collected by the International GPS Service. The chaotic behavior near deep resonance was investigated using high accuracy numerical techniques over tens of years. The results suggest the existence of orbit parameters that would require fewer station-keeping maneuvers than now applied.

00-119 **Application of a Global Stochastic Method for Removing Orbit Error**
1030am J. M. Tardy, B. J. Haines, and C.A. Kluever

Geodetic satellite datasets have long been corrupted by orbit error. This report details a new method for removing the dominant long period time-varying error using existing Global Positioning System (GPS) software. A stochastic filter is used to exploit the once-per-revolution nature of this error, as well as reducing satellite-specific biases and time-invariant errors due to spacecraft miscentering. This method is applied to Seasat, Geosat, ERS-1, and ERS-2, resulting in significantly improved datasets. Application of these improved datasets to the analysis of ice sheet growth on the Greenland subcontinent is briefly discussed. Such analyses have significant implications for the study of global warming.

00-120 **Orbit Determination Using Range Rate Data at a Single Ground Station**
1050am Daniel Coyle, Henry J. Pernicka

The solution of the spacecraft orbit determination problem is highly dependent upon the type of tracking data available at the ground station. Many algorithms exist for different types and combinations of tracking data. Well-funded tracking stations are typically able to supply six or more observed parameters simultaneously, enabling explicit solution of the orbit determination problem. The ground station under development at San José State University will be able to measure only Doppler shift as a function of time, thereby providing range rate as the single observable parameter. Explicit solution of the orbit determination is not possible using Doppler shift exclusively, but orbit estimate improvement is still possible via differential correction. By utilizing a differential correction scheme in conjunction with both a batch least squares estimator along with convergence improvements, the task of maintaining an acceptably accurate knowledge of the spacecraft orbit is made possible for a single ground station utilizing a single measured parameter, even at higher levels of measurement noise and bias than those expected at the ground station.

00-121 **Ground System Support of an Onboard Navigation System: Implementation and Operations Experiences**
1110am Lauri Kraft Newman, Paul J. Noonan, and Cheryl J. Gramling

NASA's Earth Observing System Terra spacecraft utilizes an onboard orbit determination system called the Tracking and Data Relay Satellite System (TDRSS) Onboard Navigation System (TONS). TONS uses 1-way forward S-Band Doppler data measured from the TDRSS communications signal to determine the spacecraft trajectory. This state vector is then used for a variety of purposes, both onboard and on the ground. On the ground, the vector is used by Flight Dynamics to model the future state of the spacecraft and to provide upload tables and science planning aids. The state is also propagated onboard and used in the attitude determination and control software and to point the high gain antenna. This paper discusses issues that have arisen through the implementation of TONS on Terra and what solutions were put in place. Implementation differences between the onboard flight software and the ground software, automation of the ground support system, and accommodation of input data from external sources introduce challenges into many aspects of each of these processes. Lessons learned from the Terra TONS implementation indicate the need for a ground system to analyze the performance of any onboard navigation system, aid other mission planners in anticipating impacts on the ground system imposed by any onboard navigation system implementation, and provide some suggestions for methods of addressing those issues.

00-122 **An Autonomous Navigation System for the German Small Satellite Mission BIRD**

1130am Eberhard Gill, Oliver Montenbruck

As part of the German micro-satellite project BIRD, an autonomous navigation system will provide precise spacecraft position data for the real-time onboard geocoding of the BIRD imaging sensor data. The autonomous navigation process is based on SPS position fixes from a five channel GEM-S GPS receiver by Rockwell Collins, that delivers instantaneous position fixes with 90 m standard deviation and maximum errors of several hundred meters. The requirements for the autonomous navigation system are to provide a dense WGS-84 position trajectory with 75 m accuracy within an orbit prediction interval of 20 minutes. To achieve this goal an autonomous navigation concept has been developed, that comprises a numerical integration of the equations of satellite motion making use of an advanced, but still basic, numerical integration scheme, that extends the common Runge-Kutta 4th order algorithm by a Richardson extrapolation and a Newton interpolation. Furthermore, an analysis of the required force model has shown, that a gravity model complete to order and degree of 10 is fully sufficient to satisfy the requirements for BIRD, while an efficient computation of the spacecraft acceleration is realized using the algorithm of Cunningham. The estimation of the BIRD position will be based on an extended Kalman filter. Using a sample set of GPS position data from the GPS/MET experiment onboard the MicroLab-1 satellite, it turns out that a filter steady state is reached within 1-2 orbital revolutions. As result, a steady state position variance of about 50 m is achieved with a standard deviation of the filtered position solution with respect to a precision reference trajectory of 16 m, that very well meets the requirements for autonomous orbit determination for the BIRD satellite mission.

Monday Afternoon Sessions

Session 4:	***Attitude Determination and Estimation***
1:30pm – 4:10pm	**Club Room**
Chair:	**Alfred Treder**

00-123 **GLAS Spacecraft Attitude/Pointing Determination**
0130pm Sungkoo Bae and Bob E. Schutz

The Geoscience Laser Altimeter System (GLAS), which will be carried by the Ice, Cloud and land Elevation Satellite (ICESAT) in 2001, needs to determine the attitude/pointing of its laser beam with 1.5 arcsecond (1 sigma) accuracy in post-processing. For the precise attitude/pointing determination, the GLAS will carry a CCD equipped star tracker, Hemispherical Resonator Gyros and the Stellar Reference System, which is specially designed by the GLAS instrument team. This paper develops the algorithms utilizing the given instruments and shows some simulation results. In addition, we discuss how to remove the effect of the systematic errors embedded in measurement data.

00-124 **A Sub-Optimal Algorithm for Attitude Determination from Multiple Star Cameras**
0150pm Malcolm D. Shuster

In 1994 Brouzenec and Bender [1] proposed a suboptimal algorithm which they applied to an attitude system consisting of one star camera capable of observing multiple stars simultaneously and one horizon scanner. Their method consisted of averaging the directions (unit vectors) of the observed stars to obtain an effective single direction (a unit vector) and using this in the QUEST algorithm together with the nadir vector sensed by the horizon scanner. Bender and Brouzenec presented simulations of the algorithm, but no detailed covariance analysis. A careful covariance analysis shows that for the case considered the algorithm will show significant accuracy loss committed to the case where the complete data is considered. However, for the case of two star cameras, their suboptimal method can be shown to perform very well with little loss of accuracy. We have carried out a complete and detailed analytical study of the Brouzenec-Bender algorithm comparing it with the QUEST algorithm using the complete star-camera data. Numerical results are also available for a complete range of sensor geometries.

00-125 **Cooperative Attitude Determination**
0210pm Sergei Tanygin

The paper discusses approach to attitude determination that utilizes advances in communication technology for formation flying spacecraft. Smaller and cheaper transmitters/receivers facilitate information exchange and cost-effective distribution of traditionally autonomous operations among cooperating spacecraft and ground stations. The design goal then becomes autonomous and robust attitude determination for the formation, i.e. for each and every spacecraft in it, not for each and every spacecraft separately.

00-126 **Attitude Determination Performance Improvement Through Enhanced QUEST Algorithm Modification**
0230pm Injung Kim and Jinho Kim

For last three decades ago, a lot of algorithms to determine the attitude and angular rates without gyros have been proposed. Enhanced QUEST algorithm (EQA) determines the attitude by the estimated quaternion from QUEST instead of the measurement of Kalman filter. In this paper, we propose two methods to improve EQA. One is to tune the gain using the number of measurements and the covariance matrix and the other is to propagate the attitude by utilizing the estimated angular rates. This algorithm is verified through the simulation of Korea multipurpose satellite (KOMPSAT-II).

0250pm – 0310pm Coffee Break

00-127 **A Kalman Filter Approach to System Alignment Calibration**
0310pm Mark E. Pittelkau

Many spacecraft missions require precise pointing of their payload boresight and precise knowledge of the payload boresight attitude from ground processing of attitude sensor and gyro telemetry. Such precision is obtained at reasonable expense in part by system alignment calibration. This paper treats specifically the problem of relative and absolute alignment calibration of a system comprising two star trackers, a gyro, and an imaging instrument via an alignment Kalman filter. An overview of the misalignment processes and the concepts of relative and absolute alignment are defined and illustrated. Misalignment models and gyro scale factor error models are derived and their implementation in the Kalman filter is presented. Results demonstrate convergence and performance characteristics. The effect of calibration residuals on a six-state filter is shown.

00-128 **k-vector Range Searching Techniques**
0330pm Daniele Mortari, Beny Neta

Various k-vector techniques for the range-searching problem are presented here. These methods accomplish the range searching problems by taking advantage of an n-long vector of integers, called the k-vector, to minimize the search time. The price is increased memory requirement for the k-vector allocation. However, it is possible to balance the extra memory required and the speed attained by choosing a step parameter h which samples the k-vector. A two-level k-vector technique is also presented to minimize the speed of the admissible data identification associated with a given range. The proposed methods are compared with the well-known “binary search” technique, and demonstrate a high speed gain rate (from 9 to more than 18 times). Finally, just to show one of the wide-range possible applications, a method to compute the *arcsin* function, based on the k-vector technique and a look-up table, is presented.

00-129 **Optimal Linear Attitude Estimator**
0350pm Daniele Mortari, F. Landis Markley and John L. Junkins

A new approach for optimal estimation of spacecraft attitude, named Optimal Linear Attitude Estimator (OLAE) is presented here. The method, which can be used in both the single-point and in the real-time estimations, uses the Rodriguez (or Gibbs) vector, a minimum-element attitude parameterization. The optimality criterion, which does not coincide with the constrained Wahba's criterion, is linear and unconstrained. The singularity, which may occur in a ‘‘single frame”, is avoided by one sequential rotation. Meaningful plots quantify the obtained accuracy and show the high computational speed.

00-130 **Singularity and Attitude Estimation**
0410pm Daniele Mortari, Michela Angelucci,F. Landis Markley

All of the minimum-element attitude parameterizations, suffer of becoming singular for some values of the principal angle. This is the reason why minimum-element attitude parameterizations are not so widely used in the main attitude related applications. In order to avoid singularities, it is necessary to parameterize the attitude with a four-element mathematical tool: the quaternion (Euler symmetric parameters). This is why the quaternion has encountered such a wide success in dynamics and attitude determination applications. Moreover, another common argument in favor of the quaternion is that it does not require any trigonometric step during rotation products. The latter, however, was a problem at the time when the trigonometric functions were computed by series expansion. Nowadays, they are more efficiently computed (in double precision) using interpolation and lookup tables. Nevertheless, the quaternion, with its fourth cumbersome element, still remains the king of the attitude parameterization mainly because it is singularity free. This is why most of the attitude estimation algorithms provide the attitude by means of quaternion. However, the present trend to develop faster optimal attitude estimation procedures leads to use a minimum-element attitude parameterization partly because, as is well known, the orientation (and/or the rotation) depends on three parameters, only. The purpose of this paper is to attempt to provide an answer to the following question: is it possible to devise a general procedure which keeps an algorithm, using a minimum-element attitude representation, working constantly far enough from its singular working position, such that the singularity is avoided every time?

Session 5:	***Low-Thrust Orbit Transfers***
1:30pm – 4:10pm	**Heritage Room**
Chair:	**Ron Lisowski**

00-131 **New Analytic Solutions to the Fuel-Optimal Orbital Transfer Problem Using Low-Thrust Exhaust-Modulated Propulsion**
0130pm Robert H. Bishop and Dilmurat M. Azimov

The present work is devoted to the investigation of motion of spacecraft powered by a power-limited exhaust-modulated propulsion system employing *analytical* methods. It is shown that utilizing Poisson's brackets and the invariant relations for the switching functions yields new classes of analytical solutions. As an example, the problem of fuel-optimal transfer between two elliptic orbits via a low-thrust spiral arc is discussed. The formulas for the determination of coordinates of the switching points and components of the primer-vector are obtained using analysis of the continuity conditions at the switching points and the transversality conditions. Numerical results are used for comparison.

00-208 **Analytic Solution to the Problem of Turning of an Elliptic Orbital Plane via Spherical Intermediate Thrust Arcs**
0150pm Dilmurat M. Azimov and Robert H. Bishop

New analytical solutions for spherical IT arcs are obtained using the conditions of existence of the IT arcs, properties of the underlying canonical equations, and Poisson's brackets. It is shown that the solutions generalize previously known solutions for circular and spherical IT arcs, and that they satisfy Robbin's necessary condition of optimality. The problem of minimization of the characteristic velocity of turning the plane of given elliptic orbit about the line which is perpendicular to line of nodes via the obtained spherical IT arcs is considered.

00-132 **Fuel-Optimal Three-Dimensional Earth-Mars Trajectories with Low-Thrust Exhaust-Modulated Plasma Propulsion**
0210pm R. S. Nah, S. R. Vadali, E. Braden

In this paper, three-dimensional trajectories from an Earth parking orbit to a variety of arrival orbits about Mars are considered with minimum fuel expenditure as the objective function. The spacecraft is expected to complete a single trip within a specified time frame. At departure, the spacecraft is assumed to be in a circular orbit at a nuclear-safe altitude of 1,200 *km*. A 1-SOL or sun-synchronous orbit is specified for Mars capture. An indirect, multiple shooting method is used to solve the optimization problem. This approach utilizes Newton's method with line searches and backtracking. Both spherical and rectangular coordinates have been used in the dynamical formulation for the interplanetary trajectory. In order to avoid numerical sensitivity, the entire trajectory is separated into three segments with various frames of reference. Nonlinear intermediate state constraints result from the enforcement of continuity at the segment interfaces. In addition, jump conditions on the adjoint variables at the interfaces are also taken into account to ensure continuity of the control variables. Due to the complexity involved, a number of problems involving relaxed boundary conditions and are solved in priori before determining a complete Earth-Mars trajectory. Upon obtaining a solution to the problem of interest, additional optimal trajectories are obtained using continuation in several parameters such as the flight time, departure and arrival orbit inclinations, initial mass, and power rating. The effects of the parameters on the fuel required are examined.

00-133 **A Hohmann Transfer Analog for Power-Limited, Continuous Thrust Transfers Between Coplanar Circular Orbits**
0230pm Nikos Markopoulos

Transferring between two orbits is in practice always accomplished within a finite time, and using finite thrust. For a given vehicle and type of propulsion the desire to maximize the final mass after the transfer leads to an optimal guidance problem. The simplest such problem is encountered when the two orbits are coplanar and circular. This affords many interesting and practically significant mathematical idealizations. The well-known Hohmann transfer and the transfer under the so-called Tangential class of continuous thrust programs presented here lie at two diametrically opposite ends of such idealizations. The Hohmann transfer is optimal for the case in which the thrust is infinitely concentrated in time (impulsive). It satisfies minimum velocity change requirements when the ratio of the diameters of the two orbits is less than about 12. A transfer under the Tangential class on the other hand is optimal when the thrust is infinitely spread out in time. This happens when the transfer duration tends to infinity. The optimality here is valid for a power-limited propulsion system, namely, one in which the energy supplied to the propellant comes from a source independent than the propellant itself. In practice, just as a Hohmann transfer can be performed only nearly optimally using high (but finite) thrust, a transfer under the Tangential class can be performed only nearly optimally using low thrust and large (but finite) transfer duration. This is consistent with the types of propulsion systems used for the two classes of transfers, high thrust chemical propulsion being suitable for the former and low thrust electric propulsion being suitable for the latter. The Tangential class itself is a class of continuous thrust programs. It is obtained by making the tangential thrust assumption in the costate equations of the corresponding power-limited, optimal guidance problem. After that the equations of motion corresponding to the classical, two-body, inverse-square gravity model can be analytically integrated without any further approximations. The presentation will include examples of such transfers and optimality comparisons with exact, numerical results.

0250pm – 0310pm Coffee Break

00-134 **Trajectories To Comets Using Solar Electric Propulsion**
0310pm Jon A. Sims

In situ analysis of a cometary nucleus and return of a sample are high priority scientific goals. Rendezvous and sample return trajectories to comets using low-thrust ion propulsion are presented. Several launch opportunities exist for each comet apparition, providing flexibility in mission design. Compared to chemical propulsion, ion propulsion is shown to reduce the propellant mass by over 60%, enabling the use of a smaller launch vehicle, while also reducing the flight time by several years.

00-135 **Guidance Schemes for Low-Thrust Orbit Transfers**
0330pm Dan O'Shaughnessy , Craig Kluever

While much work has been devoted to the development of computing optimal transfers for low-thrust vehicles, the body of work concerning guidance schemes for these spacecraft is comparably limited. This article presents a simple, robust method for on-board spacecraft guidance for a LEO-GEO transfer of a nominal spacecraft. The problem is separated into two stages: the guidance to deliver the spacecraft to the proper orbit, and guidance to hit a target location in GEO. Trajectory re-optimization is addressed for significant deviations. The performance in the face of perturbations is also presented.

00-136 **Low Thrust Eccentricity and Out-Of-Plane Corrections**
0350pm Sebastien Herbiniere, Vincent Martinot, Sophie Geffroy and Pascal Brousse

In case of positioning with low-thrust propulsion, the satellite pointing modes may not be versatile enough to achieve a fine rendezvous of all the orbital parameters during the orbit raising phase. In that case, final corrections in dedicated attitude modes are necessary to remove the remaining eccentricity, inclination and ascending node errors, while keeping the semi-major axis and phase rendezvous. This article presents an original and practical method to implement these final corrections for a satellite in a low-Earth nearly circular orbit with low-thrust propulsion. A case study inspired from emerging broad-applications is presented.

Session 6:	***Satellite Constellations and Formations***
1:30pm – 4:10pm	**Founders Room**
Chair:	**Felix Hoots**

00-137 **Radio Interference Between Non-Geostationary Communication Satellite Constellations**

0130pm Ronald Proulx, David Castiel, John Draim, Paul Cefola

The ELLIPSO™ system design team has identified the intrusion of other Big-LEO Mobile Communications System (Globalstar, ICO, and Constellation) satellites into the main beams of the ELLIPSO™ feeder stations as an area of concern that must be characterized. The sharing of the same C-band feeder down-link spectrum (6.875 - 7.075 GHz) by ELLIPSO™ and other systems presents system design and system operational challenges. RF interference occurs when the intruding satellite becomes co-aligned with the ELLIPSO™ satellite and the feeder station that is tracking the ELLIPSO™ satellite. This undesired situation is called "main beam coupling"; it can significantly increase the noise environment from which the ELLIPSO™ feeder station receivers must detect the ELLIPSO™ downlink signal. The effect of the increased RF noise level will have a direct consequence on overall system performance. This paper concentrates on developing a better understanding of the statistical nature of main beam coupling, treating the intrusion problem as one involving the basic geometry between the various satellites and the feeder stations. Individual RF interference threats between ELLIPSO™ and other LEO systems, (Globalstar, ICO, and CONSTELLATION) will be characterized through a comprehensive set of relevant statistics. Although not part of a LEO communication system, the effect of solar interference is also included in this analysis.

00-138 **Orbital Debris Hazard Assessment Methodologies for Satellite Constellations**

0150pm David B. Spencer, K. Kim Luu, W. Spencer Campbell, Marlon E. Sorge, Alan B. Jenkin

The expected proliferation of satellite constellations in the next decade will tax the space environment in several ways. This paper examines two categories of environmental impacts: the effects of the constellations on the space debris environment, as well as the effects of the environment on the satellite constellations. Included in this study are issues such as inter-satellite collision hazards for both controlled and uncontrolled spacecraft, intra-satellite constellation collision hazard (collision risks between members of two or more satellite constellations), and collision risk between constellation members and the cataloged and uncataloged space population. Additional analysis of compliance issues with national space policy, voluntary national debris mitigation guidelines, and international concerns are addressed. The first objective is to define and assess key system-level issues and identify areas for further analysis. To accomplish this, the long- and short-term effects on the environment, the constellation system, and other users of space are assessed. Additionally, an assessment is performed to examine compliance approaches with national policy and guidelines. Since the national debris mitigation guidelines are in the draft stage, published guidelines are used to illustrate the assessment process.

00-139 **Average and Maximum Revisit Time Trade Studies for Satellite Constellations Using a Multiobjective Genetic Algorithm**
0210pm Edwin A. Williams, Williams A. Crossley, Thomas J. Lang

Recently, Genetic Algorithms (Gas) have successfully generated sparse coverage satellite constellations for low Earth orbits that appear to outperform traditionally developed constellations. The objective of these constellations was to minimize the maximum revisit time over a latitude band of interest. However, many constellation designers are also concerned with the average revisit time, and contrary to expectations, these two objectives often compete with each other. This paper presents a multiobjective GA approach to show the trade off between the objectives in a single computer run. The designs generated using this approach will be analyzed to develop general trends.

00-141 **The Implementation of Maintaining Constant Distance Between Satellites in Elliptic Orbits**
0230pm Zhaozhi Tan, Peter M. Bainum and Avaine Strong

A novel idea maintaining constant separation between satellites in a coplanar elliptical orbiting constellation is developed. A possible scientific application of this system would be in measuring the curl of the Earth's magnetic field by taking simultaneous measurements along the elliptical orbit. The strategy involves an initial impulsive maneuver which would cause small shifts in the direction of the semi-major axes of the daughter satellites with respect to a reference or mother satellite. With this approach for Keplerian type orbits the separation distance between adjacent satellites remains within 2-3% of nominal separation distance. Simulations are conducted by both MATLAB and the BG14 orbital propagator; the latter is used to evaluate the effects of non-Keplerian type perturbations.

0250pm – 0310pm Coffee Break

00-142 **Using Reflected GPS Signals for Satellite Remote Sensing**
0310pm David Mickler, George Born

GPS signals that have reflected off of the ocean's surface have shown potential for use in oceanographic and atmospheric studies. The research described here investigates the possible deployment of a GPS reflection receiver onboard a remote sensing satellite in low Earth orbit (LEO). The coverage and resolution characteristics of this receiver are calculated and estimated. This mission analysis examines using reflected GPS signals for several remote sensing missions. These include measurement of the total electron content in the ionosphere, sea surface height, and ocean wind speed and direction. Also discussed is the potential test deployment of such a GPS receiver on the space shuttle. Constellations of satellites are proposed to provide adequate spatial and temporal resolution for the aforementioned remote sensing missions. These results provide a starting point for research into the feasibility of augmenting or replacing existing remote sensing satellites with spaceborne GPS reflection-detecting receivers.

Tuesday Morning Sessions

Session 7:	***Attitude Dynamics and Control***
8:30am – 11:10am	**Club Room**
Chair:	**Richard Barnisin**

00-144 **Attitude Maneuvers for MIGHTYSAT II.1 Hyperspectral Data Collects**
0830am Craig A. McLaughlin and Capt. Scott Carter

The characteristics of the Fourier Transform Hyperspectral Imager (FTHSI) have a significant effect on the attitude maneuvers required for data collection. In order to obtain the desired image characteristics for a given set of instrument settings, the velocity of the swath across the ground must be precisely maintained. This requires the spacecraft to maneuver constantly during the data collection. This paper examines the design of the attitude maneuver and how the different instrument settings affect the required attitude maneuver. The image characteristics for the different instrument settings are also examined.

00-145 **Attitude Control System and Star Tracker Performance of the Wide-Field Infrared Explorer Spacecraft**
0850am Russ Laher, Joe Catanzarite, Tim Conrow, Tom Correl, Roger Chen, Dave Everett, David Shupe, Carol Lonsdale, Perry Hacking, Nick Gautier, and Ken Lebsock

The Wide-Field Infrared Explorer (WIRE) spacecraft was launched into sun-synchronous orbit on March 4, 1999. An anomaly that occurred soon after successful orbital insertion rendered its science instrument useless. Nevertheless, WIRE operations have continued, using the spacecraft as an engineering test bed, and for new science experiments. On-orbit data from the GSFC-developed attitude control system and Ball Aerospace CT-601 star-tracker have been analyzed to assess their performance. All applicable requirements have been met or exceeded. In particular, the results show that the pointing accuracy and stability of the spacecraft are excellent.

00-146 **Improvement of the Satellite Attitude Stability by the Sliding Mode Control while a Robot Arm Works on a Satellite**
0910am Mitsushige Oda

When a robot arm works on a satellite, robot arm's motion disturbs satellite attitude's stability. However since tele-operation and monitor of the onboard robot arm is conducted from the on-ground control station, stability of the satellite attitude and antenna pointing control are necessary. This paper proposes a new approach to stabilize the satellite attitude motion against the robot arm motion using the gains scheduling of the satellite's attitude control system. Experiment results, which are gained by NASDA's ETS-VII satellite, are also included.

00-147 **Numerical Calculation of Flow Field in Equatorial Mounted Fluid-in-Tube Satellite Dampers**
0930am M. Creaven, R. Flanagan

Traditionally the European Space Agency fluid-in-tube dampers have been of the meridian design (the GEOS satellite) and have behaved in a predictable manner. However, the introduction of an equatorial mounting (the Ulysses satellite) produced unpredictable results and subsequent damper failure in orbit. This paper presents numerical evidence to highlight the reasons for failure of the ESA analytical model to predict the fluid behaviour in the equatorial mounting. The CFD results have shown how non-planar flow and tube/endpot vortex blocking make the analytical model redundant for the design of equatorial mounted dampers.

0950am – 1010am Coffee Break

00-148 **Magnetic Hysteresis Damper for a Thin Plate - Type Satellite**
1010am Anna D. Guerman

We study the motion of a satellite that moves in the passive attitude control mode using the gravity field of the Earth as a source of restoring torque. To damp the oscillations that appear during its flight, the satellite is equipped with several thin rods made of magnetically soft material. With the motion of the satellite, these hysteresis rods are remagnetized in the geomagnetic field and dissipate the energy of parasite oscillations. Some analysis of such an attitude control system was done showing its high efficiency. Along with its low weight, reliability and independence from any source of energy, this makes the hysteresis damping system a tempting choice in small satellite programs. Two different cases of orientation of the damping rods in the body of satellite have to be studied separately. Analysis performed for the general orientation of the rods showed that on approaching the thin-plate resonance the motion becomes unstable.

00-149 **Optimal Design of a Two-Dimensional Passive Coning Attenuator for Spinning Spacecraft Under Thrust**
1030am Dominic M. Halsmer and Andrew Lang

A procedure for designing an optimal, two-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. Results are verified with a numerical example where the performance of a two-dimensional attenuator is compared to that of a one-dimensional attenuator. 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, and in choosing the number of degrees of freedom for the attenuator.

00-150 **Symbolic Math Generalized Equations of Attitude Motion for ATTDES, II**
1050am Donald L. Mackison

Development of the equations of motion for a complex satellite, which may include flexible members, gimbaled devices, momentum wheels, and control moment gyros - both constant speed and variable speed rotors, can be a daunting task. Several coupled body programs, such as SDExact have been in use for several years. Here, we use a Lagrangian approach, where the appropriate Lagrangian for each of the various parts of the satellite are cataloged, and added to the system Lagrangian as needed. Then, using the symbolic math capability of Matlab, the appropriate derivatives can be computed to generate the full equations of motion of the system. Linearization of the model is easily accomplished using elements of symbolic math, which leads to a quick generation of linear equations of motion, to be used in LQ design methods.

Session 8:	***Orbit Dynamics and Stability***
8:30am – 11:10am	**Heritage Room**
Chair:	**David Spencer**

00-151 **Parallel Numerical Integration Methods for Orbital Motion**
0830am Peter Nagel Bob E. Schutz

Various parallel numerical integration methods for use with satellite related problems were tested and compared to two of the most efficient serial methods in use today. Tests were completed for two cases, the normalized two-body problem and a single GPS satellite including nominal forces. None of the parallel methods, including Parallel Runge-Kutta, Parallel Runge Kutta Nystroem, and Parallel Extrapolation, showed significant speed-up compared to the serial methods for the two-body problem. For the GPS orbit problem, only variations of the Parallel Extrapolation method performed as well as the fastest serial method, a general Class II Predictor Corrector method.

00-152 **MEO Disposal Orbit Stability and Direct Reentry Strategy**
0850am C. C. Chao

The disposal orbit stability and a direct reentry (direct retrieval) strategy for the medium altitude orbits (MEO) are studied. In this study only two regions of altitudes are considered: one region between 2000 km and 4000 km altitudes and the other region covering GPS, Molniya and GTO. The long-term orbit perturbations and stability of the selected MEO disposal orbits are understood through both analytical (singly and doubly averaged equations) and numerical (TRACE integration) investigations. Initial disposal orbit elements (for GPS, etc) are identified to prevent significant growth in eccentricity. The minimum altitude change to disposal orbit for safe separation is examined and a recommended strategy of direct reentry with its ΔV requirement is also discussed.

00-153 **Spacecraft Motion About Slowly Rotating Asteroids**
0910am W. Hu and D.J. Scheeres

This paper studies the orbital motion of a spacecraft about slowly rotating asteroids. It was shown by Scheeres and Hu previously that the averaged Lagrange equations for this problem are integrable if the central body does not rotate. The current paper investigates how to modify the solution when the central body rotates slowly. Specifically, it compares the analytical solution of the averaged orbital equations to the numerical solution of the equations of motion both with and without central body rotation. The calculations show that the analytical results agree well with numerical solutions and that the analytical solution can be used to understand spacecraft motion about a slowly rotating asteroid.

00-154 **Stability Analysis of the Europa Orbiter**
0930am D. J. Scheeres and M. D. Guman

A study of the Europa orbiter is given, using both numerical and analytical techniques. This study is motivated by the fact that numerically integrated, low altitude Europa *S/C* orbits often impact on that moon's surface after a short period of a few days to weeks. Numerical integrations indicate that these impact orbits only occur for inclinations within ~ 45^{o} of a polar orbit. This paper will describe an analytical study of this problem which results in an approximate, closed form solution for the Europa orbiter dynamics. The solution includes the effect of the Jupiter tide and the Europa oblateness, with the assumption that the eccentricity of the orbit is small. This solution is used to compute limits for impacting and non-impacting orbits at Europa and provides excellent agreement with numerical computations of these limits performed with the DPTRAJ program at JPL. Furthermore, the analytical result predicts a set of initial conditions which can postpone impact with the Europa surface for considerable lengths of time. This result is also validated numerically.

0950am – 1010am Coffee Break

00-155 **Temporary Satellite Capture of Short-Period Jupiter Family Comets from the Perspective of Dynamical Systems**
1010am B.G. Marchand, K.C. Howell, and M.W. Lo

The Temporary Satellite Capture (TSC) of short-period comets such as Oterma, Helin-Roman-Crockett and Gehrels 3 by Jupiter has intrigued astronomers for many years. A widely accepted approach to study TSC is to numerically integrate the equations of motion for the *n*-body problem using a wide range of heliocentric *two*-body problem initial conditions and search for instances when the Joviocentric energy becomes negative. More recently, the application of Dynamical Systems Theory (DST) to the Sun-Jupiter-Comet *three*-body problem has provided significant insight into the motion in the Sun-Jupiter system and offered a simple model to account for the TSC phenomena observed in Jupiter family short-period comets.

00-156 **Periodic Orbits Around Geostationary Positions**
1030am M. Lara and A. Elipe

As it well known, the dynamics of a satellite under the action of a truncated potential that takes into account the effect of the second order harmonics (the zonal J_2 and the tesserals C_{22} and S_{22}) has four equilibria, the so called geostationary points. The linear stability is also well established; two are of stable character, while the other two are unstable. Even more, recently, it has been proven [3] that, for the Earth and Earth-like planets, the two points linearly stable are stable in the Lyapunov sense. Thus neighborhoods of the stable points seems to be good candidates to place satellites, fact that has been realized a long time ago. However, in this communication, we show that it is possible to find periodic orbits around unstable points and that these orbits may be stable.

00-157 **Focal-Type Elements Based on Quasi-Keplerian Systems. An Application to Satellite Motion**
1050am Ignacio Aparicio, Luis Floria

On the basis of harmonic-oscillator solutions to exactly linearizable perturbations of the two-body problem related to certain generalized quasi-Keplerian systems arising in Artificial Satellite Theory, we treat the J_2 problem in terms of generalized focal elements attached to perturbed two-body systems with perturbations compatible with exact linearization. We adapt developments in our previous paper, in incorporating the major J_2 secular effects into the new elements: our starting point are the constants of motion in the solution to the oscillator equations to which perturbed Keplerian systems with Deprit-type potentials are reduced in focal variables. We derive generalized focal element equations, and apply them to the artificial satellite under the effect of the second zonal harmonic of the geopotential.

00-158 **A Flight Mechanics Analysis of ARIANE 5 SRB Separation**
1110am O. Bayle

The European heavy launcher ARIANE 5 is propelled at liftoff by the main cryogenic engine (VULCAIN engine, ten per cent of total thrust at liftoff) and by two solid rocket boosters (SRB, ninety per cent of total thrust at liftoff). After a 140-second flight, SRB thrust fades and the SRBs are jettisoned. The separation of the SRBs from the launcher is a major and critical event of the flight, as involving simultaneously flight mechanics, propulsion, aerodynamics, GNC, mechanical dynamics and plume impingement. This paper first describes the logic that was used to manage the different studies that were necessary to guarantee a safe separation. The stress will then be laid on the separation and distancing problem itself, by describing the simulator created to analyze the problem. As a conclusion, modeling results will be compared to in-flight data coming from two ARIANE 5 recent test launches.

Session 9:	***Special Session: Mission Analysis for Earth Observing Satellites***
8:30am – 11:10am	**Founders Room**
Chair and Organizer:	**Lauri K. Newman**

00-159 **An Improved Strategy for Maintaining Repeat Ground Tracks at High Latitudes**
0830am Peter Demarest and Bob E. Schutz

It is required that the ground track of the Ice, Cloud, and land Elevation Satellite be maintained within 800-m of a repeating reference at all latitudes. Although techniques for maintaining the ground track at the equator are well established, a more optimal strategy needs to be developed for high latitude maintenance. The technique explored in this paper involves first calculating a maneuver that maximizes the time before the constraint is violated, then a minimum ΔV solution is found for that arc. Compared to latitude targeting, this strategy reduces the total ΔV required over the ICESat mission.

00-160 **Risk Mitigation using Monte Carlo**
0850am Conrad Schiff, Susan Good , Dave Rohrbaugh

We present a method for mitigating risks inherent in spacecraft missions using a Monte Carlo approach within FreeFlyer. By exploiting the object-oriented design of FreeFlyer, we are able to apply a specified probability distribution to any set of independent parameters. The resulting distribution in any set of dependent parameters is then determined by propagating a representative sample of the independent parameters as separate Monte Carlo trials. Our method is robust in that no assumption of linearity is needed to propagate the influence of the uncertainty (propagation of error). In addition, it is applicable to risk sources arising from both uncertainties in dynamical parameters, such as noise in the orbit or attitude state, and from those uncertainties associated on a programmatic level such as launch date or station visibility. The application of Monte Carlo analysis to the ICESat and Terra missions are examined as real examples of minimizing mission risk.

00-161 **Earth Observer – 1 (EO-1) Ascent Strategy**
0910am Paul Noonan, Susan Good, Robert Defazio

The mission design for the EO-1 spacecraft calls for it to fly in very close formation with Landsat-7, in order for the EO-1 instruments to image nearly identical scenes. Achieving the proper flight formation with Landsat-7 means simultaneously satisfying an array of orbital parameters driven by the Landsat-7 orbit at the time of the EO-1 launch, including semi-major axis, inclination, right ascension of the ascending node, and coincident orbital path. The EO-1 ascent strategy must also account for launch dispersions and achieve the proper argument of perigee and eccentricity for a frozen orbit. This paper explains the ascent strategy employed to efficiently achieve these goals and establish the proper formation.

00-162 **Landsat-7 Ascent Planning**
0930am E.Lucien Cox, Jr.

The Landsat-7 spacecraft is in a Sun-synchronous, frozen polar orbit maintaining a daylight equator crossing and longitudinal drift pattern conducive for Earth imaging. The paper will discuss several aspects important to the Landsat-7 mission. Requirements analysis will be discussed first with an emphasis on launch window definition, launch vehicle insertion dispersions, and mission constraint definition. The approach utilized to construct the mission ascent plan will discuss maneuver size and execution required for eventual phasing with the Landsat-5 spacecraft. Trajectory design will emphasize maneuver targeting analysis necessary for achieving the final Landsat-7 frozen orbit and ground track drift pattern. The software and desktop environment used for the Landsat-7 mission will also be discussed as it relates to past mission support initiatives. A discussion outlining the routine orbit maintenance and operations plan will follow providing necessary steps for ongoing mission support.

0950am – 1010am Coffee Break

00-164 **Mission Planning for the Twin GRACE Satellites**
1010am Wallace Fowler, Srinivas Bettadpur, and Byron Tapley

The GRACE mission requires precise measurement of the satellite-to-satellite range between two low-altitude satellites flying one behind the other along a nearly polar orbit. The early mission sequence includes injection into orbit from a common booster, a separation sequence to place the two satellites in a common orbit separated by 230 km, and three calibration maneuvers. Operational planning requires consideration of interactions among the competing factors of (1) the control of the relative positions of two satellites, (2) very stringent attitude requirements (each satellite must point at the other), (3) recalibration maneuvers, (4) orbital reboost maneuvers, (5) the swapping of positions by the leading and lagging satellites, and (6) a contingency "safe" mode for the satellites. Qualitative descriptions of candidate maneuver sequences will be presented and the models used in evaluating these sequences will be described. Comparisons between simplified analyses and analyses developed using multiple drag models will be presented.

00-163 **GRACE Mission Design: Impact of Uncertainties in Disturbance Environment and Satellite Force Models**

1030am Daniel D. Mazanek, Renjith R. Kumar, Hans Seywald, Min Qu,

The Gravity Recovery and Climate Experiment (GRACE) primary mission will be performed by making measurements of the inter-satellite range change between two co-planar, low altitude, near-polar orbiting satellites. Understanding the uncertainties in the disturbance environment, particularly the aerodynamic drag and torques, is critical in several mission areas. These include an accurate estimate of the spacecraft orbital lifetime, evaluation of spacecraft attitude control requirements, and estimation of the orbital maintenance maneuver frequency necessitated by differences in the drag forces acting on both satellites. The FREEMOL simulation software has been developed and utilized to analyze and suggest design modifications to the GRACE spacecraft. Aerodynamic accommodation bounding analyses were performed and worst-case envelopes were obtained for the aerodynamic torques and the differential ballistic coefficients between the leading and trailing GRACE spacecraft. These analyses demonstrate how spacecraft aerodynamic design and analysis can benefit from a better understanding of spacecraft surface accommodation properties, and the implications for mission design constraints such as formation spacing control.

Tuesday Afternoon Sessions

Session 10:	***Interplanetary Missions***
1:30pm – 4:10pm	**Club Room**
Chair:	**Bob Melton**

00-165 **Altimeter Range Processing Analysis for Spacecraft Navigation about Small Bodies**
0130pm J. J. Bordi, P. G. Antreasian, J. K. Miller, and B. G. Williams

The impact of using altimeter range measurements as an observation type for navigation of spacecraft about small bodies is evaluated. The altimeter range measurements can supplement or replace the standard optical landmark and Deep Space Network (DSN) radiometric tracking. Navigation of spacecraft orbiting small bodies, like asteroids, can be challenging since the a priori physical characteristics of the central body can have larger than normal uncertainties. The addition of the altimeter range data into the orbit determination problem can be used to alleviate the increased uncertainty in the dynamics of the spacecraft, due to uncertainties in the gravity model of the body. Additionally, the altimeter data can be used to speed up determination of a more accurate gravity field model. An advantage of the altimeter data is that the measurements can be taken continuously, without the sunlight restrictions of optical landmark tracking, or the station visibility restrictions of DSN tracking. Simulations of various mission scenarios are used as test cases, to assess the usefulness of the altimeter range data as a navigation tool.

00-166 **Petit Grand Tour**
0150pm Wang Sange Koon, Martin W. Lo, Shane Ross, Jerrold Marsden

The recent discovery of the mechanism which controls the temporary capture of Jupiter comets suggests a new Jupiter satellite tour design called "The Petit Grand Tour". Previous planetary tours exploited planetary flybys to study the moons and planets. For the Petit Grand Tour, we propose a series of orbiting visits to the various moons of Jupiter. As the spacecraft approaches each Jovian moon, the "temporary capture mechanism" enables the spacecraft to automatically orbit the moon for a predetermined number of orbits where mapping and imaging of the moon may be performed. At the end of the last orbit around the moon, the spacecraft automatically departs and inserts onto a low energy transfer trajectory to the next moon. Propulsive maneuvers may be required for insertion onto the transfer trajectory between moons. A few small deterministic maneuvers are required to control the temporary capture orbits and to maintain the trajectory. This low energy trajectory is obtained from a deeper understanding of the three body dynamics which controls the global transport of material within the Jovian system.

00-167 **Cassini Maneuver Experience: Finishing Inner Cruise**
0210pm Troy D. Goodson, Donald L. Gray, Yungsun Hahn, and Fernando Peralta

The Cassini project is an international effort to study the planet Saturn and its moons with an orbital tour. The interplanetary trajectory to Saturn requires four gravity-assists, two from Venus, one from Earth, and another from Jupiter. Although no science investigations are planned, there are many activities to be accomplished within this time, including the execution of 21 trajectory correction maneuvers (TCMs). This paper reports the execution of eight of these maneuvers, the last of the inner cruise. This maneuver analysis separates maneuver execution errors into two categories: magnitude and pointing. The statistical models for these errors are updated based on the best estimates of the maneuvers discussed above. This new model will provide more realism to predictions of the fuel required to navigate the tour of Saturn's system.

00-168 **Cassini Orbit Determination From First Venus Flyby to Earth Flyby**
0230pm Mark D. Guman, Duane C. Roth, Rodica Ionasescu, Troy D. Goodson, Anthony H. Taylor, Jeremy B. Jones

This paper describes Cassini orbit determination results from the first Venus flyby through the Earth flyby. Emphasis is placed on orbit determination modeling and the resulting orbit solutions. Key solutions supporting maneuver designs are compared against reconstructed trajectory results. Reconstructed maneuver and planetary flyby events are provided. The use of spacecraft telemetry to improve modeling of post-maneuver accelerations is discussed. The characterization of smaller ΔV events such as reaction wheel assembly exercises and attitude control deadband tightenings is also presented.

0250pm – 0310pm Coffee Break

00-169 **Aeroassist Technology Planning for Exploration**
0310pm Michelle M. Munk

Now that the International Space Station is undergoing assembly in space, NASA is strategizing about the next logical destination for humans. NASA's current efforts are in developing technologies that will make human flight to other bodies both safe and affordable. One of these enabling technologies for future robotic and human exploration missions is Aeroassist. This paper will (1) explain the definition, benefit, and use of Aeroassist, and (2) describe an easy, low-cost method by which distributed teams such as the Aeroassist Technology Development Team assemble, present, use, and archive technology information.

00-170 **A Light-Weight Hypersonic Inflatable Drag Device for a Neptune Orbiter**
0330pm Angus D. McRonald

The author has analyzed the use of a light-weight inflatable hypersonic drag device, called a ballute, for flight in planetary atmospheres, for entry, aerocapture, and aerobraking. Studies to date include Mars, Venus, Earth, Saturn, Titan, Neptune and Pluto, and data on a Neptune orbiter will be presented to illustrate the concept at a large entry speed. For a Neptune orbiter a conventional rigid lifting entry body requires about 40% of the entry mass to be in the thermal shield and structure to take the pressure and thermal loads, and analysis indicates that the ballute mass for the same task may be about one half of this value. The main advantage of using a ballute is that aero deceleration and heating in atmospheric entry occurs at much smaller atmospheric density with a ballute than without it. For example, if a ballute has a diameter 10 times as large as the spacecraft, for unchanged total mass, entry speed and entry angle, the atmospheric density at peak convective heating is reduced by a factor of 100, reducing the peak heating by a factor of 10 for the spacecraft, and a factor of 30 for the ballute. The radiative heating is also reduced, since the density decreases more than the size increases. Consequently the entry payload (descent probe, orbiter, etc) is subject to much less heating, requires a much reduced thermal protection system (possibly only an MLI blanket), and the spacecraft design is therefore relatively unchanged from its vacuum counterpart. By making the ballute large enough one can make the heat flux on the ballute small enough to be radiated at temperatures below 800 K or so. Also, the heating may be reduced further because the ballute enters at a more shallow angle than a solid vehicle, even allowing for the increased delivery angle error that one expects at shallow entry, for a given error in the target plane. Added advantages are less mass ratio of entry system to total entry mass, and freedom from the low-density instability problem that conventional rigid entry bodies suffer, since the vehicle attitude is determined by the ballute, usually released at continuum conditions. The ballute derives an entry corridor for aerocapture by entering on a path that would lead to entry, and releasing the ballute adaptively, responding to measured deceleration, at a time computed to achieve the desired orbiter exit conditions. The author will discuss presently available ballute materials and a development program of aerodynamic tests and materials that would be required for ballutes to achieve their full potential.

00-171 **Development of a Target Marker for Landing on Asteroids**
0350pm Shujiro Sawai, Jun'ichiro Kawaguchi, Daniel Scheeres, Naoki Yoshizawa, Masahiro Ogasawara

The Institute of Space and Astronautical Science (ISAS) is currently planning an asteroid sample return mission, MUSES-C. The mission plan calls for the spacecraft to approach the asteroid and touch down on its surface to collect samples that will be returned to Earth. During the touch down and sampling phase, the spacecraft will navigate using a target marker placed on the asteroid surface prior to the final approach. By using the target marker as a reference point, navigation during the landing phase will be much more reliable and precise. Because of the micro gravity environment on the asteroid surface the settling time of the target marker may take a long time. Thus, it is important to design the target marker with as small a coefficient of restitution as possible. To achieve this small coefficient of restitution the target marker will be constructed out of a bag with balls stored internally. Upon impact, the balls will dissipate energy relative to each other and hence will dissipate the total energy of the target marker. This mechanism has been designed and tested at the Japan Microgravity Center. In order to better predict the performance of such a target marker, several numerical integrations have been also performed which model the motion of a bouncing target marker across the surface of a “real” asteroid shape.

00-172 **Trajectory Design for Low-Cost Main-Belt Asteroid Sample Return Mission**
0410pm Alexander A. Sukhanov, Otávio Durão

The main-belt asteroid sample return without landing on the asteroid is suggested. The spacecraft collects the sample during asteroid flyby, crossing the dust cloud produced by a projectile, and delivers it to Earth. To lower the launch delta-V, use of the VEGA maneuver is proposed. Five launch windows in the 2004-2010 period are considered and several mission options are offered, results of the trajectory design for the options are given. A few more asteroids can be also encountered as secondary targets almost in all the mission options. After the mission completion it can be extended as follows: the spacecraft can swing by Earth and fly to another asteroid or a comet. The secondary targets and possible mission extensions are considered for some of the mission options. Spacecraft navigation is considered.

Session 11:	***Orbit Transfers: Lunar and Libration Points***
1:30pm – 4:10pm	**Heritage Room**
Chair:	**Thomas Carter**

00-173 **Optimal Trajectories for Secondary Payloads From Geosynchronous Transfer Orbit to the Moon**
0130pm Brian E. McKay and Scott R. Dahlke

Trajectories that provide fuel efficient transfers from Geosynchronous Transfer Orbits (GTO) to the Moon are examined in this paper. These trajectories are becoming more important as relatively inexpensive launch options to GTO are now available by launching as a secondary payload. The main focus of this research is to explore possibilities for reaching lunar orbit via methods other than launching directly into the lunar orbit plane or waiting in a parking orbit for orbit perturbations to create favorable transfer conditions. Through the use of carefully chosen bi-elliptic type transfers or phasing orbits with optimally placed plane changes, this research shows that relatively efficient transfers to the Moon can be obtained from GTO.

00-174 **The Efficient Computation of Transfer Trajectories Between Earth Orbit and L1 Halo Orbit Within the Framework of the Sun-Earth Restricted Circular Three Body Problem**
0150pm Jean A. Kechichian

The method of regularization is used in L1-centered rotating coordinates to construct robust codes that produce converged trajectories from LEO to the vicinity of L1 where a velocity change inserts the spacecraft into a desired periodic halo orbit. These codes, which use backwards numerical integration, are built around integrators with built-in interpolators and an unconstrained optimization algorithm. The existence of optimal values of certain target parameters that lead to the minimization of the velocity change at insertion is also shown, as well as the range of its feasible values at least in the case of the perigee location of the departure hyperbola.

00-175 **Moon Assisted Out of Plane Maneuvers of Earth Spacecraft**
0210pm C. Circi, F. Graziani, P. Teofilatto

In this paper, two different techniques for out of plane maneuvers of Earth satellites are presented and compared. In these strategies, the Moon's gravitational field is not a perturbation but rather a fundamental tool to achieve the desired transfer. In the first approach called Weak Stability Boundary Transfer (WSBT), the spacecraft crosses a region of unstable equilibrium between the Earth and Moon gravitational forces. This region, about the intermediate Earth-Moon Lagrangian point L_2 , is such that a small out of plane impulse allows relevant changes of the orbit inclination. The second Moon assisted approach is based on Moon close encounter to change both inclination and perigee height. The lunar encounter is designed by means of the Opik method. A detailed parametric and study is given, and numerical results taking into account the Sun perturbation generate plots showing the minimum energy transfers, as function of the radius ratio and of the inclination variation. Significant advantages are apparent using the proposed techniques with respect to traditional Hohmann like transfer. For instance Moon assisted transfers from Low Earth Orbits to Geostationary Orbit can be economical with respect to the conventional transfers for a wide range of initial orbit inclinations, including those easily reached from the most used Launch Bases.

00-176 **On the Weak Stability Boundary Utilization and its Characteristics**
0230pm Jun'ichiro Kawaguchi

The solar gravity assist technique that works in the boundary region of the Earth Sphere Of Influence is presented. Some mathematical property is given to account for the gravity effect, in combination with the synchronization constraint on the moon's orbit. The results are shown together with the numerical and flight results in the Nozomi (PLANET-B) Earth departure flight in 1998. The discussion is also given to the other type of utilization in the Hiten (MUSES-A) and LUNAR-A missions.

0250pm – 0310pm Coffee Break

00-177 **Some Zero Cost Transfers Between Libration Point Orbits**
0310pm G. Gomez, J. Masdemont

The paper starts from a general description of the libration orbits in a vicinity of the L_1 and L_2 points of the RTBP. The different types of orbits: Liapunov, Lissajous, vertical periodic, halo and quasihalo are presented and characterized. The final purpose of the paper is to show some transfer orbits between the above mentioned orbits being one around L_1 and the other one around L_2 or vice versa. These transfer orbits are made asymptotic to both librating orbits in the same level of energy and so in the ideal situation no Delta-V is required to perform the transfer.

00-178 **Investigation of Periodic and Quasi-Periodic Orbits around the L4 Lagrangian Point in the Elliptic Restricted Three Body Problem**
0330pm S.H. Pourtakdoust, M.A. Jalali, F. Ariaei

The Hamiltonian function of the elliptical restricted three-body problem is presented. Using a set of canonical transformations and averaging by Lie transforms, the Hamiltonian function is reduced to its normal form. The system parameters are considered near the 1:1 resonance condition. For a set of specified initial conditions, periodic and quasi-periodic orbits are determined and studied for Lyapunov's stability.

Session 12:	***Mission Analysis Tools***
1:30pm – 4:10pm	**Founders Room**
Chair:	**Dave Vallado**

00 –179 **Near-Real Time Atmospheric Density Correction Using NAVSPASUR Fence Observations**

0130pm George R. Granholm, Ronald J. Proulx, Paul J. Cefola, Andrey I. Nazarenko, Vasiliy Yurasov

Mismodeled drag effects are one of the most significant sources of error for low-altitude and highly eccentric orbits. It is currently estimated that predicted densities can differ by as much as 30% from real world conditions even using the best exosphere models (such as MSISE-90 or Jacchia-Roberts). However, we can use observations from frequently-tracked objects in the space catalog to provide an "atmosphere correction service" to users desiring more precise orbit determination for a given target orbit. Density models can be initially improved using observations from "standard" satellites, i.e. those satellites with precisely known ballistic factors. We can estimate the orbits of these satellites to include ballistic factors, and the deviations from the true ballistic factors directly reflect the amount of error in the given atmospheric model, assuming that other perturbations are well-modeled. These errors must be attributed to a specific time and altitude. Using these initial density corrections to the atmospheric model, the orbits of satellites with unknown ballistic factors are estimated, with solve-for parameters again including positions, velocities, and ballistic factors. The estimated ballistic factors averaged over one or two solar rotations are taken to be the "true" ballistic factors for these "non-standard" satellites, and the density correction algorithms are iterated using both standard and non-standard satellite observations as inputs. Iterations continue until all ballistic factors and density corrections converge to predefined tolerances. The ballistic factors for non-standard satellites are updated every solar rotation, and the density corrections are updated every few hours or as soon as new observations are available. Once the density corrections have been calculated, the corrected atmospheric model can be used to estimate the orbit of the target satellite. Density corrections are also propagated forward in time for purposes of orbit prediction. Initially, simulated data in the form of NAVSPASUR "fence" angles-only observations are used to validate the correction algorithms for various atmospheric conditions and epochs. "Truth" values of ballistic factors and density variations are used to simulate truth orbits for a number of standard and non-standard objects. Angles-only observation data are generated for these orbits with error characteristics closely approximating real-world NAVSPASUR conditions. The density variations and ballistic factors of non-standard satellites are then reset to a-priori values, and the density correction algorithms are shown to converge to the truth values, given adequate numbers and types of observations. Observations of the target orbit are also simulated using the "true" values of ballistic factor and density variations. The target orbit and target ballistic factor are then estimated using these simulated observations. Accuracy of the density variation prediction algorithms is also investigated by comparing the estimated orbit with the "truth" orbit. All validations will be performed using actual NAVSPASUR observations if available.

00-180 **Precision of a Multi-Satellite Trajectory Database Estimated from Satellite Laser Ranging**
0150pm A. Clement, M. Davis and J. Seago

Satellite Laser Ranging (SLR)-based orbital ephemerides are being utilized as a tool to validate and diagnose problems in orbit determination software systems and satellite observatories. Several criteria are examined to design an ephemeris database with suitable precision to accomplish specific tasks, such as calibration of a satellite-observing radar. Definitions of the operational performance metrics used to assess the database precision are presented with results. Efficient interpolation of the database is also explored and the errors are assessed. Some preliminary results are presented while discussing forthcoming applications of the database to some current astrodynamic problems.

00-181 **Effects of Atmospheric Density Uncertainty on the Probability of Collision**
0210pm Deok-Jin Lee, K. T. Alfriend

The purpose of this paper is to analyze the effects of the uncertainty in the atmospheric density on the probability of collision, P_c, between the International Space Station (ISS) and another space object. Collision between two objects is defined to occur if they pass within some specified distance of one another. P_c is a function of the uncertainty of the orbits of the two objects, i.e. the covariance of each of the objects , the estimated miss vector at conjunction, and the specified miss distance defining a collision. For a precise calculation of P_c, it is essential that the covariance be accurate. If the sensor errors are correctly modeled the primary contributor to the covariance inaccuracy is the uncertainty in the atmospheric density. The covariance, an output of the orbit determination process, is subject to the system model and the method of differential correction, e.g. nonlinear least squares or Kalman filtering. The assumption of a perfect dynamic model results in an optimistic covariance, that is the estimated covariance too small. For the covariance generated by the differential correction process to accurately represent the state errors the atmospheric density uncertainty, which is both spatially and temporally varying, must be incorporated into the system model. In this paper the atmospheric density is modeled as the sum of N first-order Markov processes. Incorrect modeling of the sensor measurement statistics also causes an error in the covariance, but this is not addressed in this paper.

00-182 **A General Method for Calculating Satellite Collision Probability**
0230pm Russell P. Patera

A method of calculating the collision probability between two orbiting objects given the respective state vectors and error covariance matrices has been developed. The methodology, which is valid for the general case and does not require simplifying assumptions, can be readily extended to satellites of irregular shape. Analytical techniques are use to reduce the problem to that of integrating a two dimensional symmetric probability density over a region representing the combined hard-body of the colliding objects. The symmetric form of the probability density enables the two dimensional integral to be reduced to a one-dimensional path integral that permits easy numerical implementation. Test case results are in good agreement with those generated by other collision probability tools.

0250pm – 0310pm Coffee Break

00-183 **Accuracy Assessment of the Naval Space Command Special Perturbations Cataloging Ssytem**

0310pm Jonathan Boers, Shannon Coffey, William J. Barnds, David Johns, Mark Davis, John Seago

The Naval Space Command passed Initial Operational Capability (IOC) for a special perturbations catalog on July 7, 1999. Centered around a numerical integrator for orbit propagation, this system has the inherent capability to produce significantly more accurate orbits than the general perturbations method employed for decades by the Air Force and Naval Space Commands. This paper will quantify the improved orbit determination accuracy of the Navy System.

00-184 **Analysis of Preselected Orbit Generator Options for the Draper Semianalytic Satellite Theory**

0330pm Chris Sabol, Scott Carter, Megan Bir

The Draper Semianalytic Satellite Theory (DSST) represents the state of the art in semianalytic satellite theory with a wide variety of force modeling options configurable at run time. This flexibility allows the user to customized force modeling options from low accuracy/high speed configurations comparable to most general perturbation theories to high accuracy/low speed options comparable to special perturbation theories. The cost of this flexibility is a myriad of input options that may be overwhelming to the average user. To counter this, preselected orbit generator input options have been developed by astrodynamics specialists at the Air Force Research Laboratory to ease the use of DSST. The preselected orbit generator options are configured for maximum accuracy, optimized speed and accuracy, or averaged orbit generator (no short periodics) flavors for a wide variety of orbit classes. This analysis looks at the accuracy of the preselected configurations using real and simulated truth sources. Results are consistent with previous studies showing DSST to be a highly effective tool for both short term high accuracy and long term orbit evolution applications.

00-185 **The Effect of Drag on the Eccentricity of Near-Circular Orbits**
0350pm Glenn E. Peterson

The common perception is that orbits circularize as a satellite undergoes the effects of drag. This is incorrect. The orbit actually decays to the frozen value of the eccentricity. For most applications, the difference between circularization and "freezing" of the orbit are insignificant and not even noticeable. However, for orbits that begin near-circular, the difference between circularizing and freezing could have important operational implications in the subsequent behavior of the vehicle or constellation. This study shows through analytical, semi-analytic, and numerical means that the limiting value of the eccentricity decay is the frozen value, NOT zero.

00-186 **An Analysis of Optimal MSIS Parameters Retrieved from ARGOS Data to Compute Satellite Drag on LEO Objects**
0410pm A. C. Nicholas, J. M. Picone, S. E. Thonnard, R. R. Meier, K. F. Dymond, S. A. Budzien, R. P. McCoy

NRL is currently developing techniques to apply the neutral density measurements from the Advanced Research and Global Observations Satellite (ARGOS) to optimize the Mass Spectrometer Incoherent Scatter-Radar (MSIS) model for superior satellite tracking capabilities. Several LEO objects for which accurate ground truths are available will be analyzed using a high precision orbit propagator and our data inversion techniques applied to the ARGOS data. The propagator integrates the equations of motion using Runge-Kutta-Fehlberg methods of order 7-8. The MSIS and Jacchia 1971 models at the time of the ground truth measurement will provide alternative representations of the atmospheric density. In this paper we will evaluate the performance of the retrieved neutral density specification and the standard atmospheric models by comparing the known drag coefficients and the residuals between the propagated and ground truth positions.

Wednesday Morning Sessions

Session 13:	***Tethers and Space Structures***
8:30am – 11:10am	**Club Room**
Chair:	**Peter Bainum**

00-187 **Nonplanar Deployment Dynamics of the ASTOR Tethered Satellite System**
0830am Andre P. Mazzoleni

This paper concerns analysis of the nonplanar deployment dynamics of the ASTOR (Advanced Safety Tether Operation and Reliability) satellite; in particular, this paper studies the effect of the initial conditions prior to deployment on the system dynamics and how they affect the ability of the satellite to fully deploy. The ASTOR project is managed by the Texas Space Grant Consortium and the Marshall Space Flight Center (MSFC) through the Michigan Technic Corporation. The purpose of the ASTOR Satellite is twofold: [1] demonstrate the performance of the Emergency Tether Deployment (ETD) system which is designed to overcome the safety hazard caused by snags during tether deployment; [2] provide a platform for students to design and fly a variety of space-based experiments. For some time now the possibility of tether snags has been a formidable safety issue and obstacle to flying tethers on the Shuttle. Should a snag occur, the main worry is the possible rebound and contact of the tether (and the payload on the end of the tether) with the Shuttle in the first few seconds after deployment. Thus, validation of the ETD system by the ASTOR project is critical to future Shuttle/tether missions. ASTOR will be ejected from a Hitchhiker (HH) Canister in the Shuttle bay. After the payload is a safe distance from the Shuttle (about 1 km) the payload will automatically separate into two equal halves (See Fig. 1) and the Emergency Tether Deployment (ETD) system will commence the deployment of the tether. The ETD system will first deploy 500 meters of tether, which will be packaged as a safety Sock, followed by the controlled deployment of a 1.5 km long tether; then, a "snag" will be simulated (via thin wires connecting the tether to the spacecraft which must be broken by the momentum of the tether) before an additional 450 meters of tether, also packaged as a safety Sock, are deployed. The initial deployment demonstration will take approximately 24 hours, and the total duration of the mission will be 30 days, at which time the tether will be cut and the satellite will enter the atmosphere and burn up. ASTOR is being developed through a NASA SBIR Phase II contract; the scheduled development time is two years. A Shuttle flight in early 2001 to test out the concept has been proposed.

00-190 **A New Kind of Dynamic Instability in Electrodynamic Tethers**
0850am J. Pelaez, E. C. Lorenzini, O. Lopez-Rebollal, M. Ruiz

It is well known that electrodynamic, flexible tethers (even if) in equatorial orbits can have unstable equilibrium positions. This paper presents a new dynamic instability which appears in electrodynamic tethers, rigid or flexible, deployed in inclined orbits. A clear description of the destabilizing mechanism is reached by assuming a rigid tether with a mass at the end. The rigidity of the tether, however, is immaterial to this type of instability. The key point is the vertical component of the magnetic field, which has not been considered in previous analysis. This component gives origin to a strong coupling between the "in-plane" and the "out-of-plane" motions. When the current is greater than a critical value, energy is pumped continually into the system eventually producing a dynamic instability.

00-189 **Effect of Electromagnetic Forces on the Orbital Dynamics of Tethered Satellites**
0910am E.L.M. Lanoix, A.K. Misra, V.J. Modi, G. Tyc

Effect of electromagnetic forces on the orbital motion of tethered satellites is examined. It is observed that by appropriate variation of the current, the electromagnetic forces can be used to raise the orbit (electromagnetic propulsion) , or to lower the orbit (for junk removal). The paper presents detailed simulation results for both scenarios. A simple control law to arrest the growth of attitude motion during this operation is also suggested.

00-188 **A Two Bar Model for the Dynamics and Stability of Electrodynamic Tethers**
0930am J. Pelaez, M. Ruiz, O. Lopez-Rebollal, E.C. Lorenzini & M. L. Cosmo

The dynamics of a new class of electrodynamics tethers (ET) designed to yield a significant thrust - linked to high current in the wire - with light systems is analyzed. When an ET draws current continually in inclined orbits, a strong skip-rope motion develops. The tether rotates around the line of sight between the end masses, affecting the system performances and, for certain conditions, its overall dynamic stability. In summary, for currents above a critical value, energy is pumped continually into the system, which eventually becomes unstable. The paper investigates the influence of the tether dynamics on the system stability in two cases: a) the classical ET of a conductive wire connecting two end bodies, and b) the ET of ProSEDS. We use two articulated bars to describe the tether lateral dynamics and the electrodynamic forces involved. This model, although simple, leads to the formulation of a few general conclusions on the stability of ET systems.

0950am-1010am Coffee Break

00-191 **Preliminary Orbit Determination of a Tethered Satellite**
1010am C. Qualls and D. A. Cicci

Preliminary orbit determination methods require two or more position vectors and observation times to determine the initial orbital elements of a satellite. These standard methods cannot distinguish between untethered and tethered satellites, whose motion is affected by the tether force. Modifications have been made to five preliminary orbit determination methods: Lambert's, Herrick-Gibbs, f and g series, iteration on the true anomaly, and iteration on the parameter p, to allow for the identification of a tethered satellite. In addition to orbital elements, these modified methods calculate a modified gravitational parameter capable of distinguishing between a tethered satellite and an untethered one.

00-192 **The Space Anchor: A Tethered Drag Device to Enhance Orbit Capture**
1030am Chauncey Uphoff, Frank Janssens

This paper is a presentation of the dynamics of a tethered drag device that provides significant reduction or elimination of the propulsive impulse required for orbit insertion at a planet with a substantial atmosphere. The work is an extension of research carried out while one of the authors was at the Caltech Jet Propulsion Laboratory in the late 1970s in collaboration with Professor Colombo who was then Distinguished Visiting Professor to JPL. This paper contains the results of full model numerical simulation of the dynamics of a several kilometer tether with a tip mass or "cannonball" that holds the tether and/or drag device in the atmosphere of Mars long enough to remove a significant amount of the spacecraft's approach speed. Also included are the results of studies to evaluate the lateral stability, stress levels, and dynamics of the tether throughout the entire capture maneuver. Discussions of new, highly reliable, high-temperature tethers, now under development, are included in arguments that this technology is now sufficiently mature for use on real missions to Mars or Earth return.

00-194 **Use of Tethered Satellite Filtering Methods in Identifying Re-Entering Objects**
1050am A. Lovell, S. Cho, J. E. Cochran, Jr. and D. A. Cicci

The problem addressed in this paper is the design of an algorithm to identify objects in near-Earth orbit that have a high probability of re-entering the Earth's atmosphere. Such a method must be able to account for the fact that the object in question may be a tethered satellite. Thus it will incorporate a state estimation filtering method for tethered satellite systems. This filtering method will be used to determine the orbital path of the object being tracked. It must then be assessed whether or not the object is set to re-enter. Such an assessment may be incorrect if the algorithm is designed to identify only untethered satellites, and the object being tracked is one of a tethered pair. Indeed, even a method that utilizes a tethered satellite filtering technique may wrongly assess the situation if libration of the tethered pair is not included in the filter model. A successful re-entry identification methodology must take all of these factors into account. The resulting algorithm will be discussed and applied to several cases of tethered satellite observation.

00-195 **A Flexible Beam Supporting a Moving Rigid Body**
1110am S. Djerassi

The motion of a flexible beam supporting a rigid body is studied by means of numerical simulations. The underlying equations are generated with the aid of the following idea. The beam and the rigid body are temporarily regarded as undergoing an unconstrained motion. Motion equations of the unconstrained system are constraint equations, which take into account the fact that at any given time different points of the beam come into contact with points fixed to the rigid body, are formulated. The two sets of equations are combined to produce equations governing the motion of the constrained system. Parameters affecting the response of the system to the relative motion of the beam and the body are investigated in connection with the mobile transporter of the space station.

Session 14:	***Interplanetary Missions: Mars***
8:30am – 11:10am	**Heritage Room**
Chair:	**Calina Seybold**

00-196 **Mission Design for a Wright Brothers' Centennial Mars Airplane Mission in 2003**
0830am Paul A. Penzo

There are many ways to explore Mars. Orbiters and landers, with rovers, provide a global view, and limited surface access. Other ways include penetrators, probes, balloons, gliders, planes, sample returns and, of course, human explorers. We can expect most of these methods to be used in the future, and each does have a unique advantage. This paper presents the trajectory related aspects of a mission design for a low cost mission which will deliver an airplane (powered or unpowered) to Mars in 2003. Why planes? The reason is that they have the right characteristics for a low cost mission. For a science payload of as low as 1 kg, which could consist of several remote sensors as well as imaging, the plane can be very light weight, say 20-40 kg. Also, they can be designed and then tested in the upper atmosphere of the Earth. Once the plane is deployed, the Martian atmosphere can provide maneuverability, lift, temperature control, and stability. Also helpful is that lightweight glider and plane technology is an active field, pursued by Aerovironment, for example. At Mars, high-resolution imaging and spectral measurements can be made of the stratigraphic layers on slopes and canyon walls in close proximity for tens of kilometers. For the mission design performed here, flight time would be limited to 15-20 minutes during which time data would have to be returned to the carrier, and from there transmitted back to Earth. The remaining questions, discussed in detail in the paper, require optimizing the Earth-to-Mars trajectory to satisfy the complex arrival conditions. It is shown that only a 2-hour variation in arrival time at selected sites are possible, and that the plane or glider must be capable of an azimuth change once it is released from the carrier. Also, the analysis shows that a planned Mars orbiter cannot be easily used as a relay for the plane, whereas the carrier of the plane can be made to pass above the flight path in such a manner that it can receive data from the plane, and subsequently relay the data to Earth after it flies by Mars. By a rare coincidence, the optimum date for Mars arrival happens to be the 100th anniversary, to the day, of the Wright brothers Kitty Hawk flight.

00-197 **Mars Lander Entry Reconstruction: Methodology and Level of Confidence**
0850am Rick Pastor, Scott A. Striepe and Robert H. Bishop

For future Mars missions, ever stringent precision landing requirements necessitate fast verifiable navigation methods employing observations from all available sensors. This paper describes the results of verifying a multi-leveled solution methodology for reconstructing the current generation of Mars Entry Decent and Landing (EDL) direct entry trajectories. The test scenarios include simulated data from DSMC (direct simulation Monte Carlo) runs made with the LaRC AES (Atmospheric Entry Simulation) system. Solution methods include dead reckoning, batch, Kalman filtering and smoothing based on use of accelerometer, altimeter and radar data. Various observation "channels" that measure performance in the spatial, aerodynamic, atmospheric and instrument error domains are characterized. By tracking these observational channels, solution recovery levels of confidence can be based on the channels' sensitivities and performance to known error sources. State solution and channel performances to anticipated errors and to the presence of especially large dispersions (referred to as robustness cases) are discussed. For example, the ability to 'back-out' atmospheric and aerodynamic effects, while varying the dynamic and measurement errors, is presented.

00-198 **Mars Global Surveyor Azimuth Gimbal Anomaly: The Analysis of the Problem and Solution, and the Implementation**
0910am Joseph Neelon, Stuart Spath, and Wayne Sidney

The Mars Global Surveyor (MGS) experienced an operational anomaly in the High Gain Antenna (HGA) azimuth gimbal early in its nominal mapping phase. The initial remedy to this anomaly, Fixed HGA (FHGA) Operations, would not provide adequate data return performance during the second year of the MGS mapping phase. Alternate methods of operation that mimic the nominal HGA operations were investigated. The sole viable alternative, Beta Supplement Operations, does not satisfy all the science requirements for the second half of the MGS mission, but its shortcomings are complemented by limited use of FHGA Operations. A compromise was achieved by alternating between these operational modes to gain the benefits of each.

00-199 **Aerobraking Trajectory Options for the 2004 Mars Micro Mission Telecom Orbiter**
0930am Daniel T. Lyons

A small spacecraft bus is being developed to take advantage of the excess launch capacity of the Ariane 5 launch vehicle. The first such MicroMission option is a telecom orbiter mission to Mars. The telecom orbiter would be the first in a planned constellation of of relay spacecraft at Mars. The request for proposal to build the first spacecraft has been released, and the selection process is nearly complete. The Mars MicroMission concept has a tremendous cost leverage in that it flies "for free" as a piggyback payload on a launch of a geosynchronous communications spacecraft. The MicroMission spacecraft separates from the primary payload in a Geosynchronous Transfer Orbit, and must carry sufficient propellant for the remainder of the mission. Nearly two thirds of the total 222 kg launch mass is propellant. About 1500 m/s and several flybys of the Moon and Earth are required to inject the spacecraft on a trajectory to Mars. Another 900 m/s is required to capture the spacecraft into orbit at Mars. Aerobraking will be used to remove another 1200 m/s in order to shrink the orbit apoapsis from 60,000 km (2 day capture orbit) down to 800 km. A final 148 m/s propulsive maneuver is required to raise periapsis from the 100 km altitude required for aerobraking to achieve the final 800 km circular orbit. This paper will describe and contrast two of the aerobraking trajectories that have been investigated: a two-day capture orbit and a three-day capture orbit. Capturing into a larger period orbit saves about 33 m/s at Mars Orbit Insertion, but it increases the number of days and orbits that must be spent in the aerobraking phase. Solar perturbations are much more noticeable on the three day capture orbit, because the apoapsis is much further from the planet, and the geometry relative to the Sun at apoapsis results in a significant perturbation in the periapsis altitude. For the three day capture orbit, a maneuver to raise periapsis would be required every orbit to counteract the solar perturbation until the orbit period is reduced below about 40 hours.

0950am-1010am Coffee Break

00-200 **Earth Return Aerocapture of the TransHab Vehicle for a Manned Mars Mission**
1010am D. Muth, J. E. Lyne

NASA is currently considering the use of an inflatable habitat known as TransHab for the interplanetary portion of a future manned mission to Mars. Upon Earth return, the vehicle is to be inserted into a near circular low Earth orbit. This paper reports the results of a study of the Earth return aerocapture of the TransHab vehicle. Undershoot and overshoot boundaries have been determined for nominal atmospheric conditions, and the effects of simple atmospheric dispersions have been examined. A single roll maneuver was implemented in the overshoot aerocapture trajectory to target the desired orbit, and a sensitivity analysis was conducted to determine the effects on the final orbit of an error in the timing of the onset of the roll maneuver. The vehicle appears to have an adequately wide corridor for entries at speeds up to 14 km/s.

00-201 **Mars Polar Lander Navigation**
1030am P. D. Burkhart, V. Alwar, S. W. Demcak, P. B. Esposito, E. J. Graat

Mars Polar lander, launched on January 3, 1999, will arrive at Mars on December 3, 1999. This paper concentrates on the navigation required to meet the arrival criteria necessary to land at the desired landing site (195° west longitude and 76° south latitude) and simultaneously deliver two microprobes to Mars entry conditions. Results are presented for both interplanetary cruise and approach navigation. The approach navigation results using near-simultaneous tracking data collected from both Mars Polar Lander and Mars Global Surveyor and for Mars Polar Lander only are included.

Session 15:	***Control Applications***
8:30am – 11:10am	**Founders Room**
Chair:	**Don Mackison**

00-202 **Structured Adaptive Model Inversion Applied to Tracking Spacecraft Maneuvers**
0830am Kamesh Subbarao, Ajay Verma and John L. Junkins

In this paper, we introduce and demonstrate global stability and bounded tracking for a class of controllers designed using SAMI (Structured Adaptive Model Inversion), in the presence of bounded disturbances and model errors. The conventional Model Reference Adaptive Control (MRAC) approach is extended to the Structured MRAC approach, by imposing the condition that the kinematic subset of differential equations are exactly known, and all the learning is restricted to the acceleration differential equations. Dynamic Model Inversion is applied to solve for the controls explicitly and the adaptive structure is wrapped around this model inverse controller to account for the uncertainties in the system. The controller structure is designed, seeking to drive the error between the reference and the system states to zero with specified error dynamics, and we show that the closed loop system is globally stable. However no claim can be made with regards to convergence of the adaptation rates and parameters. The control law presented here realizes linear prescribed tracking error dynamics in the kinematic states' vector. The controller designed using SAMI enforces these desired kinematic states' error dynamics. The overall closed loop dynamics is non-linear in two respects: the non-linear plant itself and the non-linear adaptation process.

00-203 **Optimal Reorientation of a Multibody Spacecraft through Joint Motion using Averaging Theory**
0850am William Todd Cerven and Victoria Coverstone-Carroll

This paper addresses the problem of reorienting a multibody spacecraft using appendage joint motion alone. Averaging theory shows that small periodic actuation of such appendages results in a secular movement of the system in a direction independent of that of the control vectors. The secular variation is controllable through choice of control profiles. Using optimal control theory, an analytic control algorithm is developed for a four-link multibody system having zero angular momentum that minimizes the required control effort.

00-204 **Potential Uses of Solar Radiation Pressure in Satellite Formation Flight**
0910am Trevor Williams

One fundamental way in which satellite formation flight differs from conventional proximity operations is the extended mission lifetimes required. Consequently, long-term perturbation effects, and in particular the differential nodal regression rate caused by the oblateness of the Earth, must be corrected for. This paper considers a non-propulsive means of nulling this effect by means of the solar radiation pressure acting on a relatively small surface, termed here a *solar wing*, fixed to the satellite. Solar wings can be thought of as low-authority, extremely low frequency control actuators, or trim tabs, for the orbital formation flight problem.

00-205 **Accuracy of Costate Estimates by a Direct Transcription Method**
0930am Y. Hui, F. Fahroo, I. Mi. Ross

According to the Legendre pseudospectral method that directly solves optimal control problems, accurate costates can be obtained at the Legendre-Gauss-Lobatto (LGL) points by simply taking the multipliers of the nonlinear programming problem and dividing them by the corresponding LGL weights. In this paper, we investigate the accuracy of these costate estimates by way of a parallel-shooting algorithm. Numerical investigations reveal some interesting results leading to some new questions on the stability, accuracy and convergence of direct and indirect methods.

0950am-1010am Coffee Break

00-206 **Control Laws for Minimum Orbital Changes -- The Satellite Retrieval Problem**
1010am Timothy Cichan and Robert G. Melton

In the customary trajectory optimization problem, one seeks to minimize the time of flight or the propellant consumed; however, in situations where a liquid-propellant upper-stage has failed to burn completely, the optimization task is reversed. In such cases, the payload generally is not in the desired orbit and mission planners may deem it advisable to retrieve the payload for subsequent re-launch; however, safety concerns prohibit returning the payload and upper stage in the Shuttle cargo bay with liquid propellants still onboard. Generally, there is no means to vent the propellants and therefore, they must be consumed by re-igniting the engine. Assuming that the vehicle is presently in an orbit compatible with Shuttle operations, the thrust generated needs to be directed so as to minimize the changes in semi-major axis, eccentricity and inclination. This will help to ensure that the new orbit is essentially compatible with Shuttle retrieval capabilities. This paper will present numerical results for sample cases and compare them with the standard approach to this problem, which consists of a periodic variation in yaw angle σ in order to simply modulate the inclination about its initial value.

00-207 **Mitigating Multi-Path Error by Neural Network**
1030am Roberto V. F. Lopes; Valdemir Carrara; Werner Enderle and Christian Arbinger

This paper presents a neural network approach for calibration of multi-path delay in GPS-based spacecraft attitude determination. Mitigating the multi-path error represents an important step towards a precise and autonomous LEO spacecraft navigation and control. The Brazilian space activities in this direction are overviewed. Results are presented from digital simulation and compared with the performance of a similar algorithm based on series of spherical harmonics. The algorithm validation by a ground experiment at DLR is also addressed.

Author/Session Index

Notes

Record Of Meeting Expenses

AAS/AIAA Space Flight Mechanics Meeting
Belleview Biltmore Resort & Spa
Clearwater, Florida
January 23–26, 2000

Name: ____

Organization: ____

Registration Fee:	Member @ $175	__________
	Non-Member @ $200	__________
	Student @ $25	__________
	Non-Member @ $260 *(this rate includes 1 year membership in AAS, including renewals)	__________
Conference Proceedings @ $160		__________
Mystery Dinner Theater @ $35		__________
	TOTAL	__________

Technical Paper Purchases:	**No. Papers**	**Cost**	**Date**
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