Conference Program

18th AAS/AIAA SPACE FLIGHT MECHANICS MEETING

Galveston, Texas

AAS General Chair
Dr. Thomas Eller
Astro USA, LLC

AIAA General Chair
Frederic Pelletier
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Table of Contents

Table of Contents 1
General Information 2
  Registration 2
    Fee Schedule 2
Maps and Directions 3
Area Attractions 4
  Parks 4
  Historic Districts 4
  Museums 4
  Dining 4
  Mardi Gras Festival 4
Special Events 5
  Lunar Mission Design Workshop 5
  Early-Bird Reception 5
  Brouwer Award Lecture and Banquet 5
  Space Center Houston Tour, Awards Dinner, and Social 5
  Plenary Meeting on JAS Online Software 5
  Byron Tapley Symposium (Austin, Texas) 5
Schedule of Events 6
  Technical Sessions 8
  Special Sessions 8
  Speaker Orientation 8
  Presentations 8
  Preprint Manuscripts 8
  Conference Proceedings 9
  Volunteers 9
  Satisfaction Survey 9
  Committee Meetings 9
  Conference Center Floor Plans 10
Technical Program 11
Author Index 53
2008 Winter Conference Survey 55
Record of Meeting Expenses 57
Conference Planner 58

General Information

Welcome to the 2008 Space Flight Mechanics Meeting, hosted by the American Astronautical Society (AAS) and co-hosted by American Institute of Aeronautics and Astronautics (AIAA), January 27-31, 2008. This meeting is organized by the AAS Space Flight Mechanics Committee and the AIAA Astrodynamics Technical Committee, and held in the San Luis Resort Spa and Conference Center, at 5222 Seawall Boulevard, off the coast of the Gulf of Mexico in historic Galveston, Texas 77551. Phone 409-744-1500, email info@sanluisresort.com.

Detailed conference information is maintained at

http://www.space-flight.org/AAS_meetings/2008_winter/Galveston2008/Home.html

Registration

Online registration is highly recommended before the conference, as it is the only way registrants may gain access to preprint technical manuscripts. For those who have not pre-registered online, on-site registration and payment will be available for conference events that have not yet sold out. On-site payment by credit card (MasterCard, Visa, American Express, Discover) will be through the online registration system using a computer at the registration table. The other form of payment accepted on-site is a check, payable to the "American Astronautical Society".

Fee Schedule

AAS or AIAA Members	$410
Nonmembers (includes one year membership in the AAS)	$495
Full-time Students (present student credentials at check-in)	$100
Retired Professionals	$100
Late Fee (after Jan 7, 2008)	$25

Lunar Mission Design Workshop	*Sunday Jan. 27*	$150
Early Bird Reception	*Sunday Jan. 27*	Included ($30 per guest)
Brouwer Award Ceremony	*Monday Jan. 28*	Included ($30 per guest)
Space Center Houston Social	*Tuesday Jan. 29*	$50

A conference registration and check-in table will be located in the vicinity of the 2nd floor elevator lobby and Conference Lounge, and staffed according to the following schedule:

Sunday January 27	9:00 AM*	4:00 PM – 7:00 PM
Monday January 28	7:45 AM – 11:45 AM	1:30 PM – 3:30 PM
Tuesday January 29	7:45 AM – 11:45 AM	1:30 PM – 3:30 PM
Wednesday January 30	7:45 AM – 11:45 AM	1:30 PM – 3:30 PM
Thursday January 31	7:45 AM – 9:45 AM	

*Lunar Mission Design Workshop registrants report directly to *Tarpon* on the 1st floor.

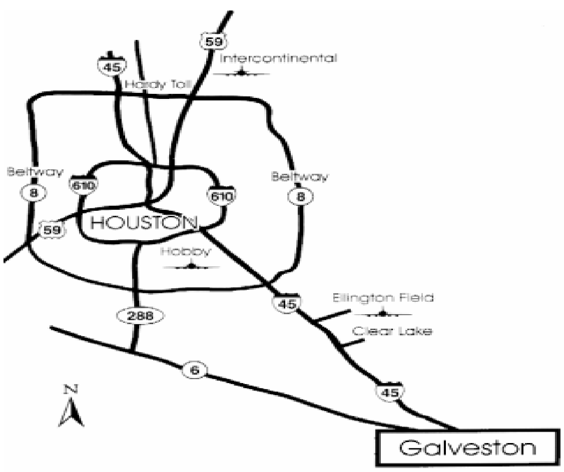
Maps and Directions

Directions from George Bush Intercontinental Airport (IAH) to Galveston:

Begin on Terminal Rd S and go east for 0.6 miles. Bear left and go southeast for 300 feet. Turn left on Greens Rd and go east for 2.4 miles. Turn right on Eastex Fwy, US-59, US-59 N and go south for 0.6 miles. Bear left on ramp and go south for 1000 feet. Continue on Eastex Fwy, US-59 and go south for 14 miles. Bear right on ramp at sign reading "I-45 to Galveston / Dallas" and go south for 0.6 miles. Continue on I-45 and go southeast for 45 miles to Galveston Island.

Directions from William P. Hobby Airport (HOU) to Galveston:

Begin on Lockheed Ave and go north for 0.2 miles. Turn left on Convair St and go west for 200 feet. Turn right on Telephone Rd, TX-35 and go north for 0.3 miles. Turn right on Airport Blvd and go east for 2.4 miles. Turn right on Gulf Fwy and go southeast for 0.6 miles. Continue on ramp at sign reading "I-45 S" and go southeast for 0.3 miles. Continue on I-45 and go southeast for 35 miles to Galveston Island.



Directions to the San Luis from Mainland:

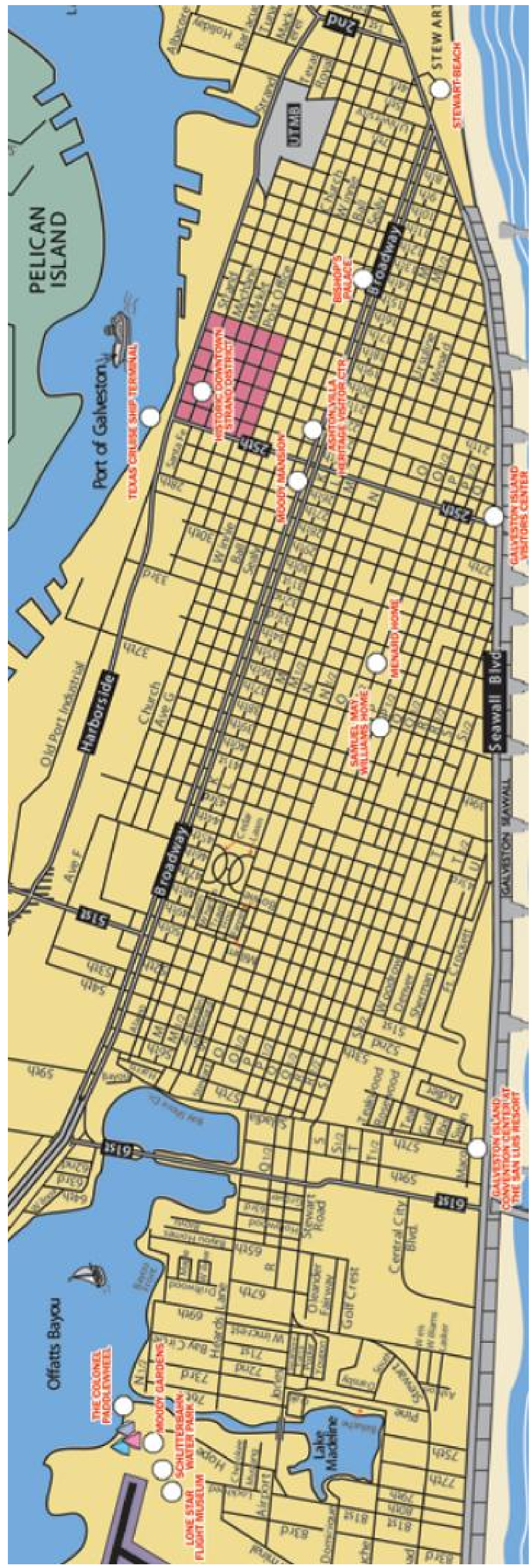
From I-45, take exit 1A toward Municipal Airport/TX-342-SPUR/W Beach/61st St. merging onto Broadway St/Ave J for 0.5 miles. Turn right at 61st St and travel south for 1.7 miles. Turn left at Seawall Blvd and travel 0.5 mi. The San Luis is on the left, past the Mary Moody Northern Blvd traffic light.

Shuttles:

Information regarding transportation to and from Houston airports may be found at:

http://transportation.destinationnext.com/

http://www.jflylimos.com/home/default.asp



Area Attractions

New to the Island? If so, then first, get oriented with a trip to one of the two Galveston Island Visitors Centers. If you envision more of a beach playday, the 2027 61st Street Visitors Center is for you. If you're thinking you want to explore Galveston's historic shopping and arts district, head to the 2215 Strand Visitors Center. Both locations offer a wealth of brochures, free maps of the Island, and friendly guides.

Parks

Two top destinations for Galveston visitors are the 242-acre Moody Gardens, and the newly-opened Schlitterbahn Galveston Island Waterpark. Part theme park, part educational and rehabilitative facility, part pleasure garden, Moody Gardens is a vacation all by itself, and Schlitterbahn is the first waterpark of its kind that is open year-round!

Historic Districts

The best way to connect to Galveston's past is by an excursion through one of its historic districts, or a tour of one of the historic homes that are open to the public. Stroll through the 36-square-block area of downtown Galveston, exploring the enticing shops on The Strand Historic District downtown, the waterfront district with docks for cruise lines, and the trendy Postoffice Street Arts District. Pick up one of Galveston Historical Foundation's excellent brochures. For a self-guided walking or driving tour of the East End Historical District (east of 19th Street) or the Silk Stocking District (from 23rd to 26th streets, between Avenues K and P).

Museums

Museum's abound, whether you fancy land, sea, or air - from the art deco Railroad Museum at the foot of The Strand, to the Ocean Star Offshore Drilling Rig and Museum on Pier 20, to the Lone Star Flight Museum (next to Moody Gardens-discount available by presenting your conference nametag), the Mardi Gras Museum, the Texas Seaport Museum on Pier 21 featuring the tall ship Elissa, and the Galveston County Historical Museum round out the Island's collection.

Dining

Dining is a Galveston highpoint. The specialty is fresh-cooked, fresh-caught Gulf Coast cuisine - available both in traditional and nouvelle settings - but you'll find restaurants for every mood and palate, from upscale continental, to hip fusion, to authentic Tex-Mex, to down-home barbecue.

Mardi Gras Festival

January 25 through February 5, 2008

The 18th Space Flight Mechanics Meeting runs concurrently with the 97th Mardi Gras Galveston Festival. More than 250,000 people visit Galveston during this week to participate in activities to numerous to list here! Please visit http://www.mardigrasgalveston.com for details.

Galveston Orientation for Spouses

Monday January 28, at 8:30 AM – 10:00 AM
Includes a light breakfast, in the *Seafarer Room*

Special Events

Lunar Mission Design Workshop

Sunday January 27, 10:00 AM

The Lunar Mission Design Workshop provides a unique training opportunity by leading experts in a hands-on environment. Workshop instructors are John Carrico of Applied Defense Solutions, Dave Folta of NASA Goddard Space Flight Center, and Jim Woodburn of Analytical Graphics Inc. *Pre-registration required*. Check-in and refreshments begin at 9:00 AM in the *Tarpon Room*, 1^{st} floor.

Early-Bird Reception

Sunday January 27, 7:00 PM

Join friends and colleagues for drinks and hors d'oeuvres at the Early-Bird Reception at the 2^{nd} floor Conference Lounge. This lounge has been specially reserved for the use of our registrants, and has two billiard tables, a shuffleboard table and electronic dartboards. Pre-paid reception tickets can be picked up at the conference check-in table starting at 4:00 PM.

Brouwer Award Lecture and Banquet

Monday January 28, 6:00 PM

Bernard Kaufman will provide banquet attendees gathered in his honor with a mealtime presentation. Cocktails will start at 6:00 PM, and dinner will follow at 6:45 PM, in the Grand Ballroom A/B on the 3^{rd} floor of the conference center.

Space Center Houston Tour, Awards Dinner, and Social

Tuesday January 29, promptly departing at 4:00 PM

Adjacent to Johnson Space Center, Space Center Houston is the Official Visitors Center of NASA's Johnson Space Center (JSC) and features a gift shop, theatres, and galleries in a modern museum environment. Guests will enjoy a one-hour tour of JSC by tram before cocktails, followed by a catered formal dinner in the Stargazer Gallery where the recipients of the Breakwell Student Travel Award and Best Paper Awards for the 2006 ASC (Keystone) and 2007 SFMM (Sedona) will be announced. The festivities conclude with a guest presentation from Dr. Wendell W. Mendell, JSC's own distinguished planetary scientist.

Chartered buses promptly depart at 4:00 PM from the 1^{st} floor lobby area in the rear of hotel, and return to the hotel following the event.

Plenary Meeting on JAS Online Software

Wednesday January 30, 5:00 PM

Dr. David B. Spencer will present a short workshop to solicit feedback on the long-anticipated on-line software the AAS is developing for the Journal of the Astronautical Sciences. All are invited.

Byron Tapley Symposium (Austin, Texas)

Friday February 1

A separate, one-day symposium, sponsored by the University of Texas at Austin Cockrell School of Engineering and the American Astronautical Society (AAS), will be held in Austin, Texas, to recognize 50 years of distinguished contributions by Dr. Tapley. A banquet will follow and a bound volume of peer-reviewed papers will be produced. Visit http://www.csr.utexas.edu/symposium/ for more information.

Schedule of Events

Date and Time	***Event***	***Location***
Sunday, January 27		
9:00 AM – 6:00 PM	Lunar Mission Design Workshop	*Tarpon*
4:00 PM – 7:00 PM	Check-in / Registration	2nd Floor Lobby
7:00 PM – 8:30 PM	Early-Bird Reception	2nd Floor Conference Lounge
Monday, January 28		
7:00 AM – 7:45 AM	Speaker Orientation	*Windjammer*
7:45 AM – 11:45 AM	Check-in / Registration	2nd Floor Lobby
8:00 AM – 9:40 AM	Special Session: Lunar Missions and Analyses	*Elissa*
8:00 AM – 9:40 AM	Spacecraft GNC I	*East Mainsail*
8:00 AM – 9:40 AM	Optimal Control	*West Mainsail*
8:30 AM – 10:00 AM	**Spouses Orientation**	***Seafarer***
9:40 AM – 10:05 AM	Morning Break	2nd Floor Lobby
10:05 AM – 11:45 AM	Special Session: Lunar Missions and Analyses	*Elissa*
10:05 AM – 11:45 AM	Spacecraft GNC I	*East Mainsail*
10:05 AM – 11:45 AM	Optimal Control	*West Mainsail*
Noon – 1:30 PM	AAS Space Flight Mechanics Committee Meeting	*Windjammer*
1:30 PM – 3:30 PM	Check-in / Registration	2nd Floor Lobby
1:30 PM – 3:10 PM	Orbital Debris & Chinese Anti-Satellite	*Elissa*
1:30 PM – 3:10 PM	Attitude Dynamics, Determination & Control I	*East Mainsail*
1:30 PM – 3:10 PM	Formation Flying & Rendezvous I	*West Mainsail*
3:10 PM – 3:35 PM	Afternoon Break	2nd Floor Lobby
3:35 PM – 5:15 PM	Orbital Debris & Chinese Anti-Satellite	*Elissa*
3:35 PM – 5:15 PM	Attitude Dynamics, Determination & Control I	*East Mainsail*
3:35 PM – 5:15 PM	Formation Flying & Rendezvous I	*West Mainsail*
6:00 PM – 8:30 PM	**Brouwer Lecture and Banquet**	***Grand Ballroom A/B***
Tuesday, January 29		
7:00 AM – 7:45 AM	Speaker Orientation	*Windjammer*
7:45 AM – 11:45 AM	Check-in / Registration	2nd Floor Lobby
8:00 AM – 9:40 AM	Tethers	*Elissa*
8:00 AM – 9:40 AM	Orbit Determination	*East Mainsail*
8:00 AM – 9:40 AM	Spacecraft GNC II	*West Mainsail*
9:40 AM – 10:05 AM	Morning Break	2nd Floor Lobby
10:05 AM – 11:45 AM	Tethers	*Elissa*
10:05 AM – 11:45 AM	Orbit Determination	*East Mainsail*
10:05 AM – 11:45 AM	Spacecraft GNC II	*West Mainsail*

Noon – 1:30 PM	AIAA Astrodynamics Technical Committee Meeting	*Windjammer*
1:30 PM – 3:30 PM	Check-in / Registration	2nd Floor Lobby
1:30 PM – 3:35 PM	Solar System Missions	*Elissa*
1:30 PM – 3:35 PM	Earth & Planetary Mission Science	*East Mainsail*
1:30 PM – 3:35 PM	Dynamical Theory of Space Flight Problems	*West Mainsail*
4:00 PM – 9:30 PM	**Space Center Houston Dinner Social**	**Departing 1st Floor Rear Lobby**
Wednesday, January 30		
7:00 AM – 7:45 AM	Speaker Orientation	*Windjammer*
7:45 AM – 11:45 AM	Check-in / Registration	2nd Floor Lobby
8:00 AM – 9:40 AM	Satellite Constellations	*Elissa*
8:00 AM – 9:40 AM	Trajectory Design & Optimization I	*East Mainsail*
8:00 AM – 9:40 AM	Orbital Dynamics, Perturbations & Stability I	*West Mainsail*
9:40 AM – 10:05 AM	Morning Break	2nd Floor Lobby
10:05 AM – 11:45 AM	Satellite Constellations	*Elissa*
10:05 AM – 11:45 AM	Trajectory Design & Optimization I	*East Mainsail*
10:05 AM – 11:45 AM	Orbital Dynamics, Perturbations & Stability I	*West Mainsail*
Noon – 1:30 PM	Joint AAS SFMC / AIAA TC Meeting	*Windjammer*
1:30 PM – 3:30 PM	Check-in / Registration	2nd Floor Lobby
1:30 PM – 3:10 PM	Formation Flying & Rendezvous II	*Elissa*
1:30 PM – 3:10 PM	Attitude Dynamics, Determination & Control II	*East Mainsail*
1:30 PM – 3:10 PM	Special Session: USA Space History	*West Mainsail*
3:10 PM – 3:35 PM	Afternoon Break	2nd Floor Lobby
3:35 PM – 4:50 PM	Formation Flying & Rendezvous II	*Elissa*
3:35 PM – 4:50 PM	Attitude Dynamics, Determination & Control II	*East Mainsail*
3:35 PM – 4:50 PM	Special Session: USA Space History	*West Mainsail*
5:00 PM – 6:00 PM	Plenary Meeting on JAS Software	*West Mainsail*
Thursday, January 31		
7:00 AM – 7:45 AM	Speaker Orientation	*Windjammer*
7:45 AM – 9:45 AM	Check-in / Registration	2nd Floor Lobby
8:00 AM – 9:40 AM	Orbital Dynamics, Perturbations & Stability II	*Elissa*
8:00 AM – 9:40 AM	Spacecraft GNC III	*East Mainsail*
8:00 AM – 9:40 AM	Trajectory Design & Optimization II	*West Mainsail*
9:40 AM – 10:05 AM	Morning Break	2nd Floor Lobby
10:05 AM – 11:45 AM	Orbital Dynamics, Perturbations & Stability II	*Elissa*
10:05 AM – 11:45 AM	Spacecraft GNC III	*East Mainsail*
10:05 AM – 11:45 AM	Trajectory Design & Optimization II	*West Mainsail*

Technical Sessions

This conference presents over 140 professional papers on space-flight mechanics, astrodynamics, and related topics, during 21 sessions (including two special sessions). Three sessions run in parallel each morning and afternoon, excluding Sunday and Thursday afternoon. Morning sessions start as soon as 8:00 AM and end by 11:45 AM. Afternoon sessions start at soon as 1:30 PM after an extended lunch break. Afternoon sessions end by 4:50 PM on Monday and by 3:35 PM on Tuesday. On Wednesday evening, a special plenary meeting has been scheduled following the regular sessions until 6:00 PM.

Sessions breaks are 25 minutes each morning at 9:40 AM and each afternoon at 3:10 PM (except Tuesday afternoon). The General Chairmen have arranged for extended food and beverage service each morning and afternoon beyond the usual break times for the convenience of attendees. Sessions are held in three meeting rooms within the conference center building: Elissa, East Mainsail, and West Mainsail. See the facilities floor plans for their locations within the conference center relative to other meeting rooms.

Special Sessions

The **Lunar Missions and Analyses** Session 1 will be held Monday morning at *Elissa*.

The **USA Space History** Session 18 will be held Wednesday afternoon at *West Mainsail*.

Speaker Orientation

On the day of their sessions, authors making presentations meet with their session chairs in the *Windjammer* room promptly at 7:00 AM. A continental breakfast will be served. Speaker attendance is mandatory.

Presentations

Each presentation is limited to twenty (20) minutes. An additional five minutes is allotted between presentations for audience participation and transition. Session chairs shall maintain the posted schedule so that attendees are able to predictably move between parallel sessions.

Each room is equipped with a microphone, a laser pointer, an electrical outlet, and a video projector that can be driven by a computer. Presenters shall coordinate with their Session Chairs regarding the computing equipment, software, and media requirements for the session; however, *each presenter is ultimately responsibility for having the necessary computer and software available to drive the presentation*. Microsoft Powerpoint and PDF are the most common formats.

A "No-Paper, No-Podium" Policy is in effect. Completed manuscripts shall be electronically uploaded to the submission site prior to the conference, be no more than twenty (20) pages in length, and conform to the AAS conference paper format. If the completed manuscript is not contributed on time, then there shall be no conference presentation; if there is no conference presentation by an author, then the contributed manuscript shall be withdrawn.

Preprint Manuscripts

Physical copies of preprinted manuscripts are no longer available or required for the Space Flight Mechanics Meetings or the Astrodynamic Specialist Conferences. Electronic preprints are available for download at least 72 hours prior to the conference at https://events.pxi.com/aas/reg/ for registrants who use the online registration system. The hotel provides conference guests with free wireless internet access in lodging areas only (outside the meeting areas). Registrants without an internet-capable portable computer, or those desiring traditional paper copies, should download and print preprint manuscripts before arriving at the conference.

Conference Proceedings

Registration includes the delivery of an electronic CD-ROM version of the conference proceedings by mail after the conference. The AAS conferences also publish bound sets of printed proceedings for personal, institutional, and library usage. Multi-volume, hardbound printed proceedings are available at a reduced pre-publication price of $190 per set for orders placed before and during the conference. Orders are accepted at the conference registration table.

Although the availability of hardcopy proceedings enhances the longevity of your work and elevates the importance of your conference contribution, please note that conference proceedings are not considered an archival publication. Authors are encouraged to submit their manuscripts after the meeting to one of the relevant journals, such as:

Journal of the Astronautical Sciences

Kathleen C. Howell, Editor
School of Aeronautics and Astronautics
1282 Grissom Hall
Purdue University
West Lafayette, IN 47907
(765) 494-5786
howell@ecn.purdue.edu

Journal of Guidance, Control and Dynamics
or
Journal of Spacecraft and Rockets

Manuscripts can be submitted via:

http://www.writetrack.net/aiaa/

Volunteers

Volunteers to staff the registration table may sign-up at the registration table.

Satisfaction Survey

Registrants are highly encouraged to record their level of satisfaction and conference preferences in an anonymous survey taken throughout the time of the conference. Please return the survey form included in this program to the registration table before departing from the conference.

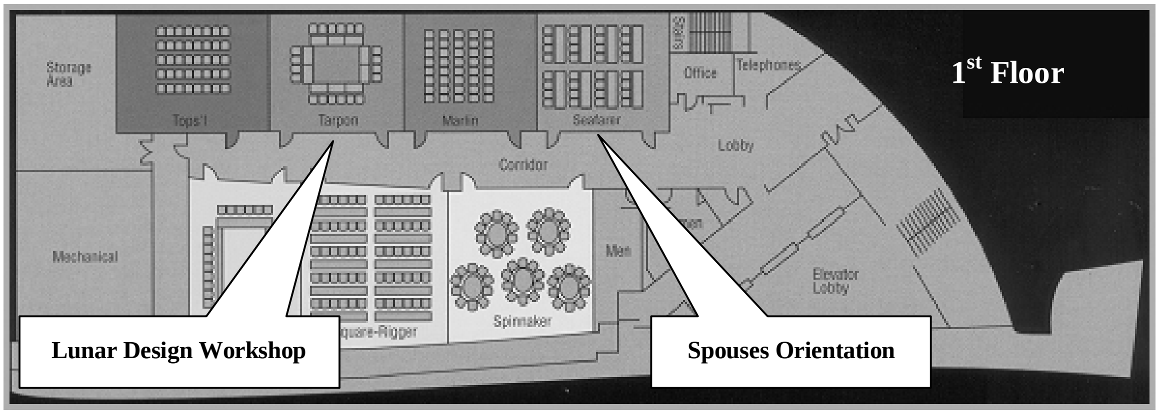
Committee Meetings

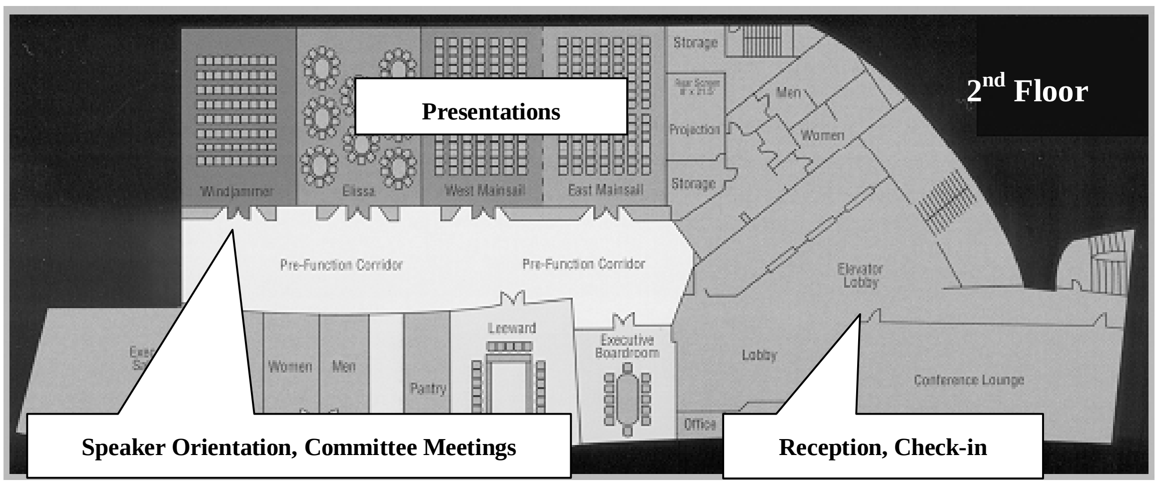
Committee seating is limited to committee members and invited guests. Committee meetings will be held according to the following schedule in the *Windjammer* room:

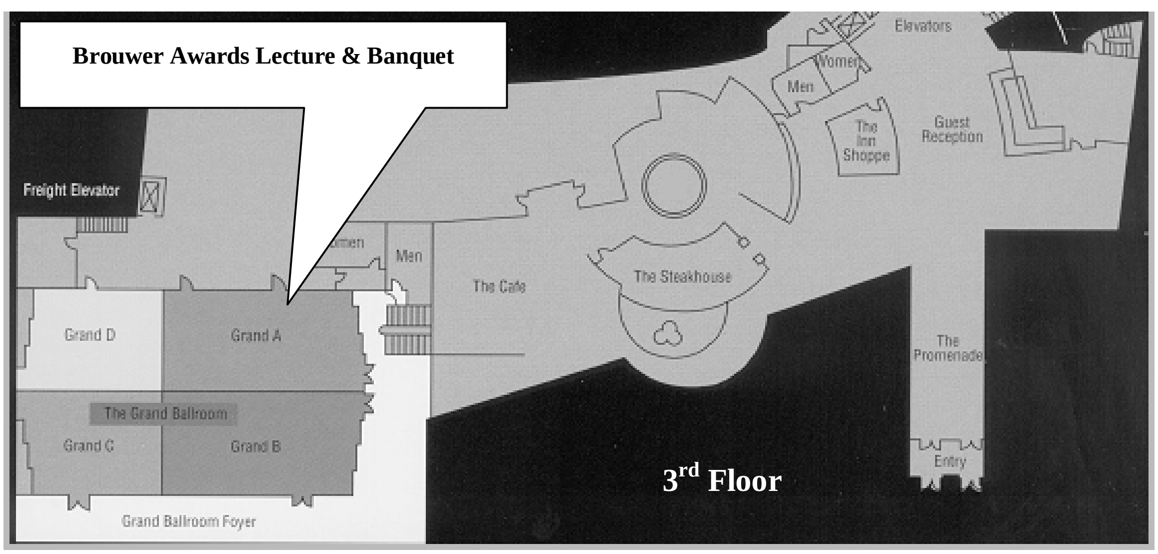
AAS Space Flight Mechanics	*Monday Jan. 28*	Noon – 1:30 PM
AIAA Astrodynamics TC	*Tuesday, Jan. 29*	Noon – 1:30 PM
Joint AAS/AIAA TC	*Wednesday, Jan. 30*	Noon – 1:30 PM

Conference Center Floor Plans

The conference events will be held on the first, second, and third floors of the San Luis Conference Center. The general location of planned events can be found on the following floor plans.







Technical Program

Monday, Jan 28, 2008 Elissa

Session 1: Special Session: Lunar Missions and Analyses

Chair: Dr. James Woodburn, AGI

08:00 **AAS 08 - 100** **Linear Covariance Analysis Techniques Applied to Orion Cislunar Operations**
Christopher D'Souza, NASA Johnson Space Center; Fred Clark, C.S. Draper Laboratory

The Orion vehicle is being designed to provide nominal crew transport to the lunar transportation stack in low Earth orbit, crew abort prior during transit to the moon, and crew return to Earth once lunar orbit is achieved. Design of guidance and navigation algorithms to perform maneuvers in support of these functions is dependent on the support provided by navigation infrastructure, the performance of the onboard GN&C system, and the choice of trajectory maneuver methodology for outbound and return mission phases. This paper presents the first use of linear covariance to investigate the guidance and navigation performance of the Orion vehicle during the cislunar phase.

08:25 **AAS 08 - 101** **Performance of an Automated Feature Tracking Lunar Navigation System**
Michael Osenar, U..S. Air Force; Fred Clark, C.S. Draper Laboratory; Christopher D'Souza, NASA Johnson Space Center

This paper describes the performance of an automated lunar feature tracking navigation system that could be used by the Orion lunar missions. The Orion vehicle will have a high resolution digital camera. It is anticipated that it will have an automated lunar landmark-based navigation system. The performance of this automated lunar landmark system has been investigated using linear covariance techniques. This paper will investigate not only the performance of a digital camera-based onboard autonomous navigation system, but it will also present the sensitivity of the state estimate to various types of cameras.

08:50 **AAS 08 - 102** **A Lunar Relay Mission Design and Navigation Initiative Using Existing NASA Resources**
David C. Folta, Michael A. Mesarch, and Ronald Miller, NASA Goddard Space Flight Center

The Space Communications and Navigation Constellation Integration Project (SCIP) is tasked with defining, developing, deploying and operating an evolving multi-decade communications and navigation infrastructure including services and subsystems that willsupport both robotic and human exploration activities at the moon. This paper discusses a proposed idea for an early demonstration of lunar relay orbits using the existing WIND spacecraft. The WIND spacecraft was placed into a Sun-Earth co-linear L1 libration point orbit that will be maintained for the foreseeable future. This paper describes an inexpensive WIND mission extension to investigate lunar orbits to support the Vision for Space Exploration (VSE) goals and validate lunar initiative research.

09:15 **AAS 08 - 103** **Orbit Determination of Satellites in Lunar Orbit Using an Optimal Sequential Filter**

James Woodburn and John H. Seago, Analytical Graphics, Inc.

Determination of orbits about the moon poses a number of challenges on top of those presented by Earth orbiting satellites. Most problematic for sequential estimation is the uncertainty in the dynamical environment. We present an a description of the deterministic and stochastic upgrades that were made to the Orbit Determination Tool Kit in pursuit of this goal. We present results for the processing of tracking data for Lunar Prospector over a one month period and STEREO during the lunar fly-by portion of the mission. Finally, we will discuss the expected improvement from SELENE derived gravity fields.

09:40 **Break**

10:05 **AAS 08 - 104** **Surface Feature Navigation in Low Lunar Orbit**

Brandon A. Jones, University of Colorado at Boulder

With the planned return of humans to the moon, demands on autonomous navigation in lunar orbit have increased. Given the relatively unknown lunar gravity field, the prediction accuracy of a ground determined orbiter state may not meet mission safety requirements. Results of a preliminary study to determine improvements using visual navigation and tracking lunar surface features from low lunar orbit are presented. Given crater lumination and location, requirements for minimum tracked surface feature size were studied. Assuming these requirements, the benefits of relative bearing measurements between the feature and the orbiter were characterized.

10:30 **AAS 08 - 105** **Optical Navigation for the Orion Vehicle**

Joel Getchius, Engineering Services Contract Group; Timothy Crain and Christopher D'Souza, NASA Johnson Space Center

The Orion vehicle is being designed to provide nominal crew transport to the lunar transportation stack in low Earth orbit, crew abort prior during transit to the moon, and crew return to Earth once lunar orbit is achieved. One of the design requirements levied on the Orion vehicle is the ability to return to the vehicle and crew to Earth in the case of loss of communications and command with the Mission Control Center. Central to fulfilling this requirement, is the ability of Orion to navigate autonomously. In low-Earth orbit, this may be solved with the use of GPS, but in cis-lunar and lunar orbit this requires optical navigation. This paper documents the preliminary analyses performed by members of the Orion Orbit GN&C System team

10:55 **AAS 08 - 106** **KAGUYA (SELENE) Trajectory Reconfiguration Plans Prepared for Anomaly in Translunar Phase**

Yasuhiro Kawakatsu, Japan Aerospace Exploration Agency

Reported in this paper are two contingency plans prepared for a Japanese Lunar explorer KAGUYA for the case that the Lunar orbit injection maneuver is not performed normally. The first case is that, it turns out prior to the Lunar orbit injection that the main engine is unable to be used. The second case is that, a certain anomaly prevents the execution of the Lunar orbit injection maneuver and KAGUYA once flies by the Moon. Not only the result of the reconfigured trajectory, but also the process of the trajectory design is to be shown in the paper.

11:20 **AAS 08 - 107** **The Lunar Slingshot -- An Electrically Powered Launcher**
Ronald M. Muller, Perot Systems Government Services

A design of an electrically driven reusable Lunar Slingshot capable of sending a 1000 kg payload to a Sun-Earth or Earth-Moon Lagrange point is presented. It would be located at the highest point near a pole. It consists of an electric motor with a vertical shaft that carries a cantilevered horizontal boom. The boom carries a reel of cable with the payload on its free end. The motor rotates the boom at a constant rate as the cable is paid out. The payload is released when at the right point in the rotation to send it on its desired trajectory.

Session 2: Spacecraft Guidance, Navigation & Control I

Chair: Dr. Don Mackison, University of Colorado

08:00 **AAS 08 - 108** **Space Station Zero Propellant Maneuver Flight Results Compared to Eigenaxis**
Naz Bedrossian and Sagar Bhatt, The Charles Stark Draper Laboratory, Inc.

This paper presents flight results for the Zero Propellant Maneuver (ZPM) control concept and compares ZPM trajectories to eigenaxis trajectories. The first-ever ZPM, which rotated the International Space Station (ISS) 90 degrees without using propellant, was performed on November 5, 2006. On March 3, 2007, another ZPM rotated the ISS 180 degrees, also without any propellant use. The same maneuvers performed with thrusters would have consumed an estimated 150lbs of propellant. A ZPM is a pre-planned time-sequenced attitude command trajectory to transition the ISS between specified initial and final states while maintaining the CMGs within their operational limits.

08:25 **AAS 08 - 109** **A Stable Clock Error Model Using Coupled First- and Second-Order Gauss-Markov Processes**
Russell Carpenter, NASA Goddard Space Flight Center; Taesul Lee a.i. solutions, Inc.

Long data outages may occur in applications of GPS orbit determination to missions that spend significant fractions of their orbits above the GPS constellation. Current clock error models based on the random walk idealization may not be suitable in these circumstances, since the covariance of the clock errors may become large enough to overflow flight computer arithmetic. A model that is stable, but which approximates the existing models over short time horizons is desirable. A coupled first- and second-order Gauss-Markov process is such a model.

08:50 **AAS 08 - 110** **Adaptive Measurement Covariance for Multi-input Kalman Filter-based Spacecraft Navigation**
Kevin K. Choi and Blair F. Thompson, Odyssey Space Research, LLC

Stringent safety and redundancy standards for spacecraft operation are satisfied, in part, by the use of multiple, simultaneous Global Positioning System (GPS) and Inertial Measurement Unit (IMU) sensors. The adaptive measurement covariance model proposed in this paper evaluates the quality of the input data by comparing it with the predicted state of the filter, and then adaptively adjusting the measurement covariance for each sensor. This strategy will serve as a bridge between Fault Detection and Isolation (FDI) and the Kalman filter; it is designed to increase the reliability of the Kalman filter-based algorithm by smoothing unexpected outliers or biases.

09:15 **AAS 08 - 111** **Lorentz Augmented Orbit Control Via Bang-bang Control Over a Partitioned Space**
Brett Streetman and Mason A. Peck, Cornell University

Orbit control by Lorentz Augmented Orbits (LAO) is examined. A spacecraft carrying an electrostatic charge moves through the geomagnetic field. The resulting Lorentz force is used to evolve the spacecraft's orbit. A high-order spherical harmonic expansion is used to model the magnetosphere. The space of longitude and latitude is partitioned in a physically meaningful way, based on the harmonic expansion. Within any given partition, orbital elements evolve only in a single direction under a constant spacecraft charge. A bang-bang controller is implemented with switching only at partition boundaries. Control sequences are developed to produce arbitrary maneuvers.

09:40 **Break**

10:05 **AAS 08 - 112** **Advanced Guidance Algorithms for the Ares V Crew Launch Vehicle**
Shelly Su and Craig Kluever, University of Missouri-Columbia

This paper presents the development of advanced guidance algorithms for the Ares V Crew Launch Vehicle. The guidance method is based on optimal control theory with interior state constraints and uses a predictor-corrector scheme. Heating-rate constraints and discontinuous events (such as escape-tower jettison during vacuum flight) are included in the guidance formulation. Numerical ascent guidance solutions are computed using an iterative technique, and these results are compared to the corresponding optimal ascent trajectories which are calculated by using parameter optimization methods such as OTIS.

10:30 **AAS 08 - 113** **Execution-Error Modeling and Analysis of the Cassini-Huygens Spacecraft Through 2007**
Sean V. Wagner and Troy D. Goodson, Jet Propulsion Laboratory

The Cassini-Huygens spacecraft arrived at Saturn in 2004, beginning a four-year tour. The Saturn tour has been extended by two years, a testament to the continued success of the mission. One contributor to this success has been the excellent performance of the spacecraft's propulsion systems and attitude control. In order to better understand this performance, the Cassini Navigation Team has analyzed and refined the Gates execution-error models of the propulsion systems. This paper documents the evolution of the execution-error models that have been employed for Cassini maneuvers, along with the analysis and software associated with the development of these models.

10:55 **AAS 08 - 114** **Feedback Control Methods to Prevent Unstart in a Hypersonic Inlet**
John Hatlelid and Maruthi Akella, University of Texas at Austin

Air breathing scramjet engines present unique opportunities for use as reusable launch vehicles. Inlet unstart is a complex dynamical phenomenon in which the shock structure in an air breathing inlet is displaced by flow disturbances, both upstream and downstream of the inlet, ultimately causing the shock structure to be expelled from the inlet. Using singular perturbation techniques, we derive a model for oblique shock wave dynamics. We validate this model by comparing with real experimental data obtained in a hypersonic windtunnel. We also derive novel feedback control techniques using the model that provide rigorous assurances of unstart prevention.

11:20 **AAS 08 - 115** **Guidance Evaluation for Mars Precision Landing**
Craig Kluever, University of Missouri-Columbia

Future Mars missions will likely require active, closed-loop guidance systems. Generally, guidance methods fall into two broad categories: 1) reference path tracking methods and 2) predictive path-planning methods. This paper evaluates the merits of these two guidance concepts for Mars entry. The reference-path guidance is based on Apollo entry guidance, while the predictive guidance re-computes a new trajectory at regular intervals. Numerical simulations are presented for Mars entry cases which include the effects of inertial navigation, attitude actuation, atmospheric density variations, and initial state dispersions.

Session 3: Optimal Control

Chair: Dr. James Turner, TAMU Aerospace Eng.

08:00 **AAS 08 - 116** **A Non-Linear Optimization Algorithm**
Prashant Patel and Daniel Scheeres, University of Michigan

We present a nonlinear optimization algorithm that extends and generalizes Differential Dynamic Programming (DDP). The algorithm generates a nonlinear control law that optimizes to the second order. The algorithm requires second order derivatives of the cost function, states, and constraints with respect to the states, control, and parameters. Like DDP the algorithm generates a control back backwards then applies the update forward. The algorithm differs from previous methods because it satisfies the constraints to the second order using a nonlinear update.

08:25 **AAS 08 - 117** **Initial Lagrange Multipliers for the Shooting Method**
David G. Hull, University of Texas at Austin

An often used numerical method for solving optimal spacecraft trajectory problems is the shooting method. However, to make it work, a good guess is needed for the initial Lagrange multipliers. A standard optimal control problem (no control bounds) and its optimality conditions are stated. Following a brief derivation of the shooting method, several methods for obtaining initial Lagrange multipliers are discussed: direct shooting, collocation, parameterization of the control within the shooting method, Speyer's method, dynamic programming, and adjoint-control transformation.

08:50 **AAS 08 - 118** **Initialization of Real-Time Optimal Control**
Hui Yan and Kyle T. Alfriend, Texas A&M University

Recently real-time optimal control has attracted increasing attention since it showed a great potential in nonlinear feedback control. Computing speed and the assurance of a reliable solution in real-time have been the major limiting factors in applying real-time optimal control. In this paper we use a neighboring optimal control to generate initial guesses of the next step optimization using pseudospectral methods. In the real-time optimal control scheme we consider the subsequent optimization as the neighboring of the current optimization, the neighboring optimal control could be used to generate accurate initializations for the subsequent optimization. Thus the speed and convergence of the real-time computation can be improved with these initializations.

09:15 **AAS 08 - 122** **Persistence filters for non-feedback linearizable systems with time-varying control gains**
S. Srikant and M.R. Akella, The University of Texas at Austin;

The generic problem of devising stabilizing control laws for systems with time-varying control gains is considered. This class of systems do not in general permit controller design through the standard feedback linearization techniques. The control gains can become singular at certain instants in time or stay singular for large time intervals, thus amounting to loss of controllability. We assume the control gains to possess certain structure expressed in terms of persistent excitation conditions. A persistence based filter construction is developed which is then used to stabilize the system. The results are applied to the attitude regulation problem of spacecrafts with magnetic actuators.

09:40 **Break**

10:05 **AAS 08 - 119** **Designing Iterative Learning Controllers from Limited Impulse Response Data**
Richard W. Longman and Anil P. Chinnan, Columbia University

Iterative learning control (ILC) produces high precision tracking at high speeds when one repeatedly performs the same tracking maneuver. There are spacecraft application to scanning with high precision sensors. ILC laws use a Toeplitz matrix of Markov parameters or impulse response, and the matrix size is the number of digital control time steps during the maneuver which can be large. Accurate parameter values for all matrix entries may not be available. This paper examines several important ILC laws anddevelops an understanding of how and when inaccuracy in knowledge of the parameters will result in instability of the learning process.

10:30 **AAS 08 - 120** **Imlementing Linear Iterative Learning Control Laws in Nonlinear Systems**
Katja D. Mombaur, University of Heidelberg; Richard W. Longman, Columbia University

Iterative learning control (ILC) applies to situations when a system performs a tracking maneuver repeatedly. The error in each run is used to adjust the command in the next run, aiming to converge to zero error. Spacecraft applications include making fine pointing equipment follow a precise scan pattern in spite of flexibility effects. Very effective, general ILC design methods have been developed for linear systems. This paper shows how internal numerical differentiation can be used to very easily extend the methods to nonlinear problems. Methods of relinearization and associated issues are also presented, to extend the range of convergence.

10:55 **AAS 08 - 121** **Feedback Concept Using Controlled Virtual Point Following**
Sergey V. Drakunov, Embry-Riddle Aeronautical University

In this paper a novel feedback design concept is considered for space flight applications. The concept is using reaching a manifold in the state space as an intermediate step to a control objective with a controllable virtual point constrained within the manifold. The virtual point is controlled by virtual controls which are used in combinations with original controls. As a result, we obtain more resilient and robust control algorithms to be used in flight dynamics for single and multiple systems control such as formations. The current study is not only theoretical and numerical, but has been already tested in on-board control systems.

11:20 **AAS 08 - 123** **The Advantages and Disadvantages of Kalman Filtering in Iterative Learning Control**
B. Panomruttanarug, King Mongkut's University of Technology; R. W. Longman, Columbia University

Iterative learning control (ILC) can eliminate deterministic tracking errors of a control system that repeatedly performs a tracking maneuver. It has spacecraft applications when fine pointing sensors perform repeated scans. When there is substantial noise one naturally considers using a Kalman filter as analyzed here, paralleling a previous analysis for repetitive control. New aspects include the transient phase, and the ability to handle repeating disturbances. The filter decreases the influence of noise, but introduces deterministic error based on the accuratacy of the system model used in the filter, implying that a Kalman filter can make the error level worse.

Session 4: Orbital Debris & Chinese Anti-Satellite

Chair: Dr. Thomas Starchville, The Aerospace Corporation

13:30 **AAS 08 - 124** **An Analysis of the Transient Collision Threat with orbital debris resulting from the Fengyun 1C Intercept**
Robert (Lauchie) Scott, Defence R&D Canada Ottawa

The destruction of Fengyun 1C weather satellite by a Chinese interceptor rocket resulted in an eccentric orbiting debris field initially dispersed in the plane of the 0830 descending-node sun-synchronous orbit. In this study, the enhancement of collision probability during the initial evolution of the debris cloud is examined by estimating the debris cloud density during conjunctions with the RADARSAT satellite. This analysis inspects the short term evolution of the debris cloud on the timescales of one to two days post-intercept during which the debris cloud density remains relatively high in comparison to the longer term density evolution of debris objects.

13:55 **AAS 08 - 125** **Close Approach Prediction Analysis of the Earth Science Constellation with the FENGYUN 1C debris**
Matthew Duncan, a.i. solutions, Inc.; Lauri K. Newman, NASA GSFC; David Rand, a.i. solutions, Inc.

Routine flight operations for the NASA Earth Science Constellation (ESC) include assessing the risk of collision between members of the constellation as well as between the constellation members and other space objects. On January 11, 2007, destruction of a Chinese weather satellite created a significant amount of debris near the ESC operational altitude. This paper describes the operational impact of this event on the ESC missions, including close approach statistics, a summary of the Terra avoidance maneuver performed in June. An analysis is also presented that predicts increased future ESC mission risk based on evolution of the debris population.

14:20 **AAS 08 - 126** **Investigating Orbital Debris Events using Numerical Methods with Full Force Model Orbit Propagation**
Timothy Carrico, Analytical Graphics, Inc.; John Carrico, Applied Defense Solutions

The authors present several techniques that can be employed to investigate and understand orbital debris events. The authors show techniques used to examine and reconstruct the Chinese FY-1 ASAT debris event empirically based on TLE data. The paper gives a method to recreate the equivalent 3-dimensional delta-v vector distributions from statistics using geometric and fuzzy logic clustering techniques. The delta-v distributions are then used to create a representative particle debris cloud model which is propagated using a high precision orbit propagator including the affects of atmospheric drag. The resultant particle ephemerides are used to examine debris cloud evolution.

14:45 **AAS 08 - 127** **Space Surveillance Network Response to Orbital Debris Events**
David Finkleman, Senior Scientist, Center for Space Standards and Innovation; Daniel L. Oltrogge, 1 Earth Research, LLC

This paper will report the response of an SSN to an orbital debris event, such as the recent Chinese test. We have developed a co-simulation among COTS and GOTS astrodynamics, sensor, and communications simulations. The simulation includes validated NASA models of debris events. We review difficulties encountered, such as propagating rapidly thousands of objects and developing message stream representations. Finally, we will compare the outcomes of standard space surveillance analyses based on kinematics and geometry and our more realistic end to end assessment of the entire process from event, through real sensor detection, and communicating data to enable reaction.

15:10 **Break**

15:35 **AAS 08 - 128** **The 2007 Chinese ASAT Test – Implications to the Impact of Space Warfare on the LEO Environment**
David Talent, Oceanit

As the numbers of debris objects increases in Low Earth Orbit (LEO), so does the threat of collision with high value assets. In January 2007, the Chinese government conducted an anti-satellite (ASAT) test at an altitude of 850 km producing over 2000 debris objects. Application of an environmental model called PODEM suggests that these debris objects will only slowly decay out of LEO over several hundred years. The impact of multiple and simultaneous ASAT events – space warfare – in LEO is examined. Environmental stability against catastrophic debris growth, as a function of altitude, is also discussed.

16:00 **AAS 08 - 129** **A Study of the Relative Velocities of Small Particles that are Orbiting the Earth**
Cláudia Celeste Celestino, Instituto Nacional de Pesquisas Espaciais - São José dos Campos; Othon C. Winter, UNESP – Guaratinguetá.; A.F.B.A. Prado, Instituto Nacional de Pesquisas Espaciais - São José dos Campos

The evolution of the velocity of particles with respect to the circular orbits that the particles will cross, suggests a range of possible velocities of impact. A study made from those results show that the maximum relative velocities occur at the semi-lactus rectum, independent of the initial semi-major axis of the particle. Considering both the solar radiation pressure and the flattening of the Earth, it is visible that a precession in the orbit occurs and a variation in the initial eccentricity of the particle as a function of its orbital region and its size.

16:25 **AAS 08 - 130** **Analysis and management of 2006 and 2007 periodic conjunctions between CNES satellites**
Stephanie Delavault, Alain Lamy, Laurence Lorda, CNES

In the last 2 years CNES had to handle a 6-month repetitive conjunction between two LEO missions : Demeter and ESSAIM (a DGA 4-satellite formation). First the relative orbits and the different monitoring strategies (especially the use of Autonomous Orbit Control) are analyzed in order to explain the long and short term repetitivity period of the encounter. The second part describes the evolution of the avoidance analyses and implemented strategies for the 3 conjunctions handled since mid-2006. In the last part, the lessons from these successive events are drawn as recommendations for the management of future cases.

16:50 **AAS 08 - 131** **Space Debris Analysis of Low-Thrust Transfer Maneuver from LEO to GEO for a Large Structure**
Yu Takahashi, Embry-Riddle Aeronautical University (Undergraduate)

This paper analyzes the space debris impact on a large structure during a low-thrust maneuver from LEO to GEO. This analysis is crucial for designing a Space Solar Power Satellite (SSPS) because of the large surface area of the SSPS and therefore the greater chance of debris impact. MASTER-2005 was used as a means to perform this debris analysis. The use of this analysis is not only limited to the SSPS but is applicable to other kinds of satellite in order to predict the effects of space debris damage on the satellites.

Session 5: Attitude Dynamics, Determination & Control I

Chair: Dr. Hanspeter Schaub, University of Colorado

13:55 **AAS 08 - 133** **On-Ground Attitude and Torque Reconstruction for the Gaia Mission**
Malak Samaan and Stephan Theil, ZARM, University of Bremen, Germany

This paper concerns the accurate On-Ground Attitude (OGA) reconstruction for the astrometry spacecraft Gaia in the presence of disturbance torques acting on the spacecraft. The reconstruction of the expected environmental torques acting on the spacecraft will be also investigated. The telemtry data from the spacecraft will include the on-board real time attitude which is of order of several arcsec. This raw attitude is the starting point for the further attitude reconstruction. The OGA will use the field coordinates of stars measured by payload instruments to improve the raw attitude. The first approach for the OGA will be using Kalman Filter. Furthermore, we will design a smoothing type estimation algorithm and batch least squares algorithm for the OGA to get more accurate OGA estimation.

14:20 **AAS 08 - 220** **Spin-Axis Attitude Determination from Earth-Chord-Angle Variations for Geostationary Satellites**
Jozef van der Ha, Kyushu University; Frank Janssens, Consultant

The paper describes a technique for the spin-axis attitude determination based on Earth-sensor data only. The method is attractive for spin-stabilized satellites in geostationary orbit where the variations in the Earth-chord-angle measurements are essentially periodic with orbital period. A set of equidistant measurements are sampled over the orbit and processed by a batch least-squares estimation method. The approach is validated and illustrated by means of realistically simulated sensor measurements aswell by actual (METEOSAT) measurements. A covariance analysis for the propagation of bias errors into the attitude solution is carried out.

14:45 **AAS 08 - 132** **Experimental Study and Analysis on Three Dimentional Reaction Wheel for Microsatellites**
Yoji Shirasawa, University of Tokyo

This paper presents a novel attitude control device which is called three dimensional reaction wheel (3DRW). 3DRW consists of only one levitated spherical mass which can rotate around arbitrary axes. This leads to the reduction of the weight and volume of the system as compared to existing reaction wheel. Furthermore, this device has no mechanical contact between rotor and stator, so the failure caused by the mechanical contact would be reduced. In this paper, the results of the analysis and experiment on the dynamics and control of 3DRW are shown, and the advantage of 3DRW for very small satellites is revealed.

15:10 **Break**

15:35 **AAS 08 - 139** **On Single-Wheel Configured Spacecraft and the Attitude Stability Revisited**
Jun'ichiro Kawaguchi, Akifumi Kitajima, Osamu Mori and Kenichi Shirakawa, Institute of Space and Astronautical Science (ISAS), Japan Aerospace Agency

This paper presents what the Hayabusa spacecraft experienced when it restarted the three axis stabilization. Due to the loss of two wheels aboard and also due to the loss of fuel, the primary axis of inertia of the spacecraft was tilted offset to the geometrical axis. The instability was observed unexpectedly since there was little thought about the instability associated with the single wheel system. The results can be applied for other spacecraft. The flight results are shown as well.

16:00 **AAS 08 - 137** **On the attitude propagation of an axisymmetric satellite**

J. Pelaez, Technical University of Madrid - Spain; A. Pizarro-Rubio, EADS Casa-Espacio - Spain

This paper describes the method developed in the Group of Tether Dynamics of the UPM to gain accuracy in the numerical propagation of the attitude dynamics of a rigid axisymmetric spacecraft. We use a perturbation method which takes as unperturbed problemthe Euler-Poinsot case (torque free). The perturbed problem provides the motion forced by non-vanishing external torques. Some numerical comparisons have been carried out to check the kindness of the procedure taking as forced motion some particular case of the Lagrange top, whose analytical solution permits a easy determination of the errors made in the numerical description of the motion.

16:25 **AAS 08 - 138** **Potential Approach for Constrained Autonomous Manoeuvres of a Spacecraft Equipped with a Cluster of Control Moment Gyros**

Giulio Avanzini, Politecnico di Torino - IItaly; Gianmarco Radice and Imran Ali, University of Glasgow - Scotland

A potential function approach for the autonomous control of attitude manoeuvres in presence of constraints on the admissible attitudes (“obstacles”) is implemented for a spacecraft controlled by a cluster of Control Moment Gyroscopes. A gimbal position command generation is employed, in order to directly implement the angular velocity command derived from the potential function defined in the quaternion error vector space.

Session 6: Formation Flying & Rendezvous I

Chair: Bo Naasz, NASA GSFC

13:30 **AAS 08 - 140** **An Attempt for Regularization and Formation Flight Expression along Two-Body Motion**
Jun'ichiro Kawaguchi and Ryu Funasa, Institute of Space and Astronautical Science (ISAS), Japan Aerospace Agency

This paper deals with how the formation flight target is expressed as trivial in some appropriate coordinates, instead of an orbital target. There is attempted to show the regularization process to obtain a special coordinate through a Levi-Civita non-linear transform. The paper will show how and which the virtual target corresponds to the physical formation configuration.

13:55 **AAS 08 - 141** **Optimal Geostationary Satellite Collocation**
Igor Beigelman and Pini Gurfil, Technion

We develop a satellite collocation algorithm using relative orbital element corrections, which represent the differences between the orbital element corrections of any two spacecraft in a geosynchronous slot. The main idea is that formulating the problem of collocation in terms of relative orbital element corrections leaves the final values of the orbital elements unconstrained. The freedom rendered by this modeling is used to find optimal impulsive maneuvers minimizing the squared L2-norm of the velocity corrections vector, which can be used for collocation initialization and control. The optimization is solved using the method of least squares. Synchronous elements are used for the linear approximation of the relative motion in order to detect optimal impulsive velocity corrections for the collocation problem.

14:20 **AAS 08 - 142** **Explicit Predictive Control Law for Satellite Formation Flying in Eccentric Orbits**
Vincent Simard Bilodeau and Jean de Lafontaine, Université de Sherbrooke

This paper presents a Model Predictive Control (MPC) law for formation flying in eccentric orbits based on the Lawden and linearized Gauss Variation Equations models. Past MPC techniques have relied on the optimization of the command effort using complex algorithm to maintain the relative position into a user-defined error box. The proposed technique rather minimizes a cost function that includes future errors subject to input constraints. A near-optimal command is explicitly obtained with a projection ofthe cost function on the constraints that reduces computing time. These control laws allow reconfiguration maneuvers and maintenance of a formation with good performance.

14:45 **AAS 08 - 143** **Formation Flying Implications of the Recoil Effects from Wireless Power Transfer**
Andrew E. Turner, Space Systems/Loral

Wireless transfer of power between spacecraft involves the exchange of momentum and therefore perturbs spacecraft orbits. This could cause clusters of spacecraft to contract, risking collision, if the spacecraft are arranged in a “pearls on a string” formation, unless compensatory measures are introduced. Formations in which spacecraft undergo circular or elliptical relative motion may benefit from modified geometry to mitigate power transfer recoil effects. A platform intended to beam power down to the surface of the Earth from geosynchronous orbit (GEO) for domestic consumption will experience perturbations not previously encountered in this widely used orbit, requiring new techniques for compensation.

15:10 **Break**

15:35 AAS 08 - 144 Nonlinear Optimization of Low-Thrust Trajectory for Satellite Formation: Legendre Pseudospectral Approach

Baolin Wu, Danwei Wang, Guangyan Xu and Hang Yue, Nanyang Technological University

We propose a method to determine fuel-optimal trajectories for satellite formation maneuver subjected to collision avoidance using low-thrust continuous propulsion. A final bounded desired formation is obtained by including terminal energy-matching condition and final geometry configuration constraints in the optimization formulation. The dynamics model used is a newly developed exact nonlinear relative dynamics considering eccentricity and earth oblateness. Resulting nonlinear optimal control problem is transcribed into nonlinear programming problem by a recently developed direct transcription method called Legendre pseudospectral method. The nonlinear programming problem is then solved using a sparse nonlinear optimization algorithm named SNOPT. Examples are presented across a range of applications. These examples demonstrate the applicability of Legendre pseudospectral method to optimal trajectory design for formation maneuver.

16:00 AAS 08 - 145 Dynamics and Control of Satellite Formations Using a Quasi-Rigid Body Formulation

Christopher Blake and Arun K. Misra, McGill University

The quasi-rigid body (QRB) formulation views a satellite formation as a single entity. We present a general definition of a QRB frame, which captures the orientation of a formation, and we show how it may be incorporated into system dynamics, using both Newtonian and Lagrangian methods. For geocentric formations, we present bounded relative orbit solutions, quantify the forces needed to maintain a rigid formation, and investigate an open-loop control strategy based on rigid body dynamics. The QRB formulation can facilitate development of control algorithms focused on maintaining formation orientation and performing slew maneuvers.

16:25 AAS 08 - 146 Robust Control Law for Formation Flying Satellite in Eccentric Orbits

Philippe Brazeau, Vincent Simard Bilodeau, Aymeric Kron, and Jean de Lafontaine, Universite de Sherbrooke

This article proposes a discrete robust control law for formation flying in eccentric orbits based on Lawden model. Previous robust approaches have relied on scheduled H infinity continuous controller to reconfigure and maintain cohesion of an artificial formation. This paper rather proposes a discrete, with realistic sampling rate, nonscheduled, stability guaranteed controller. This controller is obtained by choosing adequate waiting function that minimizes relative positionerror with similar command effort and by imposing strict closed-loop poles constraints to H infinity synthesis algorithm.

Session 7: Tethers

Chair: Dr. Thomas Lovell, AFRL

08:25 **AAS 08 - 148** **Stability of Tethered Satellites Using Floquet Theory**
Jean Slane, Engineering Systems Inc.; Steve Tragesser, University of Colorado

Orbiting several spacecraft in relatively close formation, or formation flying, may significantly increase the performance of applications such as remote sensing platforms. Tethers have been proposed to maintain the satellites' relative positions whileminimizing station keeping maneuvers. This research investigates the stability of a flexible formation of tethered satellites where the spin axis creates a cone in inertial space. Infinitesimal stability is evaluated by applying Floquet Theory to linearized time-periodic equations of motion at several conditions. The stability analysis provides invaluable information for evaluating the control effort necessary to maintain the satellites' relative positions in the formation.

08:50 **AAS 08 - 149** **Orbit-Nadir Aligned Coulomb Tether Reconfiguration Analysis**
Arun Natarajan, Virginia Tech; Hanspeter Schaub, University of Colorado

While reconfiguring a two craft Coulomb tether aligned along the orbit radial direction, the linearized charged equation of motion (EOM) of the out-of-plane angle is decoupled from the Coulomb forces. An analytical solution is developed for this motion using Bessel functions for a constant rate of reconfiguration. Bounds on the initial out-of-plane oscillation are deduced such that the finial oscillation will remain within the prescribed limits. This paper also presents the influence of a smoothed reconfiguration rate on the switch over oscillations of the in-plane angle and separation distance error.

09:15 **AAS 08 - 150** **Numerical Model Development and Verification for the Dynamics of an Electrodynamic Tether System**
Joshua R. Ellis and Christopher D. Hall, Virginia Tech

Two different solution methods for solving the partial differential equations of motion of an electrodynamic tether system are developed, verified, and compared. The first method is based on an expansion of the tether displacements using assumed mode functions, and the second method is a finite element method using cubic Hermite interpolation polynomials. The Method of Manufactured Exact Solutions is used to verify the accuracy of the numerical solutions produced by each method, and the two methods are compared using principles of Richardson extrapolation to determine which method is better suited to numerical simulations of EDT systems.

09:40 **Break**

10:05 **AAS 08 - 151** **Attitude Control for Tethered Formation Flying via the State-Dependent Riccati Equation Technique**
Insu Chang, Sang-Young Park, and Kyu-Hong Choi, Yonsei University

The objective of the current research is to analyze the dynamics of satellite tethered formation where the tethered units are modeled as extended rigid bodies. The three inline array system is used and the general formulation of the governing equations ofmotions of the system is obtained through a Lagrangian approach. The main contribution of this research is to introduce the State-Dependent Riccati Equation(SDRE) technique to attitude control problem in tethered formation flying. The stability region for the SDRE-controlled system is estimated by using numerical method. The simulation results for the attitude control demonstrate the effectiveness for the SDRE approach.

10:30 AAS 08 - 152 Effects of Libration on General EDT Orbital Maneuvers

Nickolas Sabey, Lockheed Martin Mission Services; Steven Tragesser, University of Colorado at Colorado Springs

For performing maneuvers with changes in all orbital elements, a time varying current along an electrodynamic tether is required. A guidance scheme to achieve arbitrary final orbital elements has been previously developed for a vertical tether. In this work, a nominal periodic solution for the libration dynamics is employed. Previously obtained periodic solutions for a constant current are extended to the case of variable current. The periodic solution is then applied to the guidance scheme to determine the degradation of the maneuver due to libration.

10:55 AAS 08 - 153 Simple Control Laws for Self-Balanced Electrodynamic Tethers

Manuel Sanjurjo-Rivo and Jesus Pelaez, Technical University of Madrid

Electrodynamic tethers exhibit an instable behavior at inclined orbits. The resolution of this undesirable performance has been tackled in several ways. One of the proposed solutions, the self-balanced electrodynamic tether (SBET) concept, allows a control procedure, namely, the continuos control, which provides high currents without destabilizing torques. In this article we undertake the improvement of this control method broaden its field of application, reducing the complexity in its practical implementation and exploring close strategies. Furthermore, we face with the possibility of extend the continuous self balanced control so the system will be asymptotically stable.

Session 8: Orbit Determination

Chair: Dr. Craig McLaughlin, University of Kansas

08:00 **AAS 08 - 154** **Alternating Directional Method Enhanced Nonlinear Filtering**
Jangho Yoon and Yunjun Xu, University of Oklahoma

Nonlinear filtering using Fokker-Planck equation (FPE) and Bayes' rule should provide better optimal estimations than Extended Kalman filter because it does not require linearized dynamics and/or measurement model. However, lack of efficient methods to solve FPE numerically limited its applications. In this paper FPE and Bayes' rule based filtering is applied to orbital position estimation. Evolution of state probability density function (PDF) between measurements is obtained by solving FPE using alternating directional implicit (ADI) method. As compared other methods, ADI method reduced computational cost dramatically. Bayes' rule updates state PDF numerically according to measurements. To further decrease computational cost, the moving domain is employed to reduce the domain of integration. Simulations for both Hill's and Keplerian equation demonstrate the feasibility of implementation in real applications.

08:25 **AAS 08 - 155** **A Gaussian function Network for Uncertainty Propagation through Nonlinear Dynamical System**
Puneet Singla and Tarunraj Singh, University at Buffalo

A Gaussian function network is proposed to solve the Fokker-Planck Equation (FPE) for exact uncertainty propagation through a general nonlinear system. The solution to the FPE, the transition probability density function, is approximated by a finite sum of Gaussian density functions whose parameters are determined by using a quadratic programming based approach. The method is applied to the FPE for two-dimensional dynamical systems, and argued to be an excellent candidate for higher dimensional systems and the transient problem. Results are compared with existing global techniques.

08:50 **AAS 08 - 156** **Application of the Backward Smoothing Extended Kalman Filter to Orbit Estimation**
Zachary Folcik, MIT Lincoln Laboratory; Paul Cefola, Massachusetts Institute of Technology

The Backward Smoothing Extended Kalman Filter (BSEKF) is a type of Iterated Extended Kalman Filter. The filter was developed for state estimation problems with highly nonlinear dynamic and measurement equations. Its purpose is to provide more reliable convergence and robustness than other types of filters, i.e. the Extended Kalman Filter and the Unscented Kalman Filter. Previously, the BSEKF was applied to a difficult spacecraft attitude estimation problem. Our intent with this paper is to apply the BSEKF to an orbit estimation problem and determine whether an analogous improvement is achieved.

09:15 **AAS 08 - 157** **Orbit Gravity Error Covariance**
James R Wright, James Woodburn, Son Truong, and William Chuba, Analytical Graphics, Inc.

Optimal orbit determination requires a physically connected method to calculate a gravity error process noise covariance function to drive the filter time-update across each propagation time interval. We derive the orbit covariance function from an acquired covariance matrix on potential function coefficient estimation errors. We employ existing theory, derived from results due to Kaula, Pechenick, and Wright to calculate a double integral in six-dimensions, the orbit covariance function for the filter. Our existing method has been limited to a single potential function, and our algorithm architecture has been limited to a restricted LEO class. Now we have constructed a new method that broadens the algorithm architecture, with applications to GRACE, EGM96, and LUNAR-PROPECTOR potential functions.

09:40 **Break**

10:05 **AAS 08 - 158** **Impact of NRLMSISE-00 Atmospheric Density Corrections on Orbit Determination and Prediction Accuracy**

Brandon Jones, University of Colorado Boulder; Dr. Matthew P. Wilkins, Schafer Corporation; Dr. Chris A. Sabol, Air Force Research Laboratory

Atmospheric drag is the primary source of modeling error for the orbit determination of low Earth orbiting satellites. Previous studies have looked at dynamic calibration of the atmosphere to provide corrections to atmospheric density modeling. This studyapplies corrections of the NRLMSISE-00 atmospheric density model to the state estimation of several satellites using satellite laser ranging data. The consistency of the state solutions both with and without the corrections is compared to determine the effectiveness of these corrections and eliminate the possibility that similar dynamical models are required for both the density correction and state estimation processes. Results demonstrated an improvement in state consistency for satellites within the altitude range of space objects used to generate the corrections.

10:30 **AAS 08 - 159** **Sample Orbit Covariance Function and Filter-Smoother Consistency Tests**

James R Wright, James Woodburn, Son Truong, and William Chuba, Analytical Grphics, Inc.

A new method was developed to accumulate and propagate an orbit sample covariance function, derived directly from an ensemble of numerical orbit integrations driven by the potential function covariance matrix. Consistency of the filter error covariance function with the sample covariance function implies consistency of the filter error covariance function with the potential function covariance matrix. Rigorous ODTK filter-smoother consistency test results, using real tracking data, are presented for JASON-GRACE, JASON-EGM96, and LUNAR-PROSPECTOR. The filter-smoother consistency test is sensitive to all modeling errors, including the existence of modeling errors in the potential function covariance matrix.

10:55 **AAS 08 - 160** **Orbit Determination Using GPS Including Perturbations Due to Geopotential Coefficients of High Degree and Order and Solar Radiation Pressure**

Rodolpho Vilhena de Moraes, UNESP/FEG; Paula Cristiane Pinto Raimundo and Helio Koiti Kuga, DMC – INPE.

Using signals of the GPS constellation the orbit of artificial satellites are determined. Perturbations due to high degree and order of the geopotential coefficients and direct solar radiation pressure were taken into account. It was also considered the position of the GPS antenna on the satellite. An application has been done, using real data from the TOPEX/POSEIDON satellite. The best accuracy obtained in position was smaller than 3 meters for short period (2 hours) and smaller than 28 meters for long period (24 hours) orbit determination.

11:20 **AAS 08 - 161** **Orbit Covariance Inner Integrals with Polynomials**

James R Wright, James Woodburn, Son Truong, and William Chuba, Analytical Graphics, Inc.

We derive the gravity error process noise orbit covariance function for the filter from an acquired covariance matrix on potential function coefficient estimation errors. We employ existing theory, derived from results due to Kaula, Pechenick, and Wright, to calculate a double integral in six-dimensions, the orbit covariance function for the filter. The double integral is calculated as an iterated integral, first an inner integral and then an outer integral. Here we describe calculation of the inner integral with polynomials.

Session 9: Spacecraft Guidance, Navigation & Control II

Chair: Dr. Kathleen Howell, Purdue University

08:00 **AAS 08 - 162** **Higher Order Methods for Estimation of Dynamic Systems, Part I : Theory**
Manoranjan Majji, James D. Turner, and John L. Junkins, Texas A&M University

An analytical approach to propagate uncertainty through nonlinear dynamical systems is considered for filtering applications. The method involves the computation of the time evolution of arbitrarily high order moments as a function of the statistics of the process at initial time by integration of high order state transition tensors as developed by [Turner, Park]. Central to the approach, is a data structure working in tandem with OCEA (Object Oriented Coordinate Embedding Method). Nonlinear Kalman filter structures are proposed the state transition tensor frameworks that make use of the excellent propagation properties. We conclude the discussion with notes on conclusions and current and future work plan

08:25 **AAS 08 - 163** **Inertia Parameters Experimental Estimation of a Satellite Simulator**
Luiz Carlos G. Souza, National Institute for Space Research- INPE, S J Campos – SP, Brasil.

This paper presents the inertia parameters estimation of the 1-D (DMC) simulator by a recursive least squares approach using experimental data. The data are obtained in a simple experiment and it consists of the torque applied by the reaction wheel and the platform angular velocity measured by a gyroscope. To perform that estimation one derives the ACS simulator equation of motion. The inertia parameters estimated is in agreement with the values obtained by other method. As a result, the 1-D DMC simulator describing the satellite dynamics and ACS is ready to implement and test different attitude control systems and control laws strategies.

08:50 **AAS 08 - 164** **Communication, Ocean, and Meteorological Satellite Orbit Determination Accuracy Improvement**
Yoola Hwang, Byoung-Sun Lee, Hae-Yeon Kim, and Jaehoon Kim, Electronics and Telecommunications Research Institute, Korea

An operational Orbit Determination and Prediction system for geostationary Communications, Ocean, and Meteorological Satellite mission requires accurate satellite positioning knowledge to accomplish Image Navigation Registration (INR) on the ground. However, the orbital longitude of the COMS is so close to that of satellite tracking site that a geometric singularity affects observability. Ranging and tracking data from single ground station are used for the Orbit Determination (OD). A method to solve azimuth bias of single station in singularity is periodically to apply a calibrated azimuth bias using two ground stations ranging and tracking data. Although the result of orbit determination using only single station was 5-6 km RSS, the difference from truth orbit was reduced to within 2-3 km when the calibrated azimuth bias was applied.

09:15 **AAS 08 - 165** **Optimal Integrated Attitude and State Estimation**
Renato Zanetti and Robert H. Bishop, The University of Texas at Austin

Conditions on the optimality of the introduction of preprocessed attitude estimates in the Kalman filter are developed. The results are applied to lunar descent to landing navigation. The attitude estimate is obtained with the Davenport q-method and a modified measurement model. Together with the attitude estimate, the preprocessor passes to the Kalman filter the estimation error covariance.

09:40 **Break**

10:05 AAS 08 - 166 Optimal Autonomous Manoeuvre Planning for Spacecraft Formation Flying - Position Assignment

Ross Burgon and Peter Roberts, Cranfield University; Finn Ankersen, European Space Technology Centre (ESTEC), The Netherlands

Formation flying of spacecraft in orbit around the Earth and in deep space is becoming an enabling technology for a number of space mission concepts. One such concept is separated spacecraft interferometry a technique to be used by ESA's Darwin planet finding mission. In this paper a position assignment algorithm is introduced designed to find the post-manoeuvre spacecraft positions that satisfy interferometry science goals whilst optimising for fuel use or fuel balancing considerations. Gains of up to 45% less fuel for fuel minimising manoeuvres and a 450% increase in fuel balancing are observed using Darwin-like mission parameters.

10:30 AAS 08 - 167 Simple Satellite Orbit Propagator

Pini Gurfil, Technion - Israel Institute of Technology

An increasing number of space missions require on-board autonomous orbit determination. The purpose of this paper is to develop a simple orbit propagator (SOP) for such missions. Since most satellites are limited by the available processing power, it is important to develop an orbit propagator that will use limited computational and memory resources. In this work, we show how to choose state variables for propagation using the simplest numerical integration scheme available -- the explicit Euler integrator. The new state variables are derived by the following rationale: Apply a variation-of-parameters not on the gravity-affected orbit, but rather on the gravity-free orbit, and teart the gravity as a generalized force.

10:55 AAS 08 - 168 Navigation Sensitivity Analysis for Lunar Landing

Kyle J. DeMars and Robert H. Bishop, The University of Texas at Austin

Sensitivity analysis is performed for a navigation filter which has been designed to facilitate precision landing at the Moon. In order to perform the sensitivity analysis, an error budget is developed. Error groups are defined by grouping elements of the initial state parameter uncertainties, the process noise spectral density, and the measurement noise covariance. The resulting state uncertainties due to each individual group are then catalogued into an error budget. From the error budget, a sensitivity analysis is performed to predict the filter performance for off-nominal values of the initial state parameter uncertainties, the process noise, and the measurement noise.

11:20 AAS 08 - 169 Time Varying Eigensystem Realization Algorithm with Repeated Experiments

Manoranjan Majji and John L. Junkins, Texas A&M University

This manuscript presents an extension of the celebrated Eigensystem Realization Algorithm (ERA) to include the identification of time varying systems. Time varying system models, in discrete time are introduced and the differences and unique properties are discussed in the light of the time invariant system models. Realization theory specialized to account for the time variation of the system models is revised to setup the conventions for the remainder of the paper. This is followed by a brief presentation of the Eigensystem Realization Algorithm for the linear time invariant plant models. The generalization of this algorithm is presented and is discussed with an example.

Session 10: Solar System Missions

Chair: Frederic Pelletier, JPL

13:30 **AAS 08 - 170** **Mission to Binary Asteroids: 1999 KW4 as a case study**
Julie Bellerose and Daniel J. Scheeres, University of Michigan

Using the energy constraints of the Restricted Full Three-Body Problem (RF3BP) we design a robotic mission at a binary asteroid system. The case of relative equilibria between the bodies is assumed for a ellipsoid-sphere system. In this work, we give an overall mission design for planetary exploration accounting for the particular dynamics of the binary system and a spacecraft in this gravitational field. We discuss approach to the binary, dynamics and control of cooperative hoppers performing surface investigation, and transfer from one body to the other. The binary asteroid 1999 KW4 is used as a case study.

13:55 **AAS 08 - 171** **Chasing a Comet with a Solar Sail**
Rob Stough, Andrew F. Heaton, and Dr. Mark Whorton, NASA

Solar sail propulsion systems enable a wide range of missions that require constant thrust or high delta-V over long mission times. One particularly challenging mission type is a comet rendezvous mission. This paper presents optimal low-thrust trajectory designs for a range of sailcraft performance metrics and mission transit times that enables a comet rendezvous mission. These optimal trajectory results provide a trade space which can be parameterized in terms of mission duration and sailcraft performance parameters such that a design space for a small satellite comet chaser mission is identified. These results show that a feasible space exists for a small satellite to perform a comet chaser mission in a reasonable mission time.

14:20 **AAS 08 - 172** **Navigation for Second Venus Flyby During MESSENGER Mission to Mercury**
K. E. Williams, A. H. Taylor, B. R. Page, J. K. Miller, J. Smith, P. Wolff, D. Stanbridge, B. G. Williams, KinetX, Inc.; J. V. McAdams, Johns Hopkins University Applied Physics Laboratory

MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) is the seventh mission in NASA's Discovery Program. The spacecraft was launched on 3 August 2004 and will arrive in orbit about Mercury beginning in March 2011. The cruise phase includes planetary gravity-assist flybys of Earth (in August 2005), Venus (in October 2006 and June 2007) and Mercury (in January and October 2008 and September 2009). This paper describes the navigation results for the period encompassing Venus flyby 2 and focuses on orbit determination, trajectory correction maneuvers, optical navigation tests performed after the encounter and implications for the upcoming first Mercury encounter.

14:45 **AAS 08 - 173** **Hayabusa's 1st Half of Return Cruise - Flight Results on Attitude Control and Ion Engines Propulsion**
Jun'ichiro Kawaguchi, Osamu Mori, Hitoshi Kuninaka, Takashi Kominato and Kenichi Shirakawa, Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA)

This paper presents the flight operation summary during the first half of the return cruise back home in Hayabusa mission. This paper focuses its attention on how we have coped with the attitude control difficulty using solar radiation pressure, also on how the guidance and navigation have been performed while propelled via ion engines. The flight results are given.

15:10 **AAS 08 - 174** **The Compensation Method of the Observation Error of the Target Position for High Accurate Navigation at Flyby**

Shunsuke Okada, University of Tokyo; Osamu Mori and Jun'ichiro Kawaguchi, Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA)

This paper describes the navigation strategy of the small probe for flyby using the images of the target. The complexity of the target shape and the shadow area on the target image make it difficult to know the center position of the target. For high accurate flyby, the observation error of the target center needs to be compensated. In this paper, the compensation method of the error is derived supposing that the target shape is sphere. The validity of the method is examined in the experiment.

15:35 **Break**

Session 11: Earth & Planetary Mission Science

Chair: Dr. Paul Schumacher, Air Force Research Laboratory

13:30 AAS 08 - 175 Evolution Mechanism and Related Astrodynamics Characteristics for Small Celestial Bodies

Jun'ichiro Kawaguchi, Masatoshi Hirabayashi, Akifumi Kitajima and Yuichi Miwa, Institute of Space and Astronautical Science (ISAS), Japan Aerospace Agency

The paper presents how the initial contact binary state was as to a near earth asteroid Itokawa, and discusses dynamics energy to speculate the evolution process. The study also looks at the fragments accretion mechanism and touches on the surface featuredistinction mechanism as well. All of the contents are looked at from Astrodynamics point of view not from scientific point of views.

13:55 AAS 08 - 176 Determination of Thermospheric Winds and Density from Analysis of GRACE Accelerometer Data

Minkang Cheng, Byron D. Tapley, Srinivas Bettadpur, and John C. Ries, The University of Texas at Austin Center for Space Research

Measuring the thermospheric neutral winds is important for improving our understanding of the ionosphere-thermosphere coupling. Thermospheric neutral winds redistribute energy globally and drive the heat balance of the thermosphere and produce additional perturbations on the along and cross-track components of the satellite orbit. The accelerometer (ACC) data from GRACE, which measure the non-gravitational forces on satellite, are particular well suited for exploring the upper atmospheric density variations and the thermospheric neutral winds as well. This paper presents the procedure for analysis of 10 Hz ACC data, and reviews the basic theory for determination of the atmospheric winds and density from the GRACE accelerometer data. Preliminary results ofatmospheric winds will be presented.

14:20 AAS 08 - 177 Comparison of Total Density Derived from CHAMP Precision Orbits and CHAMP Accelerometer

Craig A. McLaughlin, Andrew Hiatt, University of Kansas; Ben Bieber, University of North Dakota

Atmospheric density modeling has long been one of the greatest uncertainties in the dynamics of low Earth satellite orbits. Accurate density calculations are required to provide meaningful estimates of the atmospheric drag perturbing satellite motion. This paper uses precision satellite orbits from the Challenging Minisatellite Payload (CHAMP) satellite to produce a new data source for upper atmospheric density and changes that occur on time scales less than a day. The precision orbit derived density is compared to CHAMP accelerometer derived density to determine the accuracy of using precision orbit derived density over a range of time periods.

14:45 **AAS 08 - 178** **Orbit Determination Requirements for ABYSS-II: A Proposed ISS Science Payload**

C.K. Shum, Ohio State University; P.A.M. Abusali, University of Texas at Austin; James Ogle, ITT Space Systems; R. Keith Raney, Johns Hopkins University; Walter H.F. Smith, NOAA; Changyin Zhao, Purple Mountain Observatory

The Altimetric Bathymetry from Surface Slopes, ABYSS-II, a proposed 2010 or beyond science payload on the Express Logistics Carrier (ELC) of the International Space Station (ISS), is a Delay-Doppler radar altimeter (DDA) capable of measuring ocean surface slope in the 6–200 km half-wavelength band range with an accuracy of 0.5 μradians. This measurement allows an improved mapping of the global bathymetry, enabling a wide range of scientific research and applications. The non-repeat ISS orbital ground track is ideal for ABYSS-II. This paper describes a study on effects of Earth's gravity field and other errors, including thermal bending of the ISS, on orbit determination of the DDA antenna phase center location and the ISS, towards fulfilling the scienceobjectives of ABYSS-II.

15:10 **AAS 08 - 179** **Orbital Mechanics, Perturbations, and GRACE Science and Mission Design**

Srinivas Bettadpur, University of Texas at Austin Center for Space Research

The NASA/DLR GRACE mission has provided unique insights into the mass flux within the Earth system and the underlying geophysical and climate processes. The mass flux measurements at weekly to inter-annual time scales, and 300 km and larger resolutions, are derived from estimates of Earth gravity field changes extracted from precise measurements of relative orbital motion between two co-planar low-Earth orbiting satellites. This paper reviews the orbital mechanics bases behind the GRACE mission design, data processing algorithms and scientific inference.

15:35 **Break**

Session 12: Dynamical Theory of Space Flight Problems

Chair: Dr. Felix Hoots, The Aerospace Corporation

13:55 **AAS 08 - 181** **Eccentric Orbits around Planetary Moons**
Ryan P. Russell and Adam Brinckerhoff, Georgia Institute of Technology

Eccentric orbits in the third-body perturbed problem are evaluated for potential use in planetary moon missions, with a particular emphasis on Ganymede. Models for analysis include the doubly-averaged Hill's, the un-averaged Hill's plus non-spherical potential, and a full ephemeris. Promising results include long-term ephemeris stable orbits that find maximum inclinations above 60 degrees and cycle between high and low eccentricity while distributing the close approaches throughout all longitudes. The circulating orbits are less expensive to achieve than low-altitude circular orbits, and the orbital geometry and timing are favorable for a variety of both planetary moon and planetary system science.

14:20 **AAS 08 - 183** **Analysis of Two-Body Rectilinear Trajectories**
Douglas H. May, University of Arizona

This paper extends the linear trajectory solutions described in prior work that produced time-displacement equations for the complete range of two-body orbital motion. Included were the rectilinear trajectories for each type of orbit, elliptic, parabolic, and hyperbolic. This paper extends that approach with further analysis of the linear elliptic trajectory, deriving relative motion equations. With application in the context of relativity theory, the approach provides a means to relate motion between alllinear elliptic trajectories. Alternate inertial reference frames become evident in the derivation expanding the understanding of relative orbital motion.

14:45 **AAS 08 - 184** **Analytical theory for Moon Orbiter**
Alberto Abad, Antonio Elipe, University of Zaragoza; Juan F. Sanjuan, University of La Rioja

We consider the motion of an orbiter about the Moon under the Moon gravity and the third body attraction under Hill hypothesis. To this model, a perturbation theories are applied, namely elimination of the parallax and Delaunay normalization. By so doing, we get one degree of freedom normalized Hamiltonian. we determine the evolution of the phase flow, equilibria and bifurcations, that is, we find families of frozen orbits since critical points of the normalized Hamiltonian correspond to frozen orbits in the original Hamiltonian.

15:35 **Break**

Session 13: Satellite Constellations

Chair: Dr Ron Proulx, Draper Laboratory

08:00 **AAS 08 - 185** **The Flower Formation Flying. Part I: Theory**
Daniele Mortari, Texas A&M University; and Stefania Tonetti, Politecnico di Milano (Italy)

This paper presents the theory of Flower Formation Flying. Motivation comes from the need to extend the Theory of Flower Constellations to a configuration of satellites with small relative distances. Two different types of Flower Formation Flying are here presented: the Circular and the Elliptical Flower Formation Flying which are built on a reference orbit that is circular or elliptical, respectively. Similar to Flower Constellations, the Flower Formation Flying are ruled by some integer parameters for the satellite phasing and by other parameters identifying the reference orbit and the formation size. The Flower Formation Flying allows to create formations of spacecrafts with any relative distance and orbital eccentricity, overcoming the Clohessy-Wiltshire equations limits.

08:25 **AAS 08 - 186** **The Flower Formation Flying. Part II: Applications**
Stefania Tonetti, Politecnico di Milano; David Hyland and Daniele Mortari, Texas A&M University

This paper shows how to design a Flower Formation Flying for a multi-spacecraft interferometric systems to image with high resolution solar system planets, Moons, as well as satellites in GEO belt. To design the optimal formation, consisting in covering the resolution disk of the frequency plane, two optimization techniques have been adopted: Genetic Algorithm and Particle Swarm Optimization. Both design techniques include the Earth's eclipse problem. This papers shows the coverage as a function of the number of telescopes and of the image pixel number. Numerical results clearly show the coverage gain of Circular and Elliptical Flower Formations with respect to the classic string-of-pearls formations.

08:50 **AAS 08 - 187** **Multi-delay Analysis of the Stability of a Constellation of Satellites**
Yosef Gavriel Tirat-Gefen, Castel Research Inc. & George Mason University

This paper discusses the possible impact of multi-delay stability issues in the command and control of a constellation of observatory satellites controlled by telemetry from Earth. Differently from a typical communication constellation around the Earth, observatory satellites work together by sensory fusion. Inaccuracies in the relative position of the satellites may lead to degradation of the quality of the fused image. We investigate the impact of the communication delay and software processing overhead between Earth and the satellites, and among the satellites themselves in the stability and control of such constellation under presence of several perturbation types.

09:15 **AAS 08 - 188** **Non-Linear Discrete Controls for the Reconfiguration Procedure of the Tetrahedron Constellation**
Pedro A. Capo-Lugo and Peter M. Bainum, Howard University

The NASA Benchmark Tetrahedron Constellation requires a reconfiguration procedure between the different specific sizes of the proposed tetrahedrons. In previous work, the authors developed a fuzzy controller that can be used as a non-linear technique for the reconfiguration procedure of this problem. This paper will focus on the use of discrete non-linear controllers based on fuzzy controllers, non-linear discrete Lyapunov controllers, and impulsive maneuvers for the reconfiguration procedure. These non-linear discrete control techniques are used for the correction of the in-plane and out of plane motion. Hence, these discrete non-linear controllers will be used to reconfigure the proposed constellation.

09:40 **Break**

10:05 **AAS 08 - 189** **Nonlinear Stability and Control of a Two-Craft Magnetic Constellation**
Islam I. Hussein, Worcester Polytechnic Institute

Virtual-tether satellite constellations have received much interest in recent years. Virtual tethers can be created using distance action forces such as those created by a magnetic potential. In this paper, we will study a two-spacecraft magnetic system. We will derive the system equations of motion, and conserved quantities will be identified and used to reduce the size of the equations of motion. Relative equilibria will be derived and their stability tested. We will also investigate controllability of the shape dynamics of the system via magnetic actuation. Finally, we will focus on open loop control, where we use the notion of geometric phases to identify how to achieve a configuration shape change through a change in the magnetic dipole moment.

10:30 **AAS 08 - 190** **Solar Pressure Effects for a Constellation in Highly Elliptical Orbit**
Pedro A. Capo-Lugo and Peter M. Bainum, Howard University

In highly elliptical orbits, the solar pressure can perturb the motion of a constellation because of the longer exposure of the satellites to the Sun. To study these effects in formation flying, the Tschauner-Hempel equations for a perturbed motion, developed in a previous paper by the authors, are augmented to include the effects of the solar pressure force. Also, the authors develop a discrete control scheme to correct for this perturbation. In conclusion, this paper will show how the solar pressure will affect the control effort to correct the separation distance constraints for a pair of satellites within the constellation.

10:55 **AAS 08 - 191** **A Heuristic Approach to Design an Orbit for the Temporary Reconnaissance Mission Using a Few LEO Satellites**
Hae-Dong Kim, Korea Aerospace Research Institute

This paper addresses the problem of design of temporary satellite constellation with existing resources to reduce the average revisit time over a particular target site during period of time (30-days). The genetic algorithm (GA) is applied to the reconnaissance mission design as a heuristic approach. The best sets of initial conditions are sought by applying the GA algorithm to provide maximum coverage capability. Through comprehensive simulation study, the possibility of using a genetic algorithm to a target-point reconnaissance mission is demonstrated. This may be difficult to obtain by analytical approaches due to the complexity and nonlinear nature of the problem.

Session 14: Trajectory Design & Optimization I

Chair: Dr. Matthew Berry, Analytical Graphics, inc

08:00 **AAS 08 - 192** **Power-Limited Multi-Revolution Inter-Orbital Transfers**

Alexander Alexandrovich Sukhanov, Space Research Institute (IKI) of the Russian Academy of Sciences, Moscow; Antonio Fernando Bertachini de Almeida Prado, Instituto Nacional de Pesquisas Espaciais, São José dos Campos, Brazil

A multi-revolution spiral power-limited transfer between two given orbits in a strong gravity field is considered. There are various methods for solving the optimization problem in this case. However, most of the methods are rather complicated or have a limited application; in particular, they are applicable only to neighboring orbits or to planar transfers, etc. A simple and effective method for optimization of the low thrust transfers mentioned above is suggested.

08:25 **AAS 08 - 193** **Designing Trajectories in a Planet-Moon Environment Using the Controlled Keplerian map**

Piyush Grover and Shane D. Ross, Virginia Polytechnic Institute and State University

We present a method to design fuel efficient spacecraft trajectories for a multi-moon orbiter in the Jupiter-Europa-Ganymede system. Patched three-body approach is used to deal with this four body problem. Using a Hamiltonian structure preserving controlled Keplerian map derived earlier, we exploit the underlying dynamics consisting of multiple gravity assists outside the sphere of influence of the perturber, and use instantaneous velocity control inputs that force the spacecraft to visit regions which lead to rapid change of semi-major axis in the desired direction. Preliminary results are encouraging and we expect to find trajectories with realistic time-of-flight and low fuel requirements.

08:50 **AAS 08 - 194** **End-to-End Optimization of Conceptual Roundtrip Mars Missions with Exact Precession Elliptical Parking Orbits**

Aaron D. Olds, Analytical Mechanics Associates, Inc.; Michael L. Cupples, Raytheon Missile Systems

Previous conceptual studies of roundtrip Mars missions have considered orbital operations independently of the optimal roundtrip interplanetary trajectory. For elliptical parking orbits that naturally allow for tangential arrival and departure maneuvers, a decoupled optimization yields a discrete set of isolated solutions. By coupling the optimization of the roundtrip trajectory and the orbital operations at Mars, the design space is extended and shown to be continuous in many regions. Additionally, improvement is found in a number of solutions that are optimal in the decoupled problem.

09:15 **AAS 08 - 195** **Orbital Stability of Spacecrafts in Unstable Environments**

Iman Alizadeh and Benjamin Villac, University of California, Irvine

Stable manifolds of periodic orbits are important in designing space missions. They provide thrust free transfers towards their associated periodic orbits and have been used to extend spacecrafts life-time in unstable orbital environments. In this paper the feasibility of targeting stable manifolds for such applications is investigated numerically and related to the dynamical properties of the target periodic orbits. In particular, a concept of boundary layer and measure is developed to characterize theseproperties. By numerical analysis it is shown that trajectories inside this boundary layer have better stability properties. These ideas are illustrated for the Earth-Moon and the Jupiter- Europa systems. These results are expected to improve the currentdesign methodologies for space missions that require good orbital stability characteristics while involving unstable dynamics.

09:40 **Break**

10:05 **AAS 08 - 196** **Power Constrained Uranus Transfer and Moons Tour by Three Body Invariant Manifolds and Electric Propulsion**

P.Pergola, C. Casaregola, K. Geurts, and M. Andrenucci, ALTA S.p.A.

The construction of a spacecraft mission to Uranus with an associated low energy tour to Uranus is described. The entire interplanetary trajectory together with the planetary tour orbiting several of the Uranian moons, is computed using coupled three bodymodels. This approach is combined with power constrained Electric Propulsion to provide for the required energy changes. The total mission is divided into two parts: the long interplanetary transfer and the planetary tour within the Uranus system. Both parts rely on different intrinsic characteristics of the three body models employed.

10:30 **AAS 08 - 197** **Optimal Earth Escape Trajectory Using Continuation Method and Costate Estimator**

Donghun Lee and Hyochoong Bang, Korea Advanced Institute of Science and Technology

Multi-Revolution Optimal Trajectory for the Earth escape is studied in this paper. The cost function is related fuel consumption of a Low-thrust, final time is fixed and some final states are fixed. The aim is to find initial costate values when we adopt indirect method at the Low Earth Orbit. Continuation method based on polynomial interpolation is used to overcome the difficulties. At High Earth Orbit, the number of revolution is small, so this solution is used for the continuation method. Initial costate values with respect to initial radius from the Earth, behaved some fashion.This behavior is approximated with polynomials. Then, at the LEO, the initial costates are estimated using the polynomials.

10:55 **AAS 08 - 198** **The Inclusion of the Higher Order J3 and J4 Zonal Harmonics in the Modelling of Optimal Low-Thrust Orbit Transfer**

Jean A. Kechichian, The Aerospace Corporation

The higher fidelity modelling of minimum-time transfers using continuous constant acceleration low-thrust is depicted by including the higher zonal harmonics J3 and J4. Two sets of dynamic and adjoint differential equations in terms of nonsingular orbit elements are derived by further considering a more accurate perturbation model in the form of the higher order earth zonal harmonics. Previous analyses involved only the first order J2 in order to model optimal low-thrust transfers between any two elliptic orbits. The mathematics of both nonsingular formulations are mutually validated by generating an optimal transfer example that achieves the same target conditions.

Session 15: Orbital Dynamics, Perturbations & Stability I

Chair: Dr. James Gearhart, Orbital Sciences Corporation

08:00 **AAS 08 - 199** **Orbit Phasing Analysis for Elliptical Orbits**

Julio C. Benavides and David B. Spencer, Pennsylvania State University

This study analyzes optimal mission velocity change magnitudes required to perform a co-orbital phasing maneuver within an elliptical and circular orbit. Analytical velocity change expressions are derived in terms of initial orbital parameters. The results demonstrate that total mission velocity change is minimized when the number of phasing orbits traveled by the chase satellite is one more than the number of orbits traveled by the target satellite for phase angles between 0 degrees and 180 degrees. For phase angles between 180 degrees and 360 degrees, velocity change is minimized when target orbits are equal to phasing orbits. These results are verified by analyzing phasing maneuvers within three distinct orbital cases.

08:25 **AAS 08 - 200** **Shrinking Forbidden Regions and Elliptic Halos in the Spatial Elliptic Restricted Three-Body Problem**

Stefano Campagnola and Martin Lo, USC

We present special forbidden regions and periodic orbits in the spatial elliptic restricted three body problem. Periodic orbits and regions of motion are fundamental keys to understand any dynamical system; Hill's surfaces or halo orbits have been extensively studied in the circular restricted three body problem. It is our opinion that their natural extensions to the spatial elliptic restricted three body problem have not been studied enough. We define shrinking forbidden regions which are valid for a revolution of the primaries. Also, we compute branches of elliptic halos bifurcating from halos in the circular restricted three body problem. The elliptic halos have principal periods and stability properties other than those of the originating halo.

08:50 **AAS 08 - 201** **Small Eccentricity Satellite Orbits: Linear Perturbations**

G. E. O. Giacaglia, University of Taubate - Brazil, B. E. Schutz, University of Texas at Austin

The well known linearized theory of satellite motion given by Kaula (1966) has proven to be very useful in categorizing the nature of perturbations on the orbit that result from zonal, tesseral and sectoral harmonic gravity coefficients. In fact, the expressions for secular variations and the amplitude of some periodic variations are well represented by this theory. Nevertheless, problems exist when the eccentricity is small, for example, because of the use of classical orbit elements in Kaula's theory. This paper examines an alternate theory in the case of small eccentricity, which is the typical case for most Earth observing satellites, and illustrates the characteristics of Kaula's theory and the alternate theory with selected numerical examples.

09:15 **AAS 08 - 206** **Variation of Parameters Using Complex Exponentials to Solve the Perturbed Two-Body Problem**

Troy A. Henderson and Gianmarco Radice, University of Glasgow; John L. Junkins, Texas A&M University

A new formulation of the variation of parameters method for the perturbed two-body problem is presented. Here, this unique formulation is based on a complex exponential solution previously derived by the authors. The complex exponential formulation provides an exact analytical solution to the two-body problem and eliminates the singularities associated with the elliptical and hyperbolic trajectories that arise at zero eccentricity and zero inclination. We present the variation of parameters formulationand highlight the benefits of this approach compared with the classical developments.

09:40 **Break**

10:05 **AAS 08 - 203** **Third Body Perturbation Using a Single Averaged Model Considering Elliptic Orbits for the Disturbing Body**

Rita de Cássia Domingos and Rodolpho Vilhena de Moraes, Universidade Estadual Paulista-Unes; Antonio Fernando Bertachini de Almeida Prado, Instituto Nacional de Pesquisas Espaciais - São José dos Campos

In the present work, the assumptions used to develop the single-averaged analytical model are the same ones of the restricted elliptic three-body problem. After that, the equations of motion are obtained from the planetary equations and we performed a setof numerical simulations. Different initial eccentricities for the perturbing and perturbed body are considered. The results obtained performs an analysis of the stability of a near-circular orbit and investigate under which conditions this orbit remainsnear-circular. We also made an analysis of the stability of equatorial orbits. A study of the behavior of some other important variables is also performed.

10:30 **AAS 08 - 204** **Two-Body Trajectories with Drag and High Tangential Speeds**

Thomas E. Carter, Eastern Connecticut State University; Mayer Humi, Worcester Polytechnic Institute

This paper considers the restricted two-body problem with atmospheric drag. A simple formula is presented that approximates the atmospheric density from raw data, replaces previous models, and is amenable to closed-form solution of the orbit equation for high tangential speeds. A procedure for subdividing an altitude interval and calculating the parameters of the formula over each subinterval leads to highly improved accuracy in the solutions and compares favorably with numerical integration. To validate our model we compare it with the trajectory and flight time of a satellite in an exponential atmosphere starting from a near circular orbit at 7120 km from the Earth center.

10:55 **AAS 08 - 205** **Validation of Gravity Acceleration and Torque Algorithms for Astrodynamics**

Blair F. Thompson, David G. Hammen,Odyssey Space Research; Albert A. Jackson, Jacobs Engineering, ESCG; Edwin Z. Crues, NASA Johnson Space Center

A technique was developed to validate spherical harmonic gravity acceleration and torque algorithms for astrodynamics. A simulated system of point masses was developed to represent a large gravitational body. Spherical harmonic gravity coefficients were generated to represent the gravitational potential of the point mass system. Acceleration and torque were simultaneously computed from the gravity coefficients and directly from the point masses, then compared to validate the gravity algorithms. The technique can be applied to the validation of any spherical harmonic gravity algorithms used for engineering or space mission operations, and is not restricted to Earth gravity algorithms.

Session 16: Formation Flying & Rendezvous II

Chair: Dr. Matthew Wilkins, Schafer Corporation

13:30 **AAS 08 - 207** **Open-Loop Electrostatic Spacecraft Collision Avoidance Using Patched Conics Analysis**
Shuquan Wang and Hanspeter Schaub, University of Colorado at Boulder

This paper considers a two-spacecraft collision avoidance problem with the craft floating a few dozen meters apart. The Coulomb thrusting approach is used to develop a trajectory programming strategy to avoid the potential collision while conserving the relative velocity direction and magnitude. By assuming the spacecraft to be floating freely in deep space and maintaining piece-wise constant electrostatic charge levels, the relative trajectory can be described through splices of conic sections. A symmetric 3-conic-section programming strategy is designed to match up the arrival direction with the departure direction. Five constraints are introduced to formulate the five degrees of freedom problem. Newton's method is used to solve for one variable that results in the symmetric conic section trajectory.

13:55 **AAS 08 - 208** **Dynamic Models of Satellite Relative Motion Around an Oblate Earth**
Guangyan Xu and Danwei Wang, Nanyang Technological University

A series of dynamic models of satellite motion around an oblate Earth are derived. Firstly, a dynamics of a single satellite is presented in terms of the Reference Satellite Variables (RSV). Secondly, an exact J2 nonlinear model of satellite relative motion is developed based on Lagrangian mechanics. Then, with the aid of Gegenbauer polynomials, the nonlinear model is linearized to a complete J2 linear relative model. At last, by means of removing the 2nd order J2 effect, the linear model is further approximated to a first order J2 linear relative model. Coincidence with the fact that J2 gravity is axi-symmetric, each developed relative model is independent of the right ascension of ascending node and expressed by 11 first-order differential equations.

14:20 **AAS 08 - 209** **Orbital Express Autonomous Rendezvous and Capture Flight Operations**
Tom A. Mulder, The Boeing Company

The Orbital Express flight demonstration was established by the Defense Advanced Research Projects Agency (DARPA) to develop and validate key technologies required for cost-effective servicing of next-generation satellites. A contractor team led by Boeing Advanced Systems built two mated spacecraft launched atop an Atlas V rocket from Cape Canaveral, Florida. The low earth orbit test flight demonstrated on-orbit transfer of hydrazine propellant and a spare battery between spacecraft. It also demonstrated autonomous rendezvous and capture (AR&C) using new sensor, guidance, and relative navigation hardware and algorithms. AR&C flight operations are the focus of this paper.

14:45 **AAS 08 - 210** **Relative Trajectory Design to Minimize Stationkeeping Effort**
Steve Tragesser and Brent Skrehart, University of Colorado

An important development in the control of satellite formations is the concept of J2 invariance, where perturbations to the period and precession of the ascending node are minimized by selecting specific combinations of orbital elements. However, through a reformulation of the J2 invariance conditions, it can be shown that this severely limits the orbit designer's ability to meet specifications on the formation geometry (e.g. the orientation of the formation plane). This paper develops a reference trajectory and control scheme that retains some of the beneficial dynamics of J2 invariance, while allowing for a specified geometry to achieve requirements related to the mission payload.

15:10 **Break**

15:35 **AAS 08 - 211** **Inter-Satellite Ranging for Satellite Constellation Formation Keeping**
Andrew E. Turner, Space Systems/Loral

Inter-Satellite Range Measurement (ISRM) appears to be an attractive sensor for orbit determination work on a secondary spacecraft that has cross-link communications capability with a primary spacecraft whose orbit is accurately determined. This paper discusses the means to arrange two spacecraft in appropriate relative geometry for effective ISRM, provides background on highly accurate orbit determination already performed using selected Loral spacecraft, and includes the mathematical background to this type of analysis. Orbit determination using ISRM holds promise for cost-effective development, fabrication, establishment, and on-orbit mission operations for large formations of spacecraft. This could provide an in-orbit infrastructure for low-cost spacecraft navigation.

16:00 **AAS 08 - 212** **The Precise Autonomous Orbit Keeping Experiment on the PRISMA Formation Flying Mission**
Sergio De Florio, Simone D'Amico and Miquel Garcia Fernandez, German Aerospace Center (DLR)

Autonomous navigation and orbit control can increase mission performance and provide significant operations cost reduction. The fulfillment of strict requirements on different orbit parameters can be achieved in real time and with a significant reduction of ground operations. The Autonomous Orbit Keeping (AOK) experiment is the secondary objective of the German Aerospace Center (DLR) contributions to the PRISMA mission. The main requirement of the experiment is to demonstrate an autonomous control accuracy of the ascending node of 10 m (1sigma). This paper analyses the control problem, its feasible solutions and how it is implemented on the on-board flight software of the PRISMA mission.

16:25 **AAS 08 - 214** **The Reconfiguration and Formation-Keeping with State-Dependent Riccati Equation Nonlinear Controller**
Han-earl Park, Sang-Young Park, and Kyu-Hong Choi, Yonsei University

In this paper, we present an optimal reconfiguration trajectory and formation-keeping in satellite formation flying using state-dependent Riccati equation control technique and newly developed state-dependent coefficient form. First, the optimal reconfiguration trajectory that minimizes energy in satellite formation flying was determined. In addition, we developed the formation-keeping controller that is used state-dependent Riccati equation. We used Taylor series and trnasformation matrix in order to make state-dependent coefficient form from the nonlinear equation of relative motion with J2. In conclusion, the optimal reconfiguration trajectory was able to minimize required energy, and the formation-keeping controller had the robustness in the perturbations.

Session 17: Attitude Dynamics, Determination & Control II

Chair: Jeff Beck, Northrop Grumman Corporation

13:30 **AAS 08 - 215** **Quaternion Constrained Kalman Filter**
Manoranjan Majji and Daniele Mortari, Texas A&M University

This paper presents a novel method of norm constrained estimation of dynamic systems. The filter thus derived is specialized to solve the attitude estimation problem.Continuous discrete attitude filter and the discrete attitude filter are presented using the specialized result. A new derivation of the state transition matrix, describing the time evolution of the quaternion is obtained using true to nature considerations. A generalized Farrenkopf process noise model has been developed to derive the discrete attitude filter presented. Numerical comparisons with the classical Multiplicative Kalman Filter have been included for three situations. The tests result highlights the gain of the proposed method for accuracy, convergence, and filter stability.

13:55 **AAS 08 - 216** **Sub-Arcsecond Attitude Control for Sounding Rocket Payloads**
Neil S Shoemaker and Charles G. Kupelian, NASA Wallops Flight Facility; Jeffrey W. Percival and Kurt P Jaehnig, University of Wisconsin; Ronald Hall, Aerojet

This paper describes an Attitude Control System that has been flight demonstrated to achieve better than 0.2 arcsec, 1 sigma and 0.5 arcsec Full Width at Half Maximum for each axis. Key components of this ACS include a roll stabilized fiber optic gyro, a precision fiber optic gyro, a cold gas linear thrust module, an uplink command system, and a 3 axis star tracker. In addition to providing gyro drift compensation, the star tracker provides celestial reference through its Lost in Space (LIS) solution. Also discussed is a maneuver algorithm to rotate the pointing axis along a great circle.

14:20 **AAS 08 - 218** **Sigma-Point Kalman Filtering for Spacecraft Attitude and Rate Estimation Using Magnetometer Measurements**
Mohammad Abdelrahman and Sang-Young Park,Yonsei University

A generalized algorithm for spacecraft three-axis attitude and rate estimation base on magnetometer measurements and their time derivatives is presented. From the family of SPKF the Unscented Kalman Filter (UKF) architecture is used to handle the addressed problem. A Monte Carlo simulation has been established to study the performance of the proposed filter with initial attitude and angular velocity sampled from uniform distributions. Then, the filter has been tested to estimate the attitude and rates during satellite detumbling and standby modes of EgyptSat-1, launched in the last April. The filter has shown the capability of estimating the attitude better than 5 deg and rate of order 0.03 deg/sec in each axis.

15:10 **Break**

15:35 **AAS 08 - 219** **An Expectation-Maximization Approach to Attitude Sensor Calibration**
Yang Cheng and John L. Crassidis, University at Buffalo

An Expectation-Maximization approach to three-axis-magnetometer calibration is presented. This approach is different from the existing attitude-independent approaches mainly in how the unknown attitude parameters in the attitude sensor measurement model are handled. The attitude-independent approaches rely on a conversion of the body and reference representations of the Earth’s magnetic field vector into an attitude-independent scalar observation by using scalar checking. The Expectation-Maximization approach essentially maximizes the expectation of the complete likelihood function with respect to the probability distribution of the attitude parameters. Three test scenarios of the Expectation-Maximization approach using simulated three-axis-magnetometer data are presented.

16:00 **AAS 08 - 221** **Attitude Control of Spinning Solar Sail with Huge Membrane**

Fuminori Hanaoka, The University of Tokyo; Osamu Mori, Yuichi Tsuda, Ryu Funase and Jun'ichiro Kawaguchi, ISAS/JAXA

ISAS/JAXA is now considering a spinning solar sail mission for future interplanetary exploration. One of major problems to solve is attitude control of spinning sail with huge membrane. In this paper, two types of attitude control is investigated, one of which is the method using conventional chemical thruster and another one is the method using devices with variable reflectivity such as liquid crystal. Both methods are found to be feasible for the next planned solar sail mission. The scope of applicationand the feature of these methods are also discussed here.

16:25 **AAS 08 - 222** **Study on Spacecraft Motion Compensation Technology for Chinese Geostationary Meteorological Satellite Image Registration**

CUI Yankai, Wang Zhigang, College of Astronautics, Northwestern Polytechnical University - China.

Because the satellite comes under influences from all kinds of disturbance during the circulation, attitude of satellite is disturbed, which results in pixel excursion of the scan mirror image. In this paper, the basic solution to spacecraft motion compensation of image registration is put forward. Spacecraft motion compensation means that the influences of attitude disturbance are eliminated through producing scan mirror motion control compensation signal according to compensation arithmetic. The result of simulation indicates that optical axis pointing deviation is obviously reduced after spacecraft motion compensation. Accordingly, the validity of compensation arithmetic and feasibility of compensation plan are proved.

Session 18: Special Session: USA Space History

Chair: Dr. Michael Gabor, Northrop Grumman

13:30 **AAS 08 - 223** **Echo I and II -- The First Communications Satellites**
Ronald M. Muller, Perot Systems Government Services

Echo I was launched on August 12, 1960 on the first successful Delta launch. This 100-foot diameter aluminized Mylar balloon satellite demonstrated satellite wide-band communications. Visually bright, it showed the world that the United States could win the "space race." The changes in its orbit proved that solar pressure was a real force. The 135 foot diameter Echo II was launched on January 25, 1964. It was constructed of aluminum foil on Mylar producing a much better sphere than was obtained by Echo I. The orbital inflation was observed by the first television from orbit.

13:55 **AAS 08 - 224** **Defining Moments in the Naval Research Laboratory's Project Vanguard**
Patrick W. Binning, Naval Research Laboratory

On December 6, 1957, the eyes of the nation, and the world, were on the Naval Research Laboratory's "first" launch attempt with the Project Vanguard system. NRL was competitively selected in 1955 by a Defense Department committee to execute America's first space program. Our nation's first response, named Test-Vehicle 3 (TV-3) by NRL, to the Soviets' two successful Sputnik launches exploded on national television shortly after leaving the pad. This defining moment in the birth of our nation's spaceflight program immediately focused America on the importance of science, technology, engineering, and mathematics education. Ultimately, NRL successfully launched Vanguard on St. Patrick's Day, 1958. The defining events in Project Vanguard will be explored.

14:20 **AAS 08 - 226** **Space Spin-Offs**
Carlos Francisco Camacho, Colin A Johnson-Giammalvo, James Wanliss, Joseph Mosca, Paige Victoria Kahler, Embry-Riddle Aeronautical University

US space technology has done more than taken man to the moon, it has facilitated the lives of the world community. While the original uses were for grander missions than making the lives of everyday people richer and more convenient, it has indeed done just that. These are what are called spin-offs. Developed specifically for the scientific community and the exploration of space, they have found uses in everyday life. Some examples of spin-offs are things like Heatsheets and WD-40.

15:10 **Break**

15:35 **AAS 08 - 227** **A History of Magnetic Momentum Dumping on Global Positioning System Satellites**
Thomas J. Eller, Astro USA, LLC; Ronald Fuchs, Boeing

In the mid 1970s the first GPS satellites were three-axis controlled vehicles using four momentum wheels. Due to biased forces on the vehicle, wheels periodically needed to have their RPM reduced—their momentum dumped. The provision for this was clusters of hydrazine thrusters fired in pairs. Following each dump, unwanted translational forces, rendered the orbital position too uncertain for use in navigation for up to 24 hours. This paper is the history of the solution to that problem. It recounts the challenges, the players involved, the theory, the mathematical approach, and the sequence of events from concept to operational use.

16:00 **AAS 08 - 228** **Historical Examination of Improvements to Libration Point Trajectory Design**
David Folta, NASA Goddard Space Flight Center

Over the years, NASA has experienced a fundamental change in how mission analysis and operations are performed. Improvements in trajectory design have been made that would at first glance seem dramatic. This paper provides a brief historical narrative on how a fundamental shift has occurred and how ‘chaos’ dynamics improve the design of missions with complex constraints. Beginning with the trajectory design of the ISEE-3 using optimization tools on mainframes, moving on to WIND design using differential correctors on PCs, and ending with JWST use of dynamical system theory of manifolds and stable modes, lessons learned from decades of continuous technical improvement are presented along with whether these methods promise to have a significant impact on future space mission design.

16:25 **AAS 08 - 229** **The Renaissance of the American Nautical Almanac Office, 1940**
Raynor Duncombe, The University of Texas at Austin

With war clouds gathering, no Air Almanac for the burgeoning Army Air Corp, delays in production of the Nautical Almanac, and the resignation of the Director of the Office, a search began for a new Director. Dr. Wallace Eckert, Head of the Computing Laboratory at Columbia University, who had been adapting punched-card machines to the solution of scientific problems, accepted the position of Director in 1938. Improvements in methods and volume of computation and production followed. These improvements led to later adaption of modern computing equipment. A description of IBM punched-card machines, with pictures, illustrate their individual functions.

Session 19: Orbital Dynamics, Perturbations & Stability II

Chair: Bob Glover, AT&T

08:00 **AAS 08 - 230** **A State Transition Matrix Using Complex Exponentials for the Two-Body Problem**
Troy A. Henderson and Gianmarco Radice, University of Glasgow; John L. Junkins, Texas A&M University

Previously, a complex exponential solution was derived which unified the elliptic and hyperbolic trajectories into a single set of equations and provided an exact analytical solution to the unperturbed two-body problem. The formulation eliminates singularities associated with the elliptical and hyperbolic trajectories that arise from these orbit trajectories. Using this complex exponential solution formulation, the state transition matrix has been analytically derived and is presented. We present the analytical state transition matrix formulation and highlight the benefits of this approach compared with the classical developments.

08:25 **AAS 08 - 231** **Orbits and Relative Motion Near an Oblate Body**
Mayer Humi, Worcester Polytechnic Institute; Thomas E. Carter, Eastern Connecticut State University

This paper studies the orbits of satellites in the non-central gravitational field of an oblate body that includes the J2 term. A discussion of the angular momenta and equations of motion of objects in the equatorial, semi-equatorial, and polar orbit is presented. Some progress toward the solution and approximate solution of the equations of motion is presented for these cases. The paper also derives the relative-motion equations that describe a spacecraft in the vicinity of a satellite in equatorial, semi-equatorial or polar orbit in this gravitational field. We show that the rendezvous equations can be simplified to resemble the corresponding equations for a central force field. In particular, equations similar to the Tschauner-Hempel equations appear for orbits in the equatorial plane.

08:50 **AAS 08 - 232** **Effect of Earth's Precession on Geosynchronous Satellites under Lunisolar Perturbations and Tesseral Resonance**
Sofia Belyanin and Pini Gurfil, Technion

In this study, we investigate the effect of Earth's precession on the orbital dynamics of geostationary satellites. Our astrodynamical model includes second-order zonal and tesseral harmonics, and lunisolar gravitation. We show that the equinoctial precession induces secular inclination growth and thus bares a non-negligible effect on north-south stationkeeping for long mission lifetimes.

09:15 **AAS 08 - 233** **GPS Forces and Orbit Evolution**
Laurent Froideval and Bob Schutz, The University of Texas at Austin

The GPS satellites experience a set of well known gravitational and nongravitational forces. The gravitational forces are dominated by Earth mass distribution and luni-solar effects. At the GPS altitude of 20,000 km, solar radiation pressure dominates the nongravitational force category, but other forces are know to exist, such as y-bias, a force directed perpendicular to the Sun-GPS line along the spacecraft y-axis. Using GPS ephemerides generated by the International GPS Service, the characteristics of the orbit evolution of the GPS satellites and the nature of the perturbing forces has been examined.

09:40 **Break**

10:05 **AAS 08 - 234** **Impact of the Initial Configuration on the Motion near the Triangular Libration Points of the Sun-Perturbed Earth-Moon System**
Jean-Philippe Munoz and Bob E. Schutz, the Univeristy of Texas at Austin

The influence of the initial configuration of the Earth-Moon-Sun system on the motion near L4 and L5 of the Earth-Moon system is studied under the approximation of the Bicircular Problem. It is found that there exist two critical initial positions of the Sun for which a particle initially at rest at L4 will remain at an average distance of 10,000 km from L4 for as long as desired, provided sufficient numerical accuracy, and that the resulting trajectories can be further improved to remain closer to L4. These results seem to persist in a more realistic model (JPL ephemerides).

10:30 **AAS 08 - 235** **Integration of Orbit Trajectories in the Presence of Multiple Full Gravitational Fields**
Matthew Berry and Vincent T. Coppola, Analytical Graphics, inc.

In this paper we demonstrate the effect of including multiple full gravitational fields in numerical orbit propagation, compared to only including one gravitational field and modeling the other bodies as point masses. Several test cases are examined in the Earth-Moon and the Jovian and Saturn systems. The tests show the increased accuracy gained by modeling multiple gravity fields, as well as the cost in run-time. The tests also show the effect of changing the reference frame of the integration on the integrated trajectory.

10:55 **AAS 08 - 236** **Long-Term Behavior of a Mercury Orbiter Perturbed by the Elliptic Motion of the Sun**
Carlos Corral, GMV Aerospace and Defence S.A.; Martin Lara, Real Observatorio de la Armada; Jesus F. Palacian and Patricia Yanguas, Universidad Publica de Navarra

The long term behavior of an orbiter around Mercury is studied. Only the main part of the problem is attacked, where Mercury and the Sun are taken as mass points. Three consecutive Lie transforms average the problem to one degree of freedom in the spacecraft's eccentricity and argument of the periherm. After averaging, the semimajor axis of the orbiter and its polar component of the angular momentum are dynamical parameters. Bifurcation lines of equilibria define different regions in the parameters plane where the phase space is fully analyzed. Finally, nominal science orbits for both MESSENGER and BepiColombo are identified.

11:20 **AAS 08 - 237** **Three-Dimensional Analysis of Capture Trajectories to the Periodic Orbits of L1 and L2 Points**
Masaki Nakamiya, Japanese Graduate University for Advanced Studies; Daniel Scheeres, University of Michigan; Hiroshi Yamakawa, Kyoto University; Makoto Yoshikawa, Japan Aerospace Exploration Agency

Spacecraft capture trajectories to the periodic orbits of L1 and L2 points in the restricted Hill three-body problem are analyzed. The specific focus is on transfer into these vicinities from interplanetary trajectories. This application is motivated by future proposals to use the Sun-Earth and Sun-Target body collinear L1 and L2 points as space hub for planetary Mission. We utilize stable manifolds for capture trajectories to periodic orbits around the L1 and L2 points. The way of linking between interplanetary transfer trajectories and the stable manifold in three dimensions is also discussed.

Session 20: Spacecraft Guidance, Navigation & Control III

Chair: Al Treder, Barrios Technology

08:00 **AAS 08 - 238** **Geostationary Satellite Station-Keeping Maneuver in the Presence of Twice-a-Day Thruster-Based Momentum Dumping**
Author Name: Byoung-Sun Lee, Hae-Yeon Kim, Yoola Hwang, and Jaehoon Kim, Electronics and Telecommunications Research Institute, Korea

Geostationary satellite should perform station-keeping maneuver to maintain the position in a pre-defined longitude and latitude box. Various orbital perturbations due to the Sun, the Moon, and the Earth cause a continuous change in nominal position of the satellite. Thruster firing operations to unload the momentum of the satellite also cause a change of the orbital element. In this paper, geostationary satellite station-keeping maneuver is analyzed when the satellite performs twice a day thruster-basedmomentum dumping which perturbs the satellite orbit. Weekly based East/West and North/South station-keeping maneuver are performed to maintain the satellite with ±0.05° longitude and latitude box.

08:25 **AAS 08 - 239** **Autonomous Navigation Algorithm for Precision Landing on Unknown Planetary Surfaces**
Baro Hyun and Puneet Singla, University at Buffalo

The purpose of this work is to provide an innovative solution for autonomous navigation of a spacecraft on an unknown planetary surface. The main features of this work is the novel framework to automate the efficient production of the topographic contour maps of the planetary terrain by stitching together various local terrain maps and inertial position and velocity of the spacecraft in a global inertial frame. Our approach is motivated in search of a navigation algorithm when any sort of inertial information is not available. Finally, numerical simulations are conducted to validate the ideas presented in this paper.

09:15 **AAS 08 - 241** **The Planning of Optical Navigation Pictures for the Cassini Extended Mission**
Stephen D. Gillam, Rodica Ionasescu, Brent Buffington, Nathan Strange, and Powtawche Williams, Jet Propulsion Laboratory

Optical navigation is necessary to the success of the Cassini extended mission at Saturn. This paper will describe the optical navigation image (opnav) planning for the Cassini extended mission, which includes nine low-altitude flybys of the icy satellites including seven of Enceladus, one of Dione and one of Rhea. Two of the Enceladus flybys have closest approach altitudes at or below 50 Km. We will present studies showing how much the uncertainties in the Enceladus ephemeris can be reduced by the inclusion of opnavs in the orbit determination. We will show that the planned opnavs will maintain the precision of the satellite ephemerides to support the close flybys, cover periods of poor radiometric data during solar conjunctions, and provide a backup data type during the

09:40 **Break**

10:05 **AAS 08 - 242** **Maneuver Planning for Conjunction Risk Mitigation with Ground Track Control Requirements**

David P. McKinley, a.i. solutions, Inc.

The planning of conjunction Risk Mitigation Maneuvers (RMM) in the presence of ground track control requirements is analyzed. Past RMM planning efforts on the Aqua, Aura, and Terra spacecraft have demonstrated that only small maneuvers are available when ground track control requirements are maintained. Assuming small maneuvers, analytical expressions for the effect of a given maneuver on conjunction geometry are derived. The analytical expressions are used to generate a large trade space for initial RMM design. This trade space represents a significant improvement in initial maneuver planning over existing methods that employ high fidelity maneuver models and propagation.

10:30 **AAS 08 - 243** **Payload Line-of-Sight Calibration with Dual Optical Sensors in Thermal Vacuum Chamber**

Tai Mao, Charles Chang, Kevin Rigg, Yaujen Wang, Peter C. Lai, Gary Hsieh, and Sabby Sabnis, Northrop Grumman

End-to-end Payload (P/L) line-of-sight (LOS) calibration with verification of software and hardware integration in thermal vacuum testing is presented. The primary focus of this effort is to verify an onboard autonomous attitude determination algorithm. This autonomous process involves area of interest star window generation from star field, star image acquisition, the brightest star and centroid location extraction from the image and subsequent computations of attitude and its update in all three axes. The collimated beams from the star scene are placed within 1.8º x 1.8º collimator field of view (FOV). Star window is generated within 1.6º x 1.6º FOV. One of the keys to the success of this test is resolving the star beams to be within the window by adjusting scan mirror assembly.

10:55 **AAS 08 - 244** **Image Navigation and Registration Technology for Chinese Geostationary Meteorological Satellite**

CHEN Yinchao, WANG Zhigang, and CHEN Shilu, Northwestern Polytechnical University - China

The deviation of the orbit and attitude of the meteorological satellite results in the optical axis of the payloads to deviate its normal direction and then the image quality becomes lower. To acquire high quality image, an algorithm of image navigation and registration is designed in this paper. Simulation results demonstrate that the proposed algorithm can effectively compensate the deviation of the optical axis from the motion of the satellite orbit and attitude.

Session 21: Trajectory Design & Optimization II

Chair: Dennis Byrnes, Jet Propulsion Lab

08:00 **AAS 08 - 245** **Rapid Orbital Transfers Between Non-Coplanar Orbits with J2 Perturbation Based on Invariability of Descending Nodical Local Time**
LU Qisheng, WANG Zhigang, Northwestern Polytechnical University - China

The problem of rapid orbital transfers between non-coplanar circular orbits with J2 perturbation based on the invariability of descending nodical local time is studied. Precise relative motion equations are given, and the optimal control model is derived with the minimum principle. The optimal problem is solved using conjugate gradient method based on fixed transfer time and continuous thrust. The transfer time is given according to the rapidness of orbital transfers, and special boundary conditions are determined, which ensure the invariability of descending nodical local time. The validity of this orbital transfer strategy has been verified by simulation results.

08:25 **AAS 08 - 246** **Optimal Spacecraft Trajectories via Trade Space Exploration**
David B. Spencer, Daniel D. Jordan, Timothy W. Simpson, Michael A. Yukish, and Gary M. Stump, Pennsylvania State University

With recent advances in computing power and speed, designers can now simulate and evaluate thousands, if not millions, of design alternatives more cheaply and quickly than ever before. These advancements provide new opportunities to revolutionize trade space exploration for complex dynamical systems in the aerospace industry, among others. In this paper, we apply our software, ARL Trade Space Visualizer (ATSV), to search for optimal impulsive trajectories. This problem is formulated as a multiobjective optimization problem where it is desirable to explore various competing objectives. First, we show a coplanar two-burn transfer and compare the results to that obtained from the Hohmann transfer. Next, a more complex three-dimensional transfer is explored, and trends of optimal solutions (Pareto fronts) are found.

08:50 **AAS 08 - 247** **Geometry of Optimal Coverage for Space Based Targets with Visibility Constraints**
Dr. Belinda Marchand, The University of Texas at Austin; Chris Kobel, The Aerospace Corporation

The optimal satellite coverage problem traditionally refers to maximizing the visibility of ground based targets. In this study, the focus is shifts to space based targets under certain constraints. Specifically, the goal of this study is to identify a systematic approach for determining the optimal altitude that maximizes sensor visibility of an area of space enclosed within an upper and lower target altitude range. It is further assumed that sensor visibility below the local horizon is diminished due toatmospheric or environmental factors. geometrical arguments are employed to identify an analytical expression for the coverage area to be optimized.

09:15 **AAS 08 - 248** **High Road to Geosynchronous Orbit: Lunar Assist to Minimize Delta-V**
Andrew E. Turner, Space Systems/Loral

This paper develops the concept of lunar gravity assist (LGA) to benefit geosynchronous and other spacecraft requiring large inclination changes during orbit-raising. Unlike previous work such as the orbit-raising for HGS-1 that required the moon to be very near the equatorial plane during LGA to remove all inclination, the technique developed here permits the moon to be well away from the equator when encountered. Therefore, launch opportunities are permitted on most or all days of the year instead of only a few days each month. This technique will also be developed for inclination change to support other orbit raising scenarios.

09:40 **Break**

10:05 **AAS 08 - 249** **Impulsive Transfer Strategies along Stable Periodic Orbit Families**
Benjamin F. Villac, University of California, Irvine

This paper describes some impulsive transfer strategies that generalize the classic Hohmann transfers and allows to robustly guide a spacecraft along Such families often represent a safe and stable pathway from different regimes of motion in an otherwise unstable orbital environment. The proposed strategies thus ensure strong stability and recovery properties of spacecraft transfers for risk sensitive missions. As a result, this research should be useful for missions planning with constraining back-up options requirements. Examples of transfers along distant retrograde families in the neighborhood of the planetary moons are considered to illustrate the strategies.

10:30 **AAS 08 - 250** **Optimization of Trajectories for an Interplanetary Supply Chain Network**
Yosef Gavriel Tirat-Gefen, Castel Research Inc. & George Mason University

This paper discusses the design of the trajectories of a set of reconfigurable refuel space stations and other spacecraft to support interplanetary missions. We consider a likely scenario where interplanetary transport vehicles will be deployed to routine missions carrying supplies such as parts, food, water and medicine to these stations, and will form the backbone of a future supply-chain network to support human presence on Mars and beyond. Their trajectories will be constrained by time, cost, budget for fuel, and rendezvous locations. We propose the use of soft computing techniques to optimize these trajectories.

10:55 **AAS 08 - 251** **Cost-Based Launch Opportunity Selection Applied to Rendezvous with 99942 Apophis**
Jonathan S. Townley, Jonathan L. Sharma, and Jarret M. Lafleur, Georgia Institute of Technology (Undergraduate)

Pork chop plots of launch C3 and arrival excess velocity are commonly used to select launch opportunities for interplanetary missions. However, the launch dates for minimum launch C3 and minimum arrival excess velocity rarely coincide. This paper presents a method for creating program-cost-based pork chop plots based on launch C3, arrival hyperbolic excess velocity, and specifications such as payload mass. This method is applied to a mission to Apophis and shows that total program cost more closely correlates with arrival excess velocity than launch C3. Sensitivities, such as the sensitivity of program cost to payload mass uncertainty, are also assessed.

Author Index

Author	Session
Abad, A.	12
Abdelrahman, M.	17
Abusali, P.	11
Akella, M.	2
Akella, M.	3
Alfriend, K.	3
Ali, I.	5
Alizadeh, I.	14
Andrenucci, M.	14
Ankersen, F.	9
Avanzini, G.	5
Bainum, P.	13
Bang, H.	14
Bedrossian, N.	2
Beigelman, I.	6
Bellerose, J.	10
Belyanin, S.	19
Benavides, J.	15
Berry, M.	19
Bettadpur, S.	11
Bhatt, S.	2
Bieber, B.	11
Binning, P.	18
Bishop, R.	9
Blake, C.	6
Bloch, A.	13
Brazeau, P.	6
Brinckerhoff, A.	12
Buffington, B.	20
Burgon, R.	9
Camacho, C.	18
Campagnola, S.	15
Capo-Lugo, P.	13
Carpenter, R.	2
Carrico, J.	4
Carrico, J.	18
Carrico, T.	4
Carter, T.	15
Carter, T.	19
Casaregola, C.	14
Cefola, P.	8
Chang, C.	20
Chang, I.	7
Cheng, M.	11
Cheng, Y.	17
Chinnan, A.	3
Choi, K.	2
Choi, K.	7
Choi, K.	16
Chuba, W.	8
Clark, F.	1
Coppola, V.	19
Corral, C.	19
Crain, T.	1
Crassidis, J.	17
Crues, E.	15
Cupples, M.	14
D'Amico, S.	16
De Florio, S.	16
de Lafontaine, J.	6
Deiterich, C.	18
Delavault, S.	4
DeMars, K.	9
Drakunov, S.	3
D'Souza, C.	1
Duncan, M.	4
Duncombe, R.	18
Elipe, A.	12
Eller, T.	18
Ellis, J.	7
Fernandez, M.	16
Finkleman, D.	4
Folcik, Z.	8
Folta, D.	1, 18
Froideval, L.	19
Fuchs, R.	18
Funase, R.	6, 17
Getchius, J.	1
Geurts, K.	14
Giacaglia, G.	15
Gillam, S.	20
Goodson, T.	2
Grover, P.	14
Gurfil, P.	6, 9, 19
Hall, C.	7
Hall, R.	17
Hammen, D.	15
Hanaoka, F.	17
Hatlelid, J.	2
Heaton, A.	10
Henderson, T.	15, 19
Hiatt, A.	11
HIrabayashi, M.	11
Hsieh, G.	20
Hull, D.	3
Humi, M.	15
Humi, M.	19
Hussein, I.	13
Hwang, Y.	9, 20
Hyland, D.	13
Hyun, B.	20
Ionasescu, R.	20
Jackson, A.	15
Jaehnig, K.	17
Janssens, F.	5
Johnson-Giammalvo, C.	18
Jones, B.	1, 8
Jordan, D.	21
Junkins, J.	9
Junkins, J.	15, 19
K. Kuga, H.	8
Kahler, P.	18
Kawaguchi, J.	5, 6, 10, 11, 17
Kawakatsu, Y.	1
Kechichian, J.	14
Kim, H.	9, 13, 20
Kim, J.	9, 20
Kitajima, A.	5, 11
Kluever, C.	2
Kobel, C.	21
Kominato, T.	10
Kron, A.	6
Kuninaka, H.	10
Kupelian, C.	17
Lafleur, J.	21
Lai, P.	20
Lamy, A.	4
Lara, M.	19
Lee, B.	9, 20
Lee, D.	14
Lee, T.	2
Lo, M.	15

Author	Session
Longman, R.	3
Lorda, L.	4
Majji, M.	9, 17
Mao, T.	20
Marchand, B.	21
May, D.	12
McAdams, J.	10
McKinley, D.	20
McLaughlin, C.	11
Mesarch, M.	1
Miller, J.	10
Miller, R.	1
Misra, A.	6
Miwa, Y.	11
Mombaur, K.	3
Moraes, R.	15
Mori, O.	5, 10, 17
Mortari, D.	13
Mortari, D.	13, 17
Mosca, J.	18
Mulder, T.	16
Muller, R.	1, 18
Munoz, J.	19
Nakamiya, M.	19
Natarajan, A.	7
Newman, L.	4
Ogle, J.	11
Okada, S.	10
Olds, A.	14
Oltrogge, D.	4
Osenar, M.	1
Page, B.	10
Palacian, J.	19
Panomruttanarug, B.	3
Park, S.	7, 16, 17
Patel, P.	3
Peck, M.	2
Pelaez, J.	5, 7
Percival, J.	17
Pergola, P.	14
Pizarro-Rubio, A.	5
Prado, A.	4, 14
Prado, A.	15
Qisheng, L.	21
Radice, G.	5, 15, 19
Raimundo, P.	8
Rand, D.	4
Raney, R.	11
Ries, J.	11
Rigg, K.	20
Roberts, P.	9
Ross, S.	14
Russell, R.	12
Sabey, N.	7
Sabol, C.	8
Samaan, M.	5
Sanjuan, J.	12
Sanjurjo-Rivo, M.	7
Schaub, H.	7, 16
Scheeres, D.	3, 10, 19
Schutz, B.	15, 19
Scott, R.	4
Seago, J.	1
Sharma, J.	21
Shilu, C.	20
Shirakawa, K.	5, 10
Shirasawa, Y.	5
Shoemaker, N.	17
Shum, C.	11
Simard Bilodeau, V.	6
Simpson, T.	21
Singh, T.	8
Singla, P.	8
Singla, P.	20
Skrehart, B.	16
Slane, J.	7
Smith, J.	10
Smith, W.	11
Souza, L.	9
Spencer, D.	15, 21
Srikant, S.	3
Stanbridge, D	10
Stough, R.	10
Strange, N.	20
Streetman, B.	2
Stump, G.	21
Su, S.	2
Sukhanov, A.	14
Takahashi, Y.	4
Talent, D.	4
Tapley, B.	11
Taylor, A.	10
Theil, S.	5
Thompson, B.	2, 15
Tirat-Gefen, Y.	13, 21
Tonetti, S.	13
Townley, J.	21
Tragesser, S.	7, 16
Truong, S.	8
Tsuda, Y.	5, 17
Turner, A.	6, 16, 21
Turner, J.	9
van der Ha, J.	5
Vilhena de Moraes, R.	8
Villac, B.	14
Villac, B.	21
Wagner, S.	2
Wang, D.	6, 16
Wang, S.	16
Wang, Y.	20
Wanliss, J.	18
Whorton, M.	10
Wilkins, M.	8
Williams, B.	10
Williams, K.	10
Williams, P.	20
Wolff, P.	10
Woodburn, J.	1, 8
Wright, J.	8
Wu, B.	6
Xu, G.	6, 16
Xu, Y.	8
Yamakawa, H.	19
Yan, H.	3
Yanguas, P.	19
Yankai, C.	17
Yinchao, C.	20
Yoon, J.	8
Yoshikawa, M.	19
Yue, H.	6
Yukish, M.	21
Zanetti, R.	9
Zhao, C.	11
Zhigang, W.	17, 20, 21

2008 Winter Conference Survey

The organizing committee is committed to providing you with the best conference experience possible and welcomes your comments. Please fill out this questionnaire and return it to the registration desk, or to a session chair. Thank you!

General

Please tell us if you registered as

¡ Student ¡ Retired ¡ Member ¡ Non-member

Please tell us if you think the conference was well organized

¡ ¡ ¡ ¡ ¡

Poorly organized … Very well organized

Please tell us if you think that the conference information site was adequate in presenting all necessary information.

¡ ¡ ¡ ¡ ¡

Very Bad … Very Good

Approximately how many conferences of this type do you attend annually?

- ¡ 1 every other year or less
- ¡ 1-2 per year
- ¡ 2 or more per year
- ¡ Don't usually attend this conference

Where do you think our conference fee typically falls in terms of value?

¡ ¡ ¡ ¡ ¡

Very Bad … Very Good

Registration

Overall, how satisfied were you with the online registration process?

¡ ¡ ¡ ¡ ¡

Disappointing … Exceptional

Overall, how satisfied were you with the online abstract/paper submission process?

¡ ¡ ¡ ¡ ¡ ¡

Disappointing … Exceptional N/A

How much does the registration fee influence your decision or ability to regularly attend these conferences?

¡ ¡ ¡ ¡ ¡

Not at all … Extremely

Venue

Overall, how satisfied were you with the conference location?

¡ ¡ ¡ ¡ ¡

Disappointing … Exceptional

Overall, how satisfied were you with the conference facilities?

¡ ¡ ¡ ¡ ¡

Disappointing … Exceptional

If there were some financial and/or organizational benefit in limiting future conference venues, what would you prefer most?

Summer Astrodynamics

- ¡ Just keep rotating locations
- ¡ Alternate between 3 fixed locations (one West, one Central, one East)
- ¡ Maintain the same location
- ¡ Don't care
- ¡ Other: ___________________

Winter Space Flight Mechanics

- ¡ Just keep rotating locations
- ¡ Alternate between 3 fixed locations (one West, one Central, one East)
- ¡ Maintain the same location
- ¡ Don't care
- ¡ Other: ___________________

Technical Content

How satisfied were you regarding the overall technical content presented at the conference?

¡ ¡ ¡ ¡ ¡

Disappointing … Exceptional

How satisfied were you with the printed materials received?

¡ ¡ ¡ ¡ ¡

Disappointing … Exceptional

As a participant, how satisfied were you with the pre-conference correspondence / information you received?

¡ Too much ¡ Just about right ¡ Not Enough ¡ N/A

How do you feel about the publisher's 20-page limit on papers?

¡ Too long ¡ Just about right ¡ Too short ¡ Don't Care

How do you feel about having 72 hours before the conference to download / print preprints?

¡ Too long ¡ Just about right ¡ Too short ¡ Don't Care

How many presentations did you attend?

- ¡ Less than 10
- ¡ 10 to 20
- ¡ 20 to 30
- ¡ More than 30

What meeting length ideally matches your ability to attend?

¡ < 3 days ¡ 3 days ¡ 3.5 days ¡ 4 days

If your ideal meeting length cannot accommodate all accepted papers, which would you prefer most? (choose one)

- ¡ increase meeting length
- ¡ have more than 3 concurrent sessions
- ¡ shorten presentation times
- ¡ reject more papers
- ¡ other: ____

Social Events

How satisfied were you with the Sunday Early Bird reception?

¡ Disappointing ¡ Just right ¡ Exceptional ¡ Didn't Attend

What food service options would you prefer with the Brouwer award lecture?

- ¡ Shorter event with no food (reduced fee)
- ¡ Light reception following lecture
- ¡ Light reception preceding lecture
- ¡ Full meal service during lecture (increased fee)
- ¡ Don't care
- ¡ Other: ____

Regarding social events such as Space Center Houston, please check those that apply:

- ¡ Too expensive
- ¡ Good value for price
- ¡ Prefer appetizers (lower cost)
- ¡ Prefer meal (higher cost)
- ¡ Prefer no drink coupons (lower cost)
- ¡ Prefer more drink coupons (higher cost)
- ¡ Prefer no guest speaker
- ¡ Prefer guest speaker
- ¡ Prefer events/prices accommodating family/children
- ¡ other: __________________________________

Additional Survey Comments

General

Registration

Venue

Technical Content

Social Events

Record of Meeting Expenses

18th AAS/AIAA Space Flight Mechanics Meeting
San Luis Resort Spa and Conference Center, Galveston, Texas
27-31 January 2008

Name:______________________________ Organization: ______________________________

Registration Fee:				_______________________
Member @	$410,	Non-Member @	$495	
Retired @	$100,	Student @	$100	
Conference Proceedings ___ @ $190				_______________________
Lunar Mission Design Workshop @ $150				_______________________
Early Bird Reception Guest Ticket ___@ $30				_______________________
Brouwer Award Ceremony Guest Ticket ___@ $30				_______________________
Space Center Houston Social ___@ $50				_______________________
TOTAL:				_______________________

Recorded by: ____

____

Conference Planner

Monday, January 28

Session	**1**	**2**	**3**
	Elissa	*E. Mainsail*	*W.Mainsail*
08:00	08-100	08-108	08-116
08:25	08-101	08-109	08-117
08:50	08-102	08-110	08-118
09:15	08-103	08-111	08-122
Break			
10:05	08-104	08-112	08-119
10:30	08-105	08-113	08-120
10:55	08-106	08-114	08-121
11:20	08-107	08-115	08-123
Session	**4**	**5**	**6**
	Elissa	*E. Mainsail*	*W.Mainsail*
13:30	08-124	08-133	08-140
13:55	08-125	08-220	08-141
14:20	08-126	08-132	08-142
14:45	08-127		08-143
Break			
15:35	08-129	08-139	08-144
16:00	08-129	08-137	08-145
16:25	08-130	08-138	08-146
16:50	08-131	08-133	08-140

Tuesday, January 29

Session	**7**	**8**	**9**
	Elissa	*E. Mainsail*	*W.Mainsail*
08:00		08-154	08-162
08:25	08-148	08-155	08-163
08:50	08-149	08-156	08-164
09:15	08-150	08-157	08-165
Break			
10:05	08-151	08-158	08-166
10:30	08-152	08-159	08-167
10:55	08-153	08-160	08-168
11:20		08-161	08-169
Session	**10**	**11**	**12**
	Elissa	*E. Mainsail*	*W.Mainsail*
13:30	08-170	08-175	
13:55	08-171	08-176	08-181
14:20	08-172	08-177	08-183
14:45	08-173	08-178	08-184
15:10	08-174	08-179	

Wednesday, January 30

Session	**13**	**14**	**15**
	Elissa	*E. Mainsail*	*W.Mainsail*
08:00	08-185	08-192	08-199
08:25	08-186	08-193	08-200
08:50	08-187	08-194	08-201
09:15	08-188	08-195	08-206
Break			
10:05	08-189	08-196	08-203
10:30	08-190	08-197	08-204
10:55	08-191	08-198	08-205
11:20			
Session	**16**	**17**	**18**
	Elissa	*E. Mainsail*	*W.Mainsail*
13:30	08-207	08-215	08-223
13:55	08-208	08-216	08-224
14:20	08-209	08-218	08-226
14:45	08-210		
Break			
15:35	08-211	08-219	08-227
16:00	08-212	08-221	08-228
16:25	08-214	08-222	08-229
17:00			Plenary Meeting

Thursday, January 31

Session	**19**	**20**	**21**
	Elissa	*E. Mainsail*	*W.Mainsail*
08:00	08-230	08-238	08-245
08:25	08-231	08-239	08-246
08:50	08-232	08-241	08-247
09:15	08-233		08-248
Break			
10:05	08-234	08-242	08-249
10:30	08-235	08-243	08-250
10:55	08-236	08-244	08-251
11:20	08-237		

- Highlight papers of interest on this "Conference at a Glance" chart to coordinate your movement between sessions.
- Keep a record of the number of presentations you visit. Use your record to help our Conference Survey.