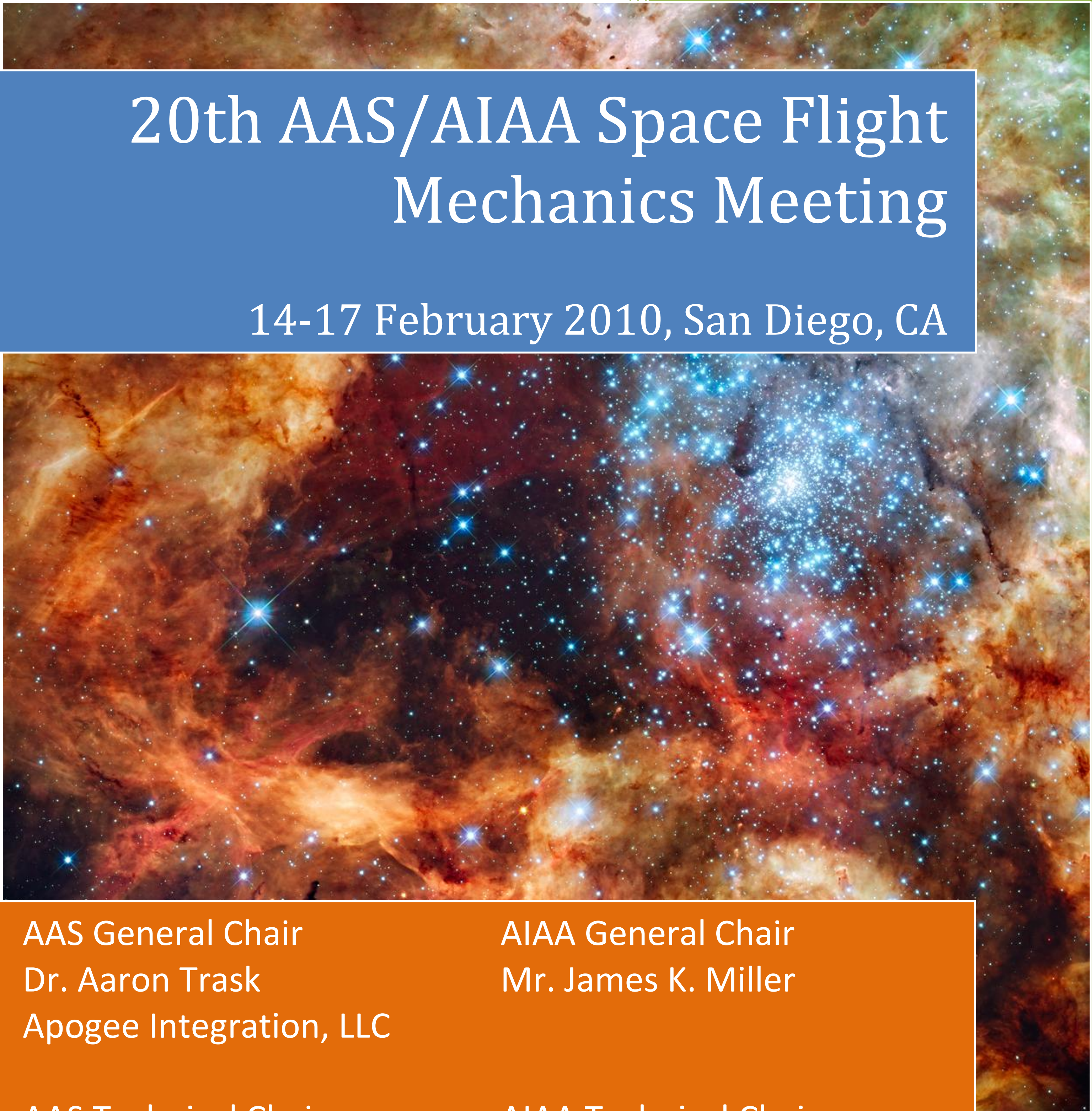
American Astronautical Society

The World's Forum for Aerospace Leadership

20th AAS/AIAA Space Flight Mechanics Meeting

14-17 February 2010, San Diego, CA



AAS General Chair
Dr. Aaron Trask
Apogee Integration, LLC

AIAA General Chair
Mr. James K. Miller

AAS Technical Chair
Dott. Daniele Mortari
Texas A&M University

AIAA Technical Chair
Dr. Thomas Starchville, Jr.
The Aerospace Corporation

Cover image: This image of a massive, young stellar grouping, called R136, was taken by Hubble's Wide Field Camera 3. The grouping resides in the 30 Doradus Nebula, a turbulent star-birth region in the Large Magellanic Cloud (LMC), a satellite galaxy of our Milky Way. Credit: NASA, ESA, and F. Paresce (INAF-IASF, Bologna, Italy), R. O'Connell (University of Virginia, Charlottesville), and the Wide Field Camera 3 Science Oversight Committee.

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20TH AAS/AIAA SPACE FLIGHT MECHANICS MEETING
CONFERENCE INFORMATION

REGISTRATION

Registration Site (https://events.pxi.com/aas/reg)

In order to encourage early registration, we have implemented the following conference registration rate structure: **Register by 15 Jan 2010 and save $50!**

Category	Early Registration (through 15 Jan 2010)	Late Registration
Full - AAS or AIAA Member	$510	$560
Full - Non-member	$595	$645
Retired*	$130	$180
Student*	$130	$180
Special Event Guest Ticket	$50	$50
Special Event Child Ticket (4-12 yrs)	$25	$25

The receptions are included for all registrants. The Tuesday night Special Event is included only for Full registration fees. The Special Event is free for children under the age of 4. On-site sales of special event tickets will be limited.

The Special Event on Tuesday will be held at the San Diego Zoo. Included with the event is admission to the Zoo on Tuesday after 4pm. The Event starts at 5pm with drinks and an animal show. Full dinner starts at 6pm. The event is tented in case of inclement weather.

On-site packet pick up and registration will be available on the following schedule:

- Sunday Feb. 14 3:00 PM - 7:00 PM
- Monday Feb. 15 8:00 AM - 2:00 PM
- Tuesday Feb. 16 8:00 AM - 2:00 PM
- Wednesday Feb. 17 8:00 AM - 10:00 AM

We will accept registration and payment on-site for those who have not pre-registered online, but we strongly recommend online registration before the conference in order to avoid delays (see URL above). Pre-registration also gives you free access to pre-print technical papers. On-site payment by credit card will be only through the AAS website using a computer at the registration table. Any checks should be made payable to the "**American Astronautical Society.**"

SCHEDULE OF EVENTS

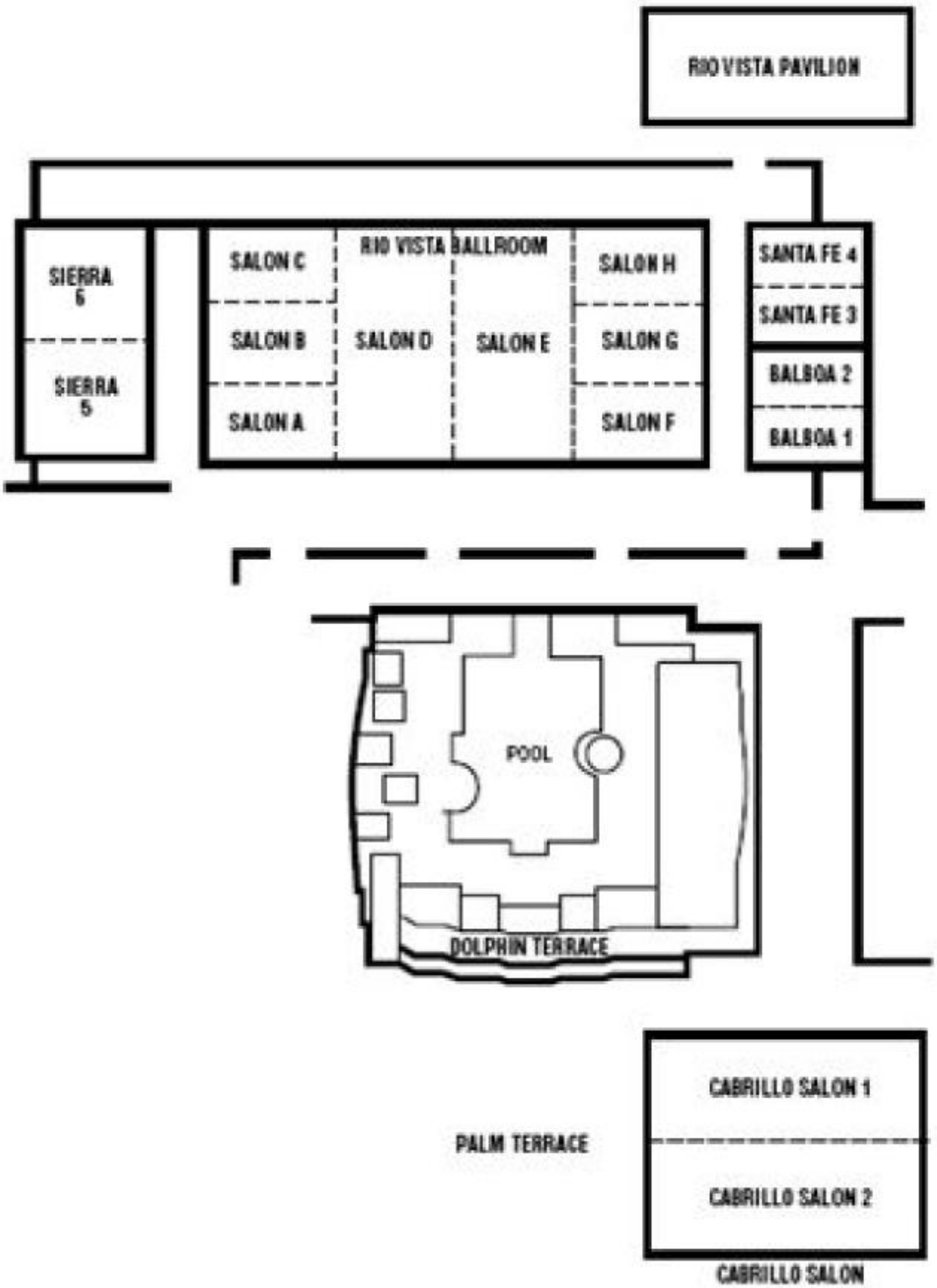
Day	Start	End	Function	Room
Sun. 14 Feb.	3pm	7pm	Registration	Cabrillo Foyer
	6pm	9pm	Early Bird Reception	Cabrillo Salon 1

Day	Start	End	Function	Room
Monday 15 February	7am	8am	Speakers Breakfast	Sierra 5-6
	8am	11:45am	Session 1: Trajectory Design & Optimization -- I	Salons A-C
	8am	11:45am	Session 2: Spacecraft Guidance, Navigation and Control -- I	Salon D
	8am	11:45am	Session 3: Dynamical Systems Theory	Salon E
	8am	11:45am	Session 4: Atmospheric Re-entry and Lunar Mission Analysis	Salons F-H
	9:40am	10:05am	Morning Break	Rio Vista Foyer
	Noon	1:30pm	Joint Technical Committee Lunch	Sierra 5-6
	1:30pm	5:15pm	Session 5: Orbital Dynamics -- I	Salons A-C
	1:30pm	5:15pm	Session 6: Attitude Dynamics and Control -- I	Salon D
	1:30pm	5:15pm	Session 7: Space Surveillance	Salon E
	1:30pm	5:15pm	Session 8: Spacecraft Relative Motion -- I	Salons F-H
	3:10pm	3:35pm	Afternoon Break	Rio Vista Foyer
	6pm	7pm	Award Ceremony and Brouwer Lecture	Cabrillo Room
	7pm	9pm	Reception	Rio Vista Pavilion

Day	Start	End	Function	Room
Tuesday 16 February	7am	8am	Speakers Breakfast	Sierra 5-6
	8am	11:45am	Session 9: Interplanetary Trajectory Design	Salons A-C
	8am	11:45am	Session 10: Satellite Constellations	Salon D
	8am	11:45am	Session 11: Orbit Dynamics -- II	Salon E
			Session 12: Planetary Missions	Salons F-H
	9:40am	10:05am	Morning Break	Rio Vista Foyer
	Noon	1:30pm	AAS Spaceflight Mechanics Committee Lunch	Sierra 5-6
	1:30pm	3:35pm	Session 13: Trajectory Solution Techniques	Salons A-C
	1:30pm	3:35pm	Session 14: Spaceflight Safety	Salon D
	1:30pm	3:35pm	Session 15: Attitude Sensors Data Processing	Salon E
	1:30pm	3:35pm	Session 16: Attitude Dynamics and Control -- II	Salons F-H
	2:20pm	2:45pm	Afternoon Break	Rio Vista Foyer
	4pm	5pm	San Diego Zoo Access (included with event ticket)	San Diego Zoo
	5pm	9pm	Offsite Event	San Diego Zoo

Day	Start	End	Function	Room
Wednesday 17 February	7am	8am	Speakers Breakfast	Sierra 5-6
	8am	11:45am	Session 17: Trajectory Design & Optimization -- II	Salons A-C
	8am	11:45am	Session 18: Orbital Perturbations	Salon D
	8am	11:45am	Session 19: Attitude Dynamics and Control -- III	Salon E
	8am	11:45am	Session 20: Orbit Determination	Salons F-H
	9:40am	10:05am	Morning Break	Rio Vista Foyer
	Noon	1:30pm	AIAA Astrodynamics Technical Committee Lunch	Sierra 5-6
	1:30pm	5:15pm	Session 21: Near Earth Object Missions	Salons A-C
	1:30pm	5:15pm	Session 22: Spacecraft Guidance, Navigation and Control -- II	Salon D
	1:30pm	5:15pm	Session 23: Satellite Relative Motion -- II	Salon E
			Session 24: Space Structures Dynamics and Control	Salons F-H
	3:10pm	3:35pm	Afternoon Break	Rio Vista Foyer
	5:30pm	6:30pm	Conference Administration Subcommittee	Salons A-C
	5:30pm	6:30pm	Technical Administration Subcommittee	Salon D
	5:30pm	6:30pm	Website Administration Subcommittee	Salon E

CONFERENCE CENTER LAYOUT



Special Events

Early Bird Reception

Sunday, 14 February 6 – 9:30pm
Location: Cabrillo Salon 1

Award Ceremony, Dirk Brouwer Award Lecture, and Reception

Monday, 15 February 6-7pm (ceremony and lecture), 7-9pm reception
Location: Cabrillo Room (ceremony and lecture), Rio Vista Pavilion (reception)

Dirk Brouwer Award Honoree

Bruce Conway is a Professor of Aerospace Engineering at the University of Illinois at Urbana-Champaign. He has been on the faculty since 1981. He received the Ph. D. in Aeronautics & Astronautics from Stanford University in 1980, working with John Breakwell. While at Stanford he worked for two years in the Mission Analysis section of Ford Aerospace (now Loral Space Systems) with colleagues including John Brown, Don Ekman and Ahmed Kamel. He is an associate fellow of the AIAA. At Illinois he has received every award for teaching excellence offered, including the College of Engineering's Rose Award for Excellence in Undergraduate Teaching in 2005, the Everitt Award for Teaching Excellence in 2006 and the College of Engineering Teaching Excellence Award in 2007. He received the Campus Award for Excellence in Undergraduate Teaching in 2007. He has supervised the Ph. D. dissertations of 12 students and the M.S. theses of 16 students. He is the author (with John Prussing) of the textbook "Orbital Mechanics" (Oxford University Press) and is the editor of the book "Spacecraft Trajectory Optimization" which will appear in 2010 (from Cambridge University Press). His research is primarily in the fields of spacecraft trajectory optimization, numerical optimization methods, differential games, and celestial mechanics.

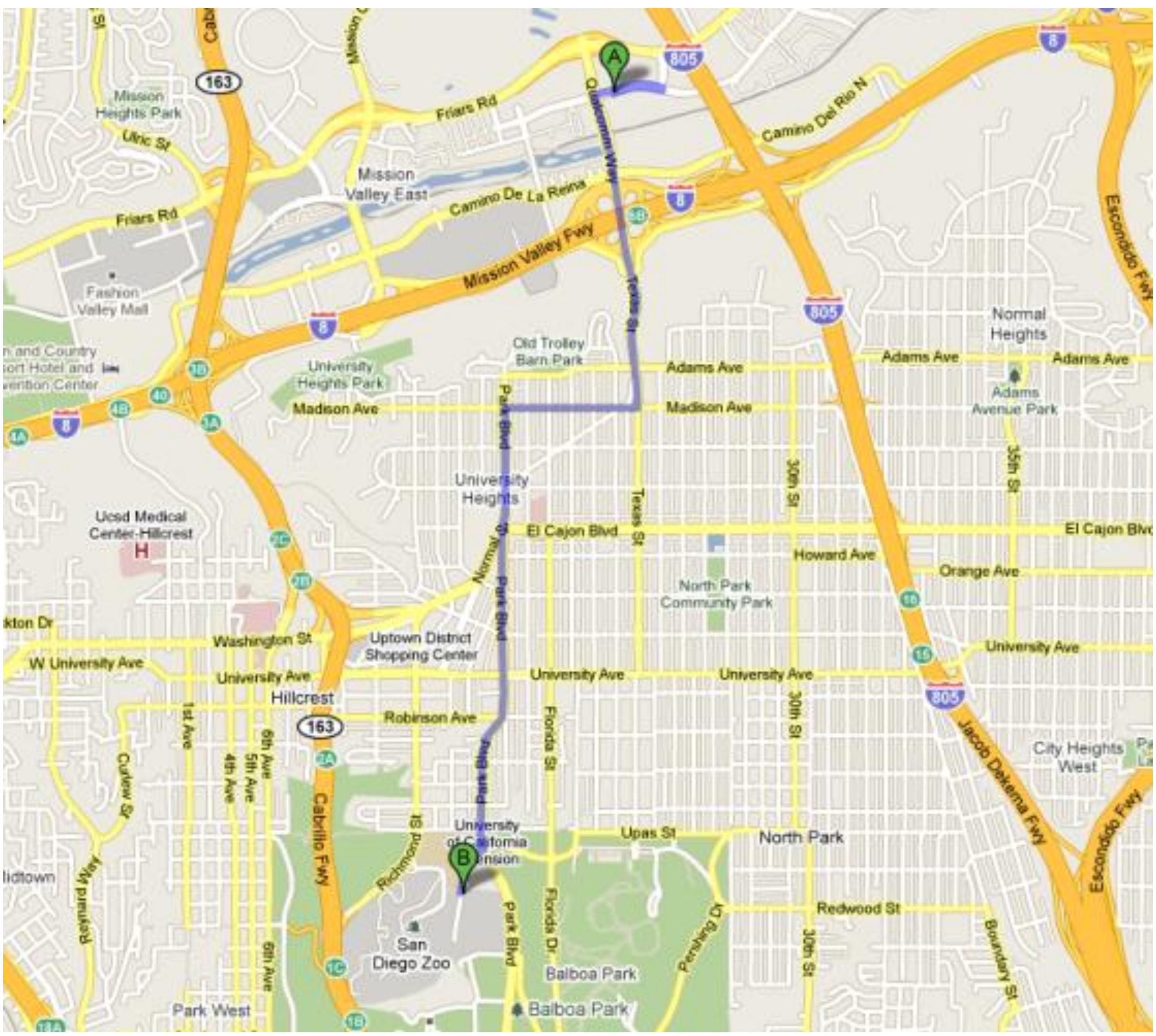
OFFSITE EVENT – SAN DIEGO ZOO

Tuesday, 16 February	4-5pm Zoo Access, 5-6pm Show and Cocktails, 6-9pm Dinner
Location	San Diego Zoo (Zoofari Party Area)

Transportation is not provided to the event.

Directions:

1. Head **east** on **Rio San Diego Dr** toward **Rio Bonito Way**	0.2 mi
2. Make a **U-turn** at **Rio Bonito Way**	0.2 mi
3. Turn **left** at **Qualcomm Way**	0.5 mi
4. Continue onto **Texas St**	0.5 mi
5. Turn **right** at **Madison Ave**	0.4 mi
6. Turn **left** at **Park Blvd**	1.5 mi
7. Turn **right** at **Zoo Dr** Destination will be on the right	0.2 mi



Conference Location

San Diego Marriott Mission Valley Hotel Accommodations

The conference is located at the San Diego Marriott Mission Valley in San Diego, CA.

San Diego Marriott Mission Valley
8757 Rio San Diego Drive
San Diego, California 92108 USA
Phone: 1-619-692-3800
Fax: 1-619-692-0769
Toll-free: 1-800-842-5329

http://www.marriott.com/hotels/travel/sanmv?groupCode=aasaasa&app=resvlink&fromDate=2/14/10&toDate=2/18/10

The Conference rate for the conference is $146 plus applicable taxes currently at 10.545% occupancy tax, 2% San Diego Tourism Marketing District assessment and $0.25 CA tourism fee. Please request the AAS/AIAA Space Flight Mechanics Meeting rate. (The deadline for securing the conference rate at the hotel is 22 January.)

Transportation Info

By Bus

San Diego Transit (PHONE: 619/233-3004; 619/234-5005 TTY/TDD, www.sdcommute.com) buses connect with the San Diego Trolley light rail system at the San Diego Zoo, Balboa Park, Lindbergh Field, Mission Beach, Pacific Beach, La Jolla, and regional shopping centers.

San Diego Transit fares range from $1.25 to $3. Discounted fares are available for seniors and for people with disabilities. Most transfers are free; request one when boarding. You must have exact change in coins and/or bills. Pay upon boarding; Day Tripper tickets must be purchased in advance. Schedules are posted at each stop, and the buses usually are on time.

By Ferry

The small San Diego-Coronado Ferry (PHONE: 619/234-4111) leaves from the Broadway Pier daily, every hour on the hour, Sunday to Thursday 9 to 9, until 10 PM Friday and Saturday. The fare is $2 each way and 50¢ for each bicycle.

By Taxi

Fares vary among companies. Taxi stands are located at shopping centers and hotels, otherwise you must call and reserve one.

By Trolley

The San Diego Trolley light rail system connects with San Diego Transit buses. The bright-orange trolleys service downtown San Diego, Mission Valley, Old Town, South Bay, the U.S. Border, and East County. The trolleys operate seven days a week from about 5 AM to midnight, depending on the station, at intervals of about 15 minutes. Bus connections are posted at each station, and bicycle lockers are available at most. Trolleys can get crowded during morning and evening rush hours. On-time performance is excellent. Rio Vista trolley stop is just outside of the hotel.

San Diego Trolley tickets are priced according to the number of stations traveled. Tickets are dispensed from self-service ticket machines at each stop; exact fare in coins is recommended, although some machines accept bills in $1, $5, $10, and $20 denominations. Transfers between buses and/or the trolley are free or require an upgrade if the second fare is higher. Day Tripper Passes are available for one, two, three, or four days ($5, $9, $12, and $15, respectively), which give unlimited rides on regional buses and the San Diego Trolley. They may be purchased from most trolley vending machines, at the Transit Store, and some hotels.

DIRECTIONS

From Airport

San Diego - SAN

- Phone: 1 619 400 2400
- Hotel direction: 8 miles NE
- Driving directions: Take Harbor Drive to Hwy 5 North. Take Hwy 8 East exit on the (Qualcom exit) left on Qualcomm Way. Turn right on Rio San Diego Drive. Hotel is on your right.
- Alternate transportation: Express Shuttle Service; fee: 12 USD (one way) ;reservation required
- Estimated taxi fare: 22.00 USD (one way)

ARRIVAL INFORMATION

Check-In and Checkout

- Check-in: 4:00 PM
  Check-out: 11:00 AM
- Video Review Billing , Video Checkout
- Express Check-In and Express Checkout

Parking

- On-site parking, fee: 1.50 USD hourly, 7 USD daily (discounted rate for conference)

High-Speed Internet Access

- Public Areas: Free Wireless
- Guest Rooms: daily rate of 5.00 USD (discounted rate for conference)

RESTAURANTS & SHOPPING

Hotel

- Café Del Sol (American & Spanish Cuisine)

Rio Vista Center (walking distance, within 6 Blocks)

- Pat & Oscars (famous for salads, sandwiches & Grilled Chicken)
- Dragon Chinese Restaurant (sit down or takeout)
- Sombrero Mexican Restaurant (sit down or takeout)
- Little Caesar's Pizza
- Wendy's
- Over 20 stores including: Sports Authority, Ross, Office Depot and Big K-mart

Mission Valley General

- Bully's East (Steak and Prime Rib)
- Kooky's Diner (50's style 24 hour Restaurant)
- Hayama (Japanese Cuisine)
- Hooters
- Mimi's Café (French Atmosphere, Home Cooking)

Mission Valley Mall (within 1 mile)

- Seau's (San Diego's hottest sports bar, restaurant and Sushi bar, featuring the city's largest big screen television)
- Wolfgang Puck Café
- In & Out Burger
- Peking Palace
- Pick Up Sticks
- Bennigans
- Pasta Bravo
- Legends Café
- AMC 20 Cinema
- Over 150 department stores and specialty shops including Loehmans, Robinsons May, Nordstrom Rack & Macy's

Fenton Parkway (within 1 mile)

- International House of Pancakes
- Oggi's Pizza and Microbrew
- Subway
- Starbucks
- Island's Restaurant
- Postal Annex
- Over 20 stores and shops including IKEA, Lowe's and Costco

Hazard Center (within 2 miles)

- Prego (Fine Italian Dining)
- Trophy's (Sports Bar and Restaurant)
- Joe's Crab Shack

Mission Center Plaza (within 2 miles)

- Ralph's Grocery Store
- Burger King
- Longs Drug Store
- Starbucks
- Blockbuster
- UPS
- Subway

Park in the Valley (within 2 miles)

- Panda Express
- On the Border
- Sammy's Woodfire Grill
- Starbuck's Coffee
- Aaron Brothers Framing
- Mikasa
- Zany Brainy
- Off Saks 5th Avenue

Mission Center West (within 3 miles)

- Gordon Biersch
- King's Fish House
- Coffee Bean
- Chevy's
- Koo Koo Roos
- Fudruckers
- Border Bookstore
- DSW
- Old Navy
- Goldsmith
- Marshalls

Fashion Valley Mall (within 4 miles)

- Cheesecake Factory
- PF Changs
- Crocodile Café
- Pizzeria Uno
- California Pizza Kitchen
- Over 200 department stores and specialty shops including, Nieman Marcus, Nordstroms, Bloomingdales and Macy's

RECREATION

Swimming

- Mission Beach (8 miles)
- Outdoor Pool
- Whirlpool

Activities

- Biking trail
- Bowling (8 miles)
- Hiking
- Horseback riding (15 miles)
- Jet-skiing (8 miles)
- Jogging/fitness trail
- Kayaking (10 miles)
- Miniature golf (8 miles)
- Sailing (8 miles)
- Sauna
- Scuba diving
- Snorkeling (10 miles)
- Sport Court® onsite
- Squash (5 miles)
- Surfing
- Volleyball
- Water-skiing (5 miles)
- Snow skiing: Big Bear (200 miles)

Fitness Facilities

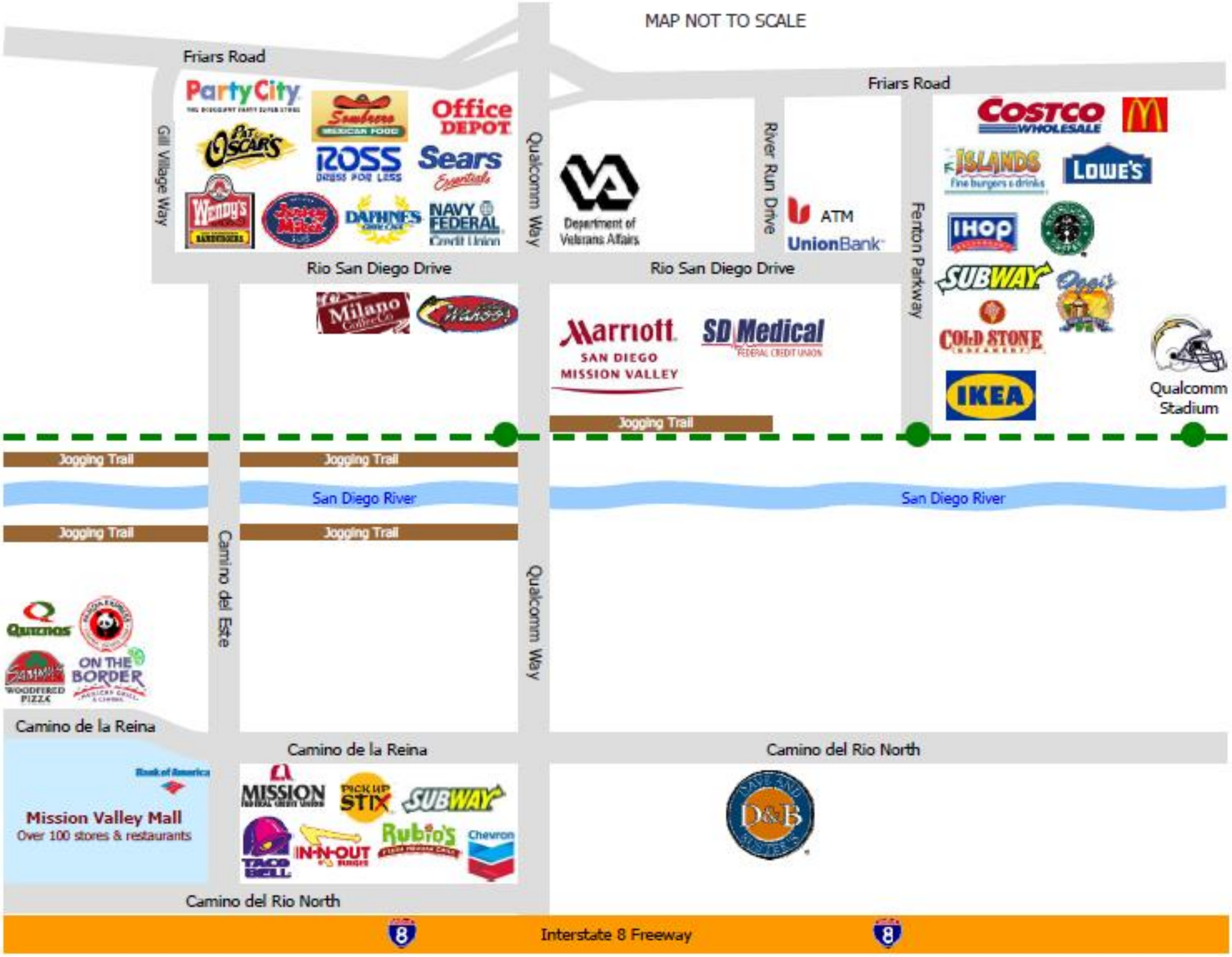
- Fitness Center

Golf

- Carmel Mountain Ranch Country Club (15 miles)
- East Lake Country Club (15 miles)
- Riverwalk (1 miles)
- Steel Canyon Golf Club (20 miles)
- Torrey Pines North La Jolla (8 miles)
- Maderas Golf Course (20 miles)

Attractions & Landmarks

- Balboa Park (619) 239-0512
- San Diego Zoo (619) 234-3153
- Cabrillo National Monument (619) 557-5450
- Sea World California (619) 226-3901
- Coronado Island Visitor Information Center (619) 437-8788
- Seaport Village (619) 235-4014
- Del Mar Racetrack (760) 793-5555
- Steven Birch Scripps Aquarium (858) 534-3774
- Gaslamp Quarter (619) 233-5227
- LEGOLAND (760) 918-LEGO
- Old Town (619) 291-4903
- San Diego Wild Animal Park (619) 234-6541



Additional Information

Speaker Orientation

On the day of their sessions, authors making presentations meet with their session chairs in the Sierra 5-6 room at 7:00 am each morning. A continental breakfast will be served. Speaker attendance is mandatory.

Volunteers

Volunteers that would like to staff the registration table may sign up at the registration table.

Presentations

Each presentation is limited to 20 minutes. An additional five minutes is allotted between presentations for audience participation and transition. Session chairs shall maintain the posted schedule to allow attendees the option of joining a parallel session. 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 responsible for having the necessary computer and software available to drive the presentation*. Microsoft PowerPoint and PDF are the most common formats.

"No-Paper, No-Podium" Policy Completed manuscripts shall be electronically uploaded to the submission site before the conference, limited to 20 pages in length, and conform to the AAS conference paper format. If the completed manuscript is not contributed on time, it will not be presented at the conference. If there is no conference presentation by an author, the contributed manuscript shall be withdrawn.

PREPRINTED 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 before 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 guest rooms and the conference meeting space. 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

All registrants will receive a CD of the proceedings mailed to them after the conference (extra copies are available for $40 during the conference). However, the hardbound volume of *Advances in the Astronautical Sciences* covering this conference will be available to attendees at a reduced pre-publication cost, if ordered at the registration desk. After the conference, the hardbound proceedings will more than double in price, although authors will still receive a special 50% discount even if they delay their order until after the conference. Cost of Proceedings:

- Conference Rate **$240**
- Post-Conference Rate **$520** (approx.)
- Authors (post-conference) **$260** (approx.)

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 Guidance, Control and Dynamics
Editor-in-Chief: George T. Schmidt, Massachusetts Institute of Technology
Manuscripts can be submitted via: http://www.writetrack.net/aiaa/

Journal of Spacecraft and Rockets
Editor-in-Chief: E. Vincent Zoby, NASA Langley Research Center
Manuscripts can be submitted via: http://www.writetrack.net/aiaa/

Journal of the Astronautical Sciences
Editor-in-Chief: Kathleen C. Howell
School of Aeronautics and Astronautics

1282 Grissom Hall
Purdue University
West Lafayette, IN 47907
(765) 494-5786
howell@ecn.purdue.edu

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 Sierra 5-6 room:

Joint AAS/AIAA Technical Committees, Monday, Noon – 1:30 pm.
AAS Space Flight Mechanics Technical Commitee, Tuesday, Noon – 1:30 pm.
AIAA Astrodynamics Technical Committee, Wednesday, Noon – 1:30 pm.

SUBCOMMITTEE MEETINGS

Conference Administration Subcommittee - Wednesday, Salon A-C 5:30-6:30pm
Technical Administration Subcommittee - Wednesday, Salon D 5:30-6:30pm
Website Administration Subcommittee - Wednesday, Salon E 5:30-6:30pm

Session 1: Trajectory Design & Optimization – I

Chair: Ryan Russell – Georgia Institute of Technology

08:00 **AAS 10 - 100** **Efficient Method for Optimization of Low-Thrust Trajectories**
Jesus Gil-Fernandez – GMV, Spain; M.A. Gomez-Tierno – Universidad Politecnica Madrid, Spain

Analysis of low thrust missions needs efficient methods to compute optimal trajectories with no a priori knowledge of the thrusting structure. The thrust-constrained, final mass maximization is reduced to a two-point boundary value problem solved in two steps: initial guess construction via systematic search on a unit 6-sphere of directions of the initial value of the adjoints, and refinement of most promising directions with a commercial gradient-based nonlinear equations solver. The radius of convergence is increased with a smoothing technique. The results prove the method find many optimal in different transfers with short computation time and few configuration parameters.

08:25 **AAS 10 - 101** **Optimal Low Thrust Transfer Trajectories with Improved Stability Properties**
Iman Alizadeh and Benjamin Villac – University of California, Irvine

In order to avoid risks in case of a missed maneuver or a propulsion system failure in unstable orbital environments, it is desirable to fly on trajectories that have good stability properties. In this paper, a fast method to analyze the stability of a trajectory based on the notion of recovery time is used directly in the optimization process to address the safety margin and stability requirements of the mission. The method is used to design a low thrust transfer from an Earth parking orbit to a halo orbit while having sufficient recovery time in case of an engine failure.

08:50 **AAS 10 - 102** **Optimal Impulsive LEO to LEO Aeroassisted Orbital Transfer for Small Satellites**
Anil V. Rao and Christopher L. Darby – University of Florida

The problem of low-Earth orbit (LEO) to LEO aeroassisted orbital transfer of small satellites is considered. The objective of the study is to characterize the fuel requirements for LEO aeroassisted orbital transfers for vehicles with limited on-board resources. The problem is to combine propulsive maneuvers with the use of atmospheric force to transfer a vehicle from an initial circular orbit to a final elliptic orbit with a change in inclination. In addition to the required inclination change, constraints are placed on the line of apsides in order to ensure that the apogee is over a particular part of the Earth. The aeroassisted orbital transfer problem is posed as multiple-phase optimal control problem and is solved using a direct collocation method.

09:15 **AAS 10 - 103** **Optimal Space Trajectories via Particle Swarm Technique**
Mauro Pontani – University of Rome, Italy; Bruce Conway – University of Illinois

The particle swarm optimization technique was first introduced by Eberhart and Kennedy in 1995 and represents a very intuitive (and easy to program) methodology for global optimization. It mimics the unpredictable stochastic motion of bird flocks while searching for food, trying to take advantage from the mechanism of information sharing that affects the overall behavior of a swarm. In this research the particle swarm optimization method is applied to a variety of space trajectory optimization problems (ranging from orbital transfers to periodic orbits in the circular restricted three-body problem), to show its simplicity, effectiveness, and numerical accuracy.

09:40 **Break**

10:05 AAS 10 - 104 Numerical Verification of Singular Arcs on Optimal Moon to Earth Transfer

Chandeok Park – Naval Postgraduate School; Hui Yan – University of California Santa Cruz; I. Michael Ross – Naval Postgraduate School; Qi Gong, University of California Santa Cruz

We analyze singular arcs of an optimal Moon-to-Earth trajectory and numerically verify its optimality. Developing a time-bound fuel-optimal three burn sequences in the context of the restricted four body problem, we apply a series of newly derived necessary conditions for singular optimality to our solution, including the generalized Legendre-Clebsche convexity condition. These necessary conditions suggest that there exist time span where singular arcs are possible control scheme. Our numerical analysis is supported by comparing our intermediate thrust arc solution with a reference bang-bang solution.

10:30 AAS 10 - 105 Optimal Low-Thrust Trajectories to the Moon with Manifolds

Christopher Martin and Bruce Conway – University of Illinois

Minimum-fuel trajectories are found for a spacecraft using continuous low-thrust propulsion to leave geosynchronous transfer orbit and enter a low-lunar orbit, transiting via the stable and unstable manifolds of a periodic orbit about the interior Earth-Moon Lagrange point. The optimizer chooses the thrust pointing angle time history, the points of arrival/departure from the stable and unstable manifold respectively and the size of the halo orbit, in order to minimize propellant consumption. The arrival position and velocity matching conditions are obtained from a parameterization of the orbit using cubic splines since no analytic description of the manifolds exist.

10:55 AAS 10 - 106 Optimality of Singular Arcs for a Rocket Trajectory of Mayer's Variational Problem

Chandeok Park and I. Michael Ross – Naval Postgraduate School; Hui Yan and Qi Gong – University of California at Santa Cruz

We study optimality of intermediate thrust arcs (singular arcs) of a space rocket trajectory subject to arbitrary number of gravitational bodies. Defining a Mayer's variational problem in the context of the restricted N-body problem, we derive a series of necessary conditions for optimality of singular arcs, including generalized Legendre-Clebshe conditions (Kelley conditions) and the explicit singular optimal control law. Our derivations are validated by (1) showing that they are identical to Lawden's if the equations of motion are reduced to be for a central gravitational field and (2) applying to the singular control portion of the Moon-Earth transfer.

Session 2: Spacecraft Guidance, Navigation and Control – I

Chair: Peter Lai – The Aerospace Corporation

08:00 **AAS 10 - 108** **Terminal-Phase GN&C Analysis of a Post-2029 Nuclear Deflection Mission for Asteroid Apophis**

Daero Lee, Dakshesh Patel, and Bong Wie – Iowa State University

This paper describes the guidance, navigation and control (GNC) system design for the terminal phase of an autonomous intercept mission for hazardous Near-Earth Objects (NEOs). A fictive post-2029 nuclear deflection mission for asteroid Apophis is considered. Deflection of Apophis after its keyhole passage in 2029 will certainly require the use of high-energy nuclear explosions. The performance and design of autonomous GNC system for the terminal phase are primarily dependent on the target configuration, arrival orbit geometry, and interceptor configuration. Critical mission requirements and constraints inherent to nuclear deflection missions include: optimal height for standoff explosions, optimal closing relative speed for subsurface explosions, and targeting accuracy.

08:25 **AAS 10 - 109** **Spacecraft Stochastic Optimal Control**

Eric D. Gustafson – University of Michigan; Daniel J. Scheeres – University of Colorado at Boulder

We present techniques useful for computing stochastic optimal control of spacecrafts. We assume multiplicative noise acting on linear control, directly applicable to many low thrust propulsion methods. The stochastic Hamilton-Jacobi-Bellman equation is expanded using a Taylor series. In general, the ordinary differential equations describing the evolution of the coefficients of the expansion at a given order depend of higher order coefficients. We show that this drawback is removed for systems with dynamics given by an odd function and an even function describing the terminal cost. We also discuss the spectral method for solving the optimal control.

08:50 **AAS 10 - 110** **Continuous-Time Bilinear System Identification using Single Experiment with Multiple Pulses**

Jer-Nan Juang – National Cheng-Kung University, Taiwan; Chen-Han Lee – National Central University, Taiwan

A novel method is presented for the identification of a continuous-time bilinear system from the input-output data generated by a single experiment with multiple pulses. In contrast to the conventional approach utilizing multiple experiments, the current work documents the advantage of using a single experiment and sets up a procedure to obtain bilinear system models. The special pulse inputs employed by earlier research can be avoided and accurate identification of the continuous-time system model is possible by performing a single experiment incorporating a class of control input sequences combining pulses with free-decay in between. The algorithm presented here-in is more attractive in practice for the real-time on-line identification of bilinear systems. Numerical examples presented demonstrate the methodology developed in the paper.

09:15 **AAS 10 - 111** **Fault-tolerant Attitude Control of Miniature Satellites Using Reaction Wheels**
Godard, Noel Abreu, and Krishna Dev Kumar – Ryerson University, Canada

An adaptive fault-tolerant nonlinear control scheme is proposed for precise 3-axis attitude tracking of miniature satellites. Two configurations of reaction wheel assembly are examined in this paper, (i) three wheels in an orthogonal configuration combined with one oblique wheel; and (ii) four wheels in pyramid configuration. Faults of reaction wheels are modeled as additive and multiplicative. The control law does not require an explicit fault detection and isolation mechanism. The main contribution of this work is the development and testing of reaction wheels for miniature satellites and the validation of a fault-tolerant algorithm for reaction wheel faults in a spacecraft.

09:40 **Break**

10:05 **AAS 10 - 112** **Absolute Stability Analysis of a Phase Plane Controlled Spacecraft**
Jiann-Woei Jang, Michael Plummer, and Nazareth Bedrossian – Charles Stark Draper Laboratory; Charles Hall and Mark Jackson – NASA Marshall Space Flight Center; Pol Spanos – Rice University

Many aerospace attitude control systems utilize phase plane control schemes that include nonlinear elements such as dead zone and ideal relay. To evaluate phase plane control robustness, stability margin prediction methods must be developed. Absolute stability is extended to predict stability margins and to define an abort condition. A constrained optimization approach is also used to design flex filters for roll control. The design goal is to optimize vehicle tracking performance while maintaining adequate stability margins. Absolute stability is shown to provide satisfactory stability constraints for the optimization.

10:30 **AAS 10 - 113** **Stationkeeping of Lissajous Trajectories in the Earth-Moon System with Application to ARTEMIS**
David C. Folta – NASA Goddard Space Flight Center; Thomas A. Pavlak and Kathleen C. Howell – Purdue University; M.A. Woodard and D. W. WoodFork - NASA Goddard Space Flight Center

In the last few decades, numerous missions have successfully exploited trajectories near the Sun-Earth L1 and L2 libration points. Recently, the collinear libration points in the Earth-Moon system have emerged as locations with immediate application. Most libration point orbits are inherently unstable and must be controlled. Two stationkeeping strategies for application to ARTEMIS are developed. A baseline orbit-targeting approach controls the vehicle to remain near a nominal trajectory; a global optimum search method searches all possible maneuver angles to determine an optimal angle and magnitude. Initial results indicate that lower stationkeeping costs can be achieved with the global search method.

10:55 **AAS 10 - 114** **Time Varying Deadbeat Controller Design**
Manoranjan Majji – Texas A&M University; Jer-Nan Juang – National Cheng Kung University, Taiwan; John L. Junkins – Texas A&M University

Time varying generalization of the classical deadbeat controller is investigated in the present paper. The natural extension of the time invariant deadbeat condition to the time varying case is to be presented by reviewing the ideas presented in the appendix of our recent paper. Investigations will be carried out as to whether the generalized time varying autoregressive model with exogenous inputs (ARX) is amenable for a deadbeat controller design. In the special case of periodic systems, where repeated experimental data is available naturally, it seems that such a controller can be designed to set the output of the closed loop system zero after a few time steps.

11:20 AAS 10 - 115 Bang-Bang Trajectory Optimization using Autonomous Phase Placement and Mesh Refinement Satisfying Waypoints and No-Fly Zone Constraints

Timothy R. Jorris – U.S. Air Force Test Pilot School; Anil V. Rao – University of Florida

Previously published analytical and numerical solutions exist solving a highly constrained reentry trajectory optimization problem. A new method is employed whereas intermediate phases, called segments, are autonomously added and the number of nodes, or polynomial fit order, is automatically adjusted; cumulatively called mesh refinement. Autonomous mesh refinement captures rapid state dynamics, discontinuities in the control, and discontinuities in the costates. The previous published problem contains interior point constraints, bang-bang control, and constraint boundary contact; herein mesh refinement will replicate those results and more accurately address the bang-bang control as a true discontinuity in the control.

Session 3: Dynamical Systems Theory

Chair: Kathleen Howell – Purdue University

08:00 **AAS 10 - 116** **Analytical Model for Lunar Orbiter Revisited**
Juan Felix San-Juan – Universidad de La Rioja, Spain

Analytical theories based on Lie--Deprit transforms are being used so as to simplify the search of families of periodic orbits about planets, natural satellites or asteroids. Normalized equations of motion permit locating the frozen orbit families depending on values of the inclination, eccentricity and semi-major axis. From analytical theories, it is possible to derive a robust an easy-to-use tool for mission planning, whenever the appropriate use force model captures the qualitative behavior of the problem.

08:25 **AAS 10 - 117** **Exploiting Distant Periodic Orbits and Their Invariant Manifolds to Design Novel Space Trajectories to the Moon**
Giorgio Mingotti, Francesco Topputo, and Franco Bernelli-Zazzera – Politecnico di Milano, Italy

Unstable periodic orbits in restricted three-body problems reveal a rich phase-portrait structure useful for many space mission opportunities. In this paper we present novel low-thrust, low-energy trajectories to distant periodic orbits in the Sun-Earth and Earth-Moon systems. Both internal (through L1 gateway) and external transfers (through L2 gateway after traveling along the Sun-Earth invariant pathways) are investigated. Special attainable and leading sets are defined to incorporate low-thrust in the invariant-manifold technique. In the Sun-Earth-Moon-Spacecraft restricted four-body problem, accurate first guess solutions are then optimized, through direct transcription and multiple shooting techniques. Propellant efficient and short flight time transfers are proposed.

08:50 **AAS 10 - 118** **Periodic Orbits Families in the Hill's Three-Body Problem with Solar Radiation Pressure**
Benjamin Villac and K.Y-Y. Liu – University of California, Irvine; S. Broschart – Jet Propulsion Laboratory

In this paper a systematic study and bifurcation analysis of the main families of periodic orbits in the Hill’s Three-Body Problem is presented when solar radiation pressure (SRP) is accounted for. This “augmented” Hill’s problem (AH3BP) represents a simplified model for the motion of a small body orbiter and the parametric study presented provides a global overview of the type of motion for such spacecraft over a larger range of SRP strengths and small body masses. Periodic orbits in the AH3BP provide a fundamental backbone to perform further detailed study of the orbiter dynamics and provide a basis for comparison of simplified analytic prediction with actual orbits. The families of periodic orbits are analyzed via continuation from the well-known families in the Hill’s problem.

09:15 **AAS 10 - 119** **Preliminary Study on Orbit Maintenance of Halo Orbits under Continuous Disturbance**
Masaki Nakamiya and Yasuhiro Kawakatsu – Japan Aerospace Exploration Agency, Japan

We studied the preliminary mission design for the next-generation infrared mission, SPICA, which is to be launched into the Sun-Earth L2 halo orbit. The specific focus is on investigating the impact of translational force (deltaV), which is caused by the thruster unloading for accumulated angular momentum on spacecraft reaction wheels in the attitude control, from the station-keeping viewpoint. Besides, suppression methods for orbital disturbances caused by unloading deltaV was proposed and validated.

09:40 **Break**

10:05 AAS 10 - 120 Computation of Quasi-Periodic Invariant Tori in the Restricted Three-Body Problem

Zubin P. Olikara and Kathleen C. Howell – Purdue University

Quasi-periodic orbits lying on invariant tori in the circular restricted three-body problem offer a broad range of mission design possibilities, but their computation is more complex than that of periodic orbits. A numerical methodology for directly computing these invariant tori is presented including a natural parameterization and a continuation scheme. Orbit families of quasi-periodic trajectories emanating from periodic orbits near the collinear libration points are generated. Stability aspects of quasi-periodic invariant tori are also considered.

10:30 AAS 10 - 121 An L5 Mission to Observe the Sun and Space Weather

Martin W. Lo – Jet Propulsion Laboratory; Pedro J. Llanos and Gerald R. Hintz – University of Southern California

L1 orbits have been the preferred venue for observing the Sun since the ISEE3 mission in 1978. In recent years, space weather and solar scientists have begun to consider missions to L5 in order to have simultaneous viewing of the Sun from different azimuths around the Sun. Surprisingly; there has been little work on mission to the Sun-Earth L5. Akiko et al. (2004) proposed an interesting mission to L5 for space weather. In this paper we characterize and size a typical L5 mission and indicate that such a mission is indeed feasible.

10:55 AAS 10 - 122 Earth Satellite Perturbation Theories as Approximate KAM Tori

William E. Wiesel – Air Force Institute of Technology

Several standard earth satellite general perturbation models can be converted into KAM tori, and are compared to KAM tori constructed from full geopotential integrations. Converting perturbation theories into tori allows absolute identification of spectral lines with the classical perturbation elements. Comparisons are made of each torus representation against numerical integrations, and the torus spectra are also compared. The torus canonical coordinates are identified as the "mean" mean anomaly, the longitude of the mean node, and the mean argument of perigee. The associated torus canonical momenta are shown to be approximately the usual Delaunay momenta. Finally, the actual "distance" between perturbation tori and geopotential tori can be measured.

11:20 AAS 10 - 123 Algorithmic Classification of Resonant Orbits Using Persistent Homology in Poincaré Sections

Thomas Coffee – Massachusetts Institute of Technology

We demonstrate a numerical algorithmic method to identify arbitrary families of periodic and quasiperiodic orbits in nonintegrable dynamical systems, in particular, the circular restricted three-body problem (CR3BP). The method is based on computing persistent homology in Poincaré sections of numerically integrated trajectories. This method extends naturally to higher-dimensional Poincaré sections, such as those encountered in spatial trajectory problems. We introduce the method applied to 2D Poincaré sections in the CR3BP, and compare these results with analytically derived families of periodic orbits. We then give results for 3D and 4D Poincaré sections in the spatial CR3BP.

Session 4: Atmospheric Re-entry and Lunar Mission Analysis

Chair: Ossama Abdelkhalik – Michigan Tech University

08:25 **AAS 10 - 125** **Design and Validation of a Trajectory Estimation System for the Hayabusa Sample Return Capsule**
Michael A. Shoemaker and Jozef C. van der Ha – Kyushu University, Japan

The Japanese Hayabusa spacecraft will return to Earth in summer, 2010, carrying samples from asteroid Itokawa. Because the sample return capsule will reenter the atmosphere at night, the capsule and surrounding air will appear as a bright light (i.e. "fireball") during the portion of the trajectory with high aerodynamic heating. Kyushu University, in collaboration with the Japan Aerospace Exploration Agency (JAXA), is developing a ground-based optical sensor system to observe the reentry and estimate the vehicle's trajectory. This paper describes the design and validation currently underway for the proposed system, in preparation for operations in mid-2010.

08:50 **AAS 10 - 126** **Skip-Entry Trajectory Planning Based on Reachable and Controllable Sets**
Joel Benito and Kenneth D. Mease – University of California, Irvine

Future manned entry missions will require handling large downrange entry trajectories to safely return the crew in abort and emergency scenarios. Large downrange entry trajectories are possible only with a skip maneuver in which the vehicle enters and exits the atmosphere and re-enters farther downrange. We introduce a trajectory planning strategy that is composed of two independent phases and includes higher order logic to interconnect them. The interconnection is made possible via reachable and controllable sets. Using this framework, the connecting point must be within the reachable set of the skip phase and the controllable set of the re-entry phase.

09:15 **AAS 10 - 127** **Mission Design and Performance Assessment for the Constellation Lunar Architecture**
Shaun M. Stewart and Jacob Williams – ERC, Incorporated; Gerald L. Condon – NASA Johnson Space Center

The NASA Constellation Program is developing an architecture to establish and support a sustained human presence on the Moon. The current mission design architecture includes the Orion Crew Exploration Vehicle and the Altair lunar lander, which together support transportation to and from the lunar surface. For a selected architecture, the trajectory design and associated performance are used to provide a compromise between vehicle propellant and desired mission capabilities. This study uses the NASA Mission Assessment Post Processor (MAPP) to support a comprehensive investigation of the anticipated performance requirements for the current Constellation Program human lunar mission architecture.

09:40 **Break**

10:05 **AAS 10 - 128** **Investigation of Alternative Return Strategies for Orion Trans-Earth Injection Design Options**
B. G. Marchand and S. K. Scarritt – University of Texas at Austin; K. C. Howell – Purdue University; M. W. Weeks – NASA Johnson Space Center

The purpose of this study is to investigate alternative return strategies for the Orion trans-Earth injection (TEI) phase. A dynamical systems analysis approach considers the structure of the stable and unstable Sun perturbed Earth-Moon manifolds near the Earth-Moon interface region. A hybrid approach, then, combines the results from this analysis with classical two-body methods in a targeting process that seeks to expand the window of return opportunities in a precision entry scenario. The resulting startup arcs can be used, for instance, to enhance the block set of solutions available onboard during an autonomous targeting process.

10:30 **AAS 10 - 129** **Evaluation of Dual-Launch Lunar Architectures Using the Mission Assessment Post Processor**

Shaun Stewart and Jacob Williams – ERC, Inc.; Juan Senent – Odyssey Space Research, LLC; Gerald Condon and David Lee – NASA Johnson Space Center

The NASA Constellation Program is currently designing a new transportation system to support human missions to the Moon and enable the eventual establishment of an outpost on the lunar surface. This report summarizes a body of work performed in support of the Review of U.S. Human Space Flight Committee. It analyzes three lunar orbit rendezvous dual-launch architecture options which incorporate differing methodologies for mitigating the effects of launch delays at the Earth. Benefits and drawbacks of each option are discussed and the overall mission performance is compared with that of the existing Constellation Program lunar architecture.

10:55 **AAS 10 - 130** **Geosynchronous Orbit via the Moon: Phasing Loops to Permit Daily Launch**

Andrew E. Turner – Space Systems/Loral

This paper develops the concept of lunar gravity assist (LGA) to benefit geosynchronous spacecraft requiring large inclination changes during orbit-raising yet also satisfying the commercial standard to be able to launch on a daily basis. Unlike a previous paper by the author where the moon could be far from the equator when encountered, here phasing loops are employed en route to assure the moon is approached only when it is near the equatorial plane. At this point LGA provides maximum inclination removal so that an equatorial geosynchronous orbit can be achieved efficiently.

11:20 **AAS 10 - 131** **Lunar Network Tracking Architecture for Lunar Flight**

Shane Robinson – Utah State University; Todd Ely – Jet Propulsion Laboratory

A trade study was conducted with the objective of comparing and contrasting the radiometric navigation performance provided by various architectures of lunar-based navigations assets. Configurations of these assets include both coplanar and linked constellations of frozen elliptic orbiters and halo orbiters. Each architecture was studied during the lunar-approach, lunar-orbit, and landing phases of a South Pole lunar sortie mission. Navigation filter performance was evaluated on the basis of filter convergence latency, and the steady state uncertainty in the navigation solution. The sensitivity of the filter solution to Earth-based tracking augmentation and availability of range measurements was also

Session 5: Orbital Dynamics – I

Chair: Daniel Scheeres – University of Colorado

13:30 AAS 10 - 132 An Adaptive Gaussian Sum Filtering Approach for Orbit Uncertainty Estimation

Dan Giza and Puneet Singla – University of Buffalo

An approach for nonlinear filtering when measurements are sparse is discussed which makes use of the Fokker-Planck-Kolmogorov Equation (FPKE). The evolution of initial state estimates is replaced with the evolution of a probability density function for state variables. The transition pdf corresponding to dynamical system state vector is approximated by using a finite Gaussian mixture model. The mean and covariance of each component are propagated through the use of an Unscented Kalman Filter (UKF), and the unknown amplitudes are found by minimizing the FPKE error over the entire volume of interest. The two-body problem with non-conservative atmospheric drag forces and

13:55 AAS 10 - 133 Analytical Expressions that Characterize Propellantless Capture with Electrostatically Charged Spacecraft

Joseph Gangestad, George Pollock, and James Longuski – Purdue University

Spacecraft that generate an electrostatic charge on their surface within a magnetic field can manipulate the Lorentz force to perform propellantless maneuvers. Analytical expressions are developed that characterize propellantless capture with the Lorentz force and demonstrate coupling among the orbital elements. The relative evolution of the orbital elements notably does not depend either on the charge or on the magnetic field strength. The analytical solutions are applied to a capture example at Jupiter and agree with numerical propagations to within a fraction of a percent. This analytical theory now explains several trends that were identified in a previous numerical study.

14:20 AAS 10 - 134 Linearized Orbit Covariance Generation and Propagation Analysis via Simple Monte Carlo Simulations

Chris Sabol – Air Force Research Laboratory; Thomas Sukut – U. S. Air Force Academy; Kyle T. Alfriend – Texas A&M University; Keric Hill – Pacific Defense Solutions; Brendan Wright and You Li – U. S. Military Academy; Paul Schumacher – Air Force Research Laboratory

Monte Carlo simulations are used to explore how representative the covariance is of orbit estimation errors when fitting to normally distributed, zero mean error observation data. The covariance is generated using a linear state transition matrix in Cartesian or mean equinoctial states, and state error distributions are analyzed in Cartesian, mean equinoctial, or curvilinear coordinates. Simulations include single radar pass and catalog-class scenarios for a LEO satellite. Results show that the generated covariance is representative of the state error distribution at epoch for all state representations; however, the Cartesian-based covariance rapidly fails to represent the error distribution away from epoch.

14:45 AAS 10 - 135 Motion About an Oblate Primary

Mohammed Ghazy and Brett Newman – Old Dominion University

The two primary masses in the three body problem are considered as oblate spheroids. The angular velocity of the rotating coordinate system attached to the primaries is proved to be larger than when the two primaries are treated as point masses. The motion of the third body is disturbed by the oblateness of the primaries but a first integral slightly different than the Jacobi integral is obtainable. Motion of a spacecraft about the larger primary is discussed when the second primary is neglected with attention is given to the change in zero velocity curves due to oblateness.

15:10 **Break**

15:35 **AAS 10 - 136** **New Families of Hybrid Orbit Propagators Based on Analytical Theories and Time Series Models**

Juan Félix San-Juan and Montserrat San-Martín – Universidad de La Rioja, Spain

In this paper, we present a methodology to perform new families of hybrid orbit propagators which combine a simplified analytical orbit propagator with time series models. This combination allows an increase in the accuracy without significant loss in efficiency of the new propagators as well as modeling those perturbations that have not been considered in the analytical theory. The above features make these types of propagators good candidates as part of an economic onboard orbit determination system.

16:00 **AAS 10 - 137** **Orbital Dispersion and Earth-Impact Probability Analysis for Deflected/Fragmented Asteroids**

Daero Lee, Dakshesh Patel, and Bong Wie – Iowa State University

This paper describes the orbital dispersion problem of a fragmented asteroid in an elliptical orbit. Earth-impact probability is used as a measure of impact likelihood with the Earth after an asteroid is deflected and/or fragmented by a high-energy deflection method. The use of a state transition matrix (STM) derived from the Clohessy-Wiltshire-Hill (CWH) equations for an elliptical orbit is emphasized in this paper. Such a computationally efficient STM approach is used for the orbital dispersion simulation and impact probability computation. The accuracy of the proposed STM-based approach is also validated by direct numerical simulations of the elliptical CWH equations.

16:25 **AAS 10 - 138** **Solution to Lambert's Problem Using Generalized Canonical Transformations**

Mai Bando and Hiroshi Yamakawa – Kyoto University, Japan

In this paper, we study this problem through the framework of the Hamilton-Jacobi-Bellman (HJB) equation appearing in optimal control theory and its application in astrodynamics. Using the generalized canonical transformation, we transform the unstable original Hamilton system into the stable one preserving the Hamiltonian structure, and then apply the iterative method to solve HJB equation. We also apply our method to obtain solution to two-point boundary-value problem by the generating function. As an application of the generating functions approach, we consider the problem of a multiple flyby mission with impulsive thrust.

16:50 **AAS 10 - 139** **Transforming Mean and Osculating Elements Using Numerical Methods**

Todd Ely – Jet Propulsion Laboratory

Mean element propagation of perturbed two body orbits has as its mathematical basis averaging theory of nonlinear dynamical systems. Averaged mean elements define the long-term evolution characteristics of an orbit. Using averaging theory, a near identity transformation can be found that transforms the mean elements back to the original short periodic osculating elements. The ability to perform the conversion is necessary so that orbit design conducted in mean elements can be converted back into osculating results. In the present work, this near identity transformation is found using the Fast Fourier Transform. An efficient method is found that is capable of recovering the osculating elements to within the order of the underlying averaging theory.

Session 6: Attitude Dynamics and Control – I

Chair: Al Treder – Barrios Technology

13:30 AAS 10 - 140 ICESat Attitude and Pointing Correction Using the Laser Reference Sensor
Sungkoo Bae, Noah Smith, and Bob Schutz – University of Texas at Austin

The Laser Reference Sensor (LRS) is a customized commercial star tracker providing reference information for ICESat precision attitude and pointing determination. Instead of measuring multiple stars in a large field of view, it makes high angular resolution measurements of the altimeter laser beam, stars, and a reference source. The LRS has been used to correct several systematic pointing errors on the scale of 20 arcseconds down to a few arcseconds. This paper describes significant LRS results and possibilities for future reference instruments.

13:55 AAS 10 - 141 Optimal Despin of a Tumbling Satellite with an Arbitrary Thruster Configuration, Inertia Matrix, and Cost Functional
Daniel Sheinfeld and Stephen Rock – Stanford University

An algorithm to generate the optimal control to despin a tumbling satellite with known, but arbitrary thruster configuration, inertia matrix, and cost is presented. The control is calculated as a set of optimal switching surfaces using numerical dynamic programming to generate optimal state trajectories and control histories. Points along the state trajectories where the control switches are points on the switching surfaces. Alternative state and staging variables provide substantially improved performance of the algorithm. Computation time savings on the order of a factor of 40 and data storage savings on the order of a factor 2000 are demonstrated through simulation.

14:20 AAS 10 - 142 Persistence Filter Based Attitude Stabilization of Micro-Satellites with Variable Amplitude Thrusters
S. Srikant and M. R. Akella – University of Texas at Austin

Thrusters are important candidates for attitude control actuators in micro-satellites due to low complexity and high power to weight ratios. Inability of conventional thrusters to produce low output thrusts prevents adaptability to micro-satellite applications. The attitude control of a micro-satellite is considered with low-cost, cold-gas thrusters subject to minimum thrust constraints. Control formulation is based on superposing a periodic step function to the control and builds upon our recent persistence filter construction to obtain exponential convergence of states to the origin. The on-off window pre-scaling and persistence filter construction increase commanded control while guaranteeing any desired exponential convergence rate. Significantly better convergence results are seen with the persistence based controller as opposed to classical proportional derivative controllers during simulations with control minimum constraints.

14:45 AAS 10 - 143 Pointing Performance Control of a Spacecraft Camera Using Piezoelectric Actuators
Ozan Tekinalp, Sharmila Kayastha, and Kemal Ozgoren – Middle East Technical University, Turkey

Control algorithm is developed for a satellite with flexible appendages to achieve a good pointing performance. Detailed modeling activity was carried out that consists of sensor and actuator models, disturbances and system dynamics. Common hardware found in the spacecraft such as reaction wheels, gyro-scopes, star trackers, etc. were included in the model. Furthermore, the Newton-Euler method is employed for the derivation of multi-body equations of motion. Evaluation of the pointing accuracy with proper pointing performance metrics such as accuracy, jitter and stability during slew maneuvers are obtained through simulations. Control strategies are proposed to improve pointing performance.

15:10 **Break**

15:35 **AAS 10 - 144** **Spacecraft Attitude Control via a Combined State-Dependent Riccati Equation and Adaptive Neuro-Fuzzy Approach**

Mohammad Abdelrahman, Sung-Woo Kim, and Sang-Young Park – Yonsei University, Republic of Korea

A hybrid controller for spacecraft attitude and rate tracking is presented combining two control techniques. A neuro-fuzzy controller based on the Adaptive Neuro-Fuzzy Inference System (ANFIS) is aided by a Modified State-Dependent Riccati Equation (MSDRE) controller to reduce computational burden that can be significantly large when MSDRE controller is solely used. Therefore, the control scheme is based on relatively large time intervals solution of the MSDRE. The global asymptotic stability of the MSDRE and MSDRE/ANFIS controllers is investigated using Lyapunov theorem. Simulation results that demonstrate real-time performance of the controllers show a considerable amount of reduction in the computational efforts.

16:00 **AAS 10 - 145** **Standalone Three-Axis Attitude Determination from Earth Images**

A. Bevilacqua, C. Bianchi, L. Carozza, A. Gherardi, N. Melega, D. Modenini and P. Tortora – Università di Bologna, Italy

The feasibility of a novel standalone spacecraft attitude sensor, capable of estimating the full three-axis orientation of an Earth-orbiting satellite is investigated in this paper. The underlying idea is that by capturing from space a sequence of images of the Earth surface (in the visible bands) and elaborating them in pairs, spacecraft attitude could be reconstructed. The following project steps were followed in about two years and are thoroughly discussed in the paper: selection of enabling technologies, definition of the attitude determination algorithm, numerical simulations followed by an acquisition campaign on an experimental test-bed.

16:25 **AAS 10 - 146** **Three-Axis Attitude Control of Satellites using Solar Radiation Pressure**

Surjit Varma and Krishna D. Kumar – Ryerson University, Canada

The paper presents the use of solar radiation pressure for three-axis attitude control of satellites. The system comprises of a satellite with four vanes. The four vanes are rotated based on the control laws to achieve desired attitude performance. The control laws are designed using sliding mode control technique. The detailed system response is numerically simulated using the set of governing equations of motion of the system in conjugation with the proposed control laws. The effects of initial attitude errors and external disturbances on the controller performance are examined. The satellite attitude is stabilized within half an orbit for all the cases considered.

16:50 **AAS 10 - 147** **Unifying the Set of Iterative Learning Control Laws using the Quadratic Cost Structure**

Jiangcheng Bao and Richard W. Longman – Columbia University

Iterative learning control (ILC) aims to converge to zero tracking error in systems performing repeated tracking maneuvers. Spacecraft applications include improved tracking in repeated scanning maneuvers of fine pointing equipment. Various ILC law families have different learning rate and stability robustness properties. These are compared as a function of frequency. It is shown that the rate vs. robustness tradeoff for each frequency can be used to create specially tailored ILC laws. It is also shown that each of the ILC laws can be generated by appropriate choice of weight matrices in quadratic cost ILC, thus generating a unifying framework.

Session 7: Space Surveillance

Chair: Felix Hoots – The Aerospace Corporation

13:55 **AAS 10 - 149** **Goodness-of-Fit Tests for Sequential Orbit Determination**
John H. Seago – Analytical Graphics, Inc.; David A. Vallado – Center for Space Standards and Innovation

Goodness-of-fit tests – sometimes called consistency tests – are useful for investigating the lack of optimality of an estimator. Statistical hypothesis tests using observation residuals are often suggested as goodness-of-fit tests for the orbit-determination problem; however, the most-commonly recommended diagnostic tests tend to be somewhat restricted in their scope and utility. In this paper, less-familiar statistical tests are discussed that potentially extend consistency testing into both the time- and frequency-domains, and also apply to observation residuals that are not necessarily spaced evenly with time. These supplemental tests are used to assess sequential-estimation results from actual satellite tracking data and simulated data.

14:20 **AAS 10 - 155** **Post-Maneuver Orbit Accuracy Recovery Analysis**
Thomas Johnson – Analytical Graphics, Inc.

Maneuvers are a routine part of spacecraft operations. These consist of periodic station-keeping maneuvers, momentum dumps, or other thrusting events which perturb the orbit. This paper analyzes a variety of maneuvers, satellite orbits, and tracking schedules to determine how long it takes to recover the orbit solution to its pre-maneuver accuracy. The results are of particular interest to operators interested in evaluating spacecraft performance and to those interested in space situational awareness. It also evaluates useful "rules of thumb" for planning satellite tracking schedules to achieve maneuver recovery.

14:45 **AAS 10 - 151** **Nonlinear Sequential Methods for Impact Probability Estimation**
Richard Linares and Puneet Singla – University of Buffalo

This work will compare three nonlinear sequential estimators, the Extended Kalman Filter (EKF), the Unscented Kalman Filter (UKF) and the Particle Filter (PF) to estimate the impact probability. Orbit determination in application to the estimation of impact probability has the goal of determining the evolution of the state Probability Density Function (pdf) and determining a measure of the probability of collision. Nonlinear gravitational interaction and non conservative forces can make the pdf far from Gaussian. Both the EKF and the UKF make the Gaussian assumption and this work investigates effect of this approximation on the impact probability calculation.

15:10 **Break**

15:35 **AAS 10 - 152** **An Adaptive Scheme on Optimal Number of Observations and Time Intervals for an Initial Orbit Determination Problem**
Reza Raymond Karimi and Daniele Mortari – Texas A&M University

An algorithm to choose the best combination of the number of observations and time intervals between the measured directions for an initial orbit determination problem is presented. The algorithm has been developed to be able to work with an angles-only IOD method capable of using multiple observations. The IOD technique developed by the current authors was used for the purpose of this paper. A preliminary orbit determination is performed first using a typical number of observations and constant time intervals. The estimated satellite ranges and range rates are the bases of the further corrections.

16:00 AAS 10 - 153 The Use of Angle and Angle Rate Data for Deep-Space Orbit Determination and Track Association

Kyle J. DeMars – University of Texas at Austin; Moriba K. Jah and Paul W. Schumacher, Jr. – Air Force Research Laboratory

The large number of earth-orbiting resident space objects (RSOs) burdens the available surveillance tracking resources enough that most deep-space objects are tracked only sparsely. Having short, widely separated arcs of data can make it difficult to reacquire some objects and correctly associate data. Nowadays, new photon-counting sensors offer the ability to measure both angle and angle rate precisely even for dim targets. We adapt the concepts of admissible regions and attributable vectors offered by Milani, Tommei and others to produce a multiple-hypothesis tracking scheme for passive optical surveillance, including probabilistic data association and orbit determination via unscented Kalman filtering.

16:25 AAS 10 - 154 Investigation of Ballistic Coefficient Generation from Two Line Element Sets

Stephen R. Mance and Craig A. McLaughlin – University of Kansas; Chin S. Lin, Frank A. Marcos, and Samuel B. Cable – Air Force Research Laboratory

This paper presents a method for generating ballistic coefficient estimates using two line elements (TLEs) and the HASDM atmospheric model. This method has been performed on eight satellites in different low earth orbit (LEO) altitude regimes. The results of this study indicate that the ballistic coefficients generated in altitude regions below 500 km using this method are on average within 10% of values obtained using other methods with some achieving less than 5%. This study also shows that the HASDM density model overestimates density in the most recent unusually low solar minimum because the ballistic coefficient decreases with solar minimum.

16:50 AAS 10 - 150 Covariance-based Network Tasking of Optical Sensors

Keric Hill, Paul Sydney, Randy Cortez, Dale Naho`olewa, and Jeff Houchard – Pacific Defense Solutions, LLC; K. Kim Luu, Moriba Jah, and Paul W. Schumacher, Jr. – Air Force Research Laboratory

A comprehensive high-fidelity simulation environment of networked optical sensors has been created under an effort called TASMAN (Tasking Autonomous Sensors in a Multiple Application Network). One of the first studies utilizing this environment is focused on a novel resource management approach, namely covariance-based tasking. Under this scheme, various observation effectiveness metrics are proposed and tested parametrically with metrics measuring sensor utility, elapsed time to meet orbit precision requirements, and necessity for object searches. Sensor outages will be simulated so that the complexities from real-time dynamic tasking are also examined.

Session 8: Satellite Relative Motion – I

Chair: James Gearhart – Orbital Sciences Corporation

13:30 **AAS 10 - 156** **A Refined Dynamical Model for Multi-tethered Satellite Formations**
Giulio Avanzini and Marco Giannini – Politecnico di Torino, Italy; Manrico Fedi – Universitat Politècnica de Catalunya, Spain

The paper considers the effects of including a massive cable model in the analysis of the dynamics exhibited by a multi-tethered satellite formation. The major objective of the work is to evaluate under which conditions cable mass has a non-negligible effect on the behaviour of the system. This objective is pursued by means of a simple bead-model for the cables, where each tether is discretized by means of a sequence of spring-damper-mass elements. Major differences with respect to the behaviour determined on the basis of simpler models, where cable mass is neglected, will be outlined in different mission scenarios.

13:55 **AAS 10 - 157** **Formation Flight of Earth Satellites on KAM Tori**
Christopher Craft – Air Force Research Laboratory; William E. Wiesel – Air Force Institute of Technology

Komolgorov, Arnold and Moser (KAM) theory provides that orbits of satellites whose dynamics are representable by an integrable Hamiltonian plus a small, real perturbation lie on tori in phase space and remain upon the KAM tori for all time. A refined technique for constructing KAM tori for Earth-orbiting satellites is developed and implemented. Theoretically, satellite formations must lie on KAM tori to have zero relative drift rates. Cluster formations with physical secular drift rates on the order of nanometers to micrometers per second are obtained in this way. A brief discussion of effects of non conservative forces on KAM tori is given.

14:20 **AAS 10 - 158** **Formation Flying of Satellites at the Earth-Moon L4 Triangular Libration Point Using Solar Radiation Pressure**
Frank Wong and Krishna D. Kumar – Ryerson University, Canada

The present paper proposes the use of solar radiation pressure for formation control of satellites at the Earth-Moon L4 triangular libration point. The formation equations of motion controller are derived using the Lagrange formulation approach. The controllers for desired formation are derived using the LQR control scheme and the sliding mode control technique. Continuous as well as bang-bang controllers are designed and their performance is compared. The effect of the solar gravity on the controller performance is also examined. Numerical simulation results along with analytical proofs show that solar radiation pressure can be a viable propellantless technique for formation control.

14:45 **AAS 10 - 159** **Relative Orbital Evolution of a Cluster of Femto-satellites in Low Earth Orbit**
P.P. Sundaramoorthy, E. Gill, and C.J.M. Verhoeven – Delft University of Technology, Netherlands

This paper investigates the temporal and spatial characteristics of a femto-satellite cluster once injected by a cluster launch mechanism into a low Earth orbit (LEO). An extensive treatment of the differential acceleration due to gravity and drag is carried out. In addition, the benefits and drawbacks of using different representation schemes to visualize the cluster's relative geometry is discussed. Quantitative relations are established that relate the relative motion between the satellites to the initial velocity increments provided by the cluster launch mechanism. Conclusions regarding the operations concept of Femto-satellite missions are drawn.

15:10 **Break**

15:35 AAS 10 - 160 Satellite Formation Flying using Differential Aerodynamic Drag

Surjit Varma and Krishna Dev Kumar – Ryerson University, Canada

In this paper we propose the use of differential aerodynamic drag for multiple satellite formation flying. The nonlinear dynamics describing the motion of the follower satellite relative to the leader satellite is considered for the case where the leader satellite is in an unperturbed reference orbit, and the stability of such a formation in the presence of external perturbations is investigated. Several cases are considered to examine the performance of the proposed control strategy to maintain the relative motion of the follower satellites by correcting for any initial offset errors and external perturbation effects that tend to disturb the formation system. Numerical simulation results confirm that the suggested methodology using differential aerodynamic drag yields reasonable formation keeping precision and its effectiveness in ensuring formation maneuvering.

16:00 AAS 10 - 161 Second-Order Analytical Solutions to Fuel-Optimal Control Problems in Satellite Formation Flying

Sangjin Lee, Sang-Young Park, and Kyu-Hong Choi – Yonsei University, Republic of Korea

In this paper, new analytical solutions to optimal control problems in formation flying is presented including the differential gravity effects to second order. The perturbation approach and the calculus of variations are applied to the optimal control problems in order to obtain approximate analytical solutions. Nonlinear relative dynamics that includes quadratic terms in the differential gravitational accelerations are used. For the sake of validity, numerical simulations are performed for satellite reconfiguration cases in which the distance between the satellites is large. Finally, we confirm the accuracy improvement of the new analytical solutions.

16:25 AAS 10 - 162 A Guidance and Control Algorithm for Optimized Close-Proximity Spacecraft Maneuvers Using Mixed-Integer Linear Programming

Nick Martinson – University of Florida

This paper outlines a method that solves for an optimized satellite maneuver in the presence of obstacles. This method constitutes an optimized plan in which the dynamics are directly incorporated in a guidance and control algorithm. Simulations indicate the guidance and control method obtains low thrust maneuvers as compared to known methods termed Artificial Potential Function Guidance and computational time required is less than using Sequential Quadratic Programming.

16:50 AAS 10 - 163 Two-Craft Coulomb Formation Relative Equilibria About Circular Orbits and Libration Points

Ravi Inampudi and Hanspeter Schaub – University of Colorado at Boulder

The relative equilibria of a two spacecraft Coulomb formation moving in a two-body system and a restricted three-body system are investigated. The relative equilibrium is called great circle if the center of mass of the formation moves on the plane with the center of the gravitational field residing on it; otherwise, it is called a nongreat-circle orbit. Past research shows that nongreat-circle equilibria do exist in LEO and this paper investigates these equilibria of two spacecraft Coulomb formation and studies the effect of nongreat-circle equilibria on two spacecraft formations existing in LEO to GEO and at a collinear Libration point.

Session 9: Interplanetary Trajectory Design

Chair: Kenneth Williams – KinetX, Inc.

08:00 **AAS 10 - 164** **A Fast Tour Design Method Using Non-Tangent V-Infinity Leveraging Transfers**

Stefano Campagnola – University of Southern California; Nathan J. Strange – Jet Propulsion Laboratory; Ryan P. Russell – Georgia Institute of Technology

In this paper we study the V-Infinity Leveraging Transfers (VILT) solution space and derive a linear approximation which greatly simplifies the computation of the transfers. We then introduce a fast design method for multiple-VILT tours. We use this method to design a trajectory from a highly eccentric orbit around Saturn to a 200 km science orbit at Enceladus. The trajectory is 2.7 years long and comprises 52 gravity assist at Titan, Rhea, Dione, Tethys, and Enceladus, and several deterministic maneuvers. The total delta-v is only 445 m/s, including the Enceladus orbit insertion, almost 10 times better than the 3.9 km/s of the Enceladus orbit insertion from the Titan-Enceladus Hohmann.

08:25 **AAS 10 - 165** **Investigation of Target Selection Schemes for a Space Telescope-Occulter System in the Sun-Earth L2 Regime**

Bradley Cheetham, Kathryn Davis, George Born and Webster Cash – University of Colorado at Boulder

Intelligent target star selection for a space telescope-occulter mission to the Sun-Earth L2 regime is vitally important to maintain mission flexibility, reduce fuel and operational costs, and maximize scientific return. A space telescope-occulter system flying in formation has been proposed as a technology capable of directly imaging planets within the habitable zones of stars beyond our solar system. Specifically this study investigates the target selection for New Worlds Observer (NWO), a mission which would accompany NASA's James Webb Space Telescope (JWST).

08:50 **AAS 10 - 166** **A Simple Numerical Procedure for Computing Multi-Impulse Lunar Escape Sequences with Minimal Time-of-Flight**

Shane Robinson and David Geller – Utah State University

A simple numerical procedure for computing multi-impulse transfers from an arbitrary elliptic orbit to a hyperbolic escape asymptote. This procedure uses simple numerical procedures to minimize the time-of-flight to the sphere of influence without violating the fuel constraint. The number of impulses is also minimized. The simplicity and robustness of this particular algorithm makes it well-suited for on-board use during contingency and abort operations. Some examples demonstrating the effectiveness of the algorithm are also presented. The results demonstrate the robustness on minimal CPU requirements of the technique.

09:15 **AAS 10 - 167** **N-Impulses Interplanetary Orbit Transfer Using Genetic Algorithm with Application to Mars Mission**

Ahmed Gad, Neelima Addanki, and Ossama Abdelkhalik – Michigan Technological University

Genetic Algorithm (GA) is used as an optimization technique to obtain the optimum parameters of the N-impulses interplanetary transfer orbit. The developed algorithm calculates the required delta-v and the optimum launch and arrival times. One or more extra delta-v are applied during the course of the spacecraft to reduce the total delta-v and/or mission duration. GA is used to determine the optimum values and locations of the extra delta-v(s). Mars mission is considered as an application to study minimum energy and minimum mission duration cases. Results show that increasing the number of impulses is more efficient in cost and duration.

09:40 **Break**

10:05 **AAS 10 - 168** **Trajectory Reconstruction for the Phoenix Mars Lander using Unscented Kalman Filtering**
Grant Wells and Robert Braun – Georgia Institute of Technology

Accurate post-flight reconstruction of a vehicle's trajectory during entry into a planetary atmosphere can produce a wide array of valuable information. Data collected through the reconstruction of entry, descent, and landing system performance enables the quantification of performance margins for future systems. Beyond the engineering knowledge gained through trajectory reconstruction, the results may also be used by planetary scientists to generate an accurate atmospheric profile. This paper provides are construction of the trajectory, vehicle orientation, and atmospheric density profile for the hypersonic and supersonic phases of the Phoenix Mars Lander spacecraft.

10:30 **AAS 10 - 169** **Solar Electric Propulsion for Jovian Capture**
Damon Landau, Nathan Strange, and Try Lam – Jet Propulsion Laboratory

The Galilean satellites can be used to capture a spacecraft into Jupiter orbit from an interplanetary trajectory without a propulsive Jupiter-orbit-insertion maneuver. A double flyby of Callisto and Ganymede or of Ganymede and Io captures at Jupiter with V-infinities less than 3.5 and 4 km/s, respectively. The relatively low energy with respect to Jupiter at arrival is achieved with a combination of SEP and gravity assists from Earth and Mars. A launch using an Atlas V 551 launch vehicle coupled with a lunar gravity assist nets 4,500 kg into Jupiter orbit with a 25-kW (@1AU) SEP system and 7-year interplanetary cruise.

10:55 **AAS 10 - 170** **Titan Trajectory Design Using Invariant Manifolds and Resonant Gravity Assists**
Natasha Bosanac – Massachusetts Institute of Technology; Jerrold E. Marsden and Ashley Moore – California Institute of Technology; Stefano Campagnola – University of Southern California

Combining invariant manifolds in the planar circular restricted three body problem and multiple resonant gravity assists allows for the design trajectories with a very low dV. The Keplerian mapping function will be explored to target desirable resonances which, at any single node, minimize the time of flight and exposure to undesired gravitational perturbations. Using this design tool, the resulting time of flight for a trajectory will be compared to that of a trajectory utilizing the maximum single point decrease in semi-major axis. Through selecting desired resonances, the effect of the Jacobi constant on the trajectory's total dV is explored.

11:20 **AAS 10 - 171** **Preliminary Approach for Constructing Robust Low-Thrust Interplanetary Trajectories Subject to Engine Failures**
Joris T. Olympio – European Space Agency, ESTEC

The study we propose considers the mass maximization optimization problem where the electrical propulsion system is subject to momentary breakdowns. A stochastic optimal control problem is posed, where the switching dates are perturbed with random durations, reducing the thrust time. The optimal control problem objective is the fuel mass minimization, subject to the satisfaction of constraints to a given probability. The choice of the optimal control is thus made on the likeliness that prescribed perturbations of the thrust durations still allows the mission to be completed.

Session 10: Satellite Constellations

Chair: William Cerven – The Aerospace Corporation

08:00 AAS 10 - 172 The Lattice Theory of Flower Constellations

Martin Avendaño, Daniele Mortari, and Jeremy J. Davis – Texas A&M University

The theory of Flower Constellations is here extended to include all symmetric configurations that were missing in the original theory. This is done by redefining a Flower Constellation as a set of satellites in space whose locations (Omega,M) are given by the points of a lattice in the torus S1xS1. These lattices are described by a matrix in Z^{2x2}. The compatibility equations have been decoupled of the symmetry equation. As a consequence, the original problems of equivalence and similarity become easier. Namely, the equivalence problem is solved by reducing a matrix to the Hermite normal form while the similarity problem by selecting any pair of integers and computing Nd and Np using a simple formula. Finally, by subset mapping, an extended Lattice theory is introduced.

08:25 AAS 10 - 173 Elliptical Lattice Flower Constellations for Global Coverage

Jeremy J. Davis and Daniele Mortari – Texas A&M University

Flower Constellations (FC) have been extensively studied for use in optimal constellation design. FCs have recently been reformulated into Lattice Flower Constellations (LFC), encompassing the complete set of harmonic FCs. Previous studies have shown FCscan provide improved performance in global navigation over existing global navigation satellite systems (GNSS). Here the LFCs are investigated to find improved results over the original FCs for GNSS. Elliptic orbits are generally avoided due to the deleterious effects of Earth's oblateness on the constellation, but here we present a novel concept for avoiding this problem and enabling more effective global coverage utilizing elliptic orbits.

08:50 AAS 10 - 174 A Study of Low-Thrust Trajectories for Low Orbit Multiple Cubesat Missions

Alexander Ghosh and Victoria Coverstone – University of Illinois

This work discusses the usage of a low-thrust micro-cavity discharge thruster on 3 kg cubesats. Based on a case study of a two-satellite system, the required trajectories, and control use is determined to allow the cubesats to recover from disturbances, and extended their usable lifetime. The approach uses a direct transcription method that employs multiple-shooting of a 4th order Runge-Kutta forward-integration of the state and control defects. It also lays the groundwork for future study into problems regarding cubesat formation phasing with larger numbers of spacecraft.

09:15 AAS 10 - 175 Guidance for Elliptic Orbit Rendezvous

Thomas V. Peters and Luigi Strippoli – GMV Aerospace and Defence, Spain

This paper presents the development of elliptic orbit rendezvous guidance algorithms for GMV's Highly Autonomous RendezVous and Docking (HARVD) simulator. The development approach is to generalize maneuver algorithms for circular orbits to elliptic orbits. Analogous relative trajectories to amongst others Hohmann transfers, zero-eccentricity drift orbits, radial hops and V-bar hold points are developed. These relative trajectories preserve the desirable characteristics of their circular orbit rendezvous counterparts. The relative trajectories defined for elliptic orbits transform into the relative trajectories associated with circular orbits as the eccentricity approaches zero. Simulation results show that the algorithms lead to successful rendezvous.

09:40 Break

10:05 AAS 10 - 176 Rigid Body Attitude Synchronization with Communication Time Delays

Tyler H. Summers, Apurva Chunodkar, and Maruthi R. Akella – University of Texas at Austin

The objective of this paper will be to design and analyze attitude control laws that asymptotically synchronize the attitude of a team of rigid bodies. There will be no common reference attitude, the communication architecture will have no leader or hierarchy, and the communicated state information will be assumed to have a constant, unknown time delay. Our approach will utilize recent results from consensus theory and attitude control with time delays to prove asymptotic stability. We will also investigate through simulation communication architectures that optimize the tradeoff between providing fast synchronization and featuring robustness to time delays.

10:30 AAS 10 - 177 Formation Keeping of Multiple Spacecraft with Communication Delays

Xi Liu and Krishna Kumar – Ryerson University, Canada

The orbital formation keeping problem for multiple spacecraft flying is investigated in this paper. New approaches for tracking control of relative translational motion between two spacecraft in a leader-follower formation are derived for the case where the leader spacecraft is in a circular orbit. A linear digital controller is developed for such a formation using Lyapunov-based method. It is shown that in the presence of time varying delays in the intercommunication, the proposed controller will guarantee global exponential stability for position and velocity tracking error to ensure desired performance (projected circular formation) during the spacecraft formation flying mission. Numerical simulations are presented to demonstrate the effectiveness of the developed controller and the robustness of the controller to nonlinearities and external disturbances.

10:55 AAS 10 - 178 A Novel Nonlinear Rendezvous Guidance Scheme with Control Direction Constraints

Shinji Mitani – JAXA; Hiroshi Yamakawa – Kyoto University, Japan

In practical rendezvous problems, the problem must be treated under complicated conditions such as the limitation of thruster activation direction, sensor FOV, the sun direction, etc. In this paper, we propose a new nonlinear guidance scheme to treat rendezvous trajectory planning with such practical constraints using control Lyapunov function (CLF) and “satisficing” concepts.

11:20 AAS 10 - 179 A Dynamical Systems Approach to Micro-spacecraft Autonomy

Blair Brown and Colin McInnes – University of Strathclyde, Scotland

The drive toward reducing the size and mass of spacecraft has put new constraints on the computational power available for control and decision making algorithms. The aim of this paper is to present alternative methods for decision making algorithms that can be introduced for nano-spacecraft. The motivation behind this work comes from dynamical system theory. Systems of differential equations can be built to define behaviors that can be manipulated to define an action selection algorithm. These algorithms can be mathematically verified and validated, providing robust autonomous control with a modest computational overhead.

Session 11: Orbit Dynamics – II

Chair: Ryan Park – Jet Propulsion Laboratory

08:00 AAS 10 - 180 The Eleventh Motion Constant of the Two-Body Problem

Andrew J. Sinclair – Auburn University; John E. Hurtado – Texas A&M University

The two-body problem is a twelfth-order time-invariant dynamic system, and therefore has eleven motion constants. Some of these motion constants are related to the ten algebraic integrals of the n-body problem, while some are particular to the two-body problem. The problem can be decomposed into mass-center and relative-motion subsystems, each being sixth order and each having five motion constants. This paper presents solutions for the eleventh motion constant, which relates the behavior of the two subsystems.

08:25 AAS 10 - 181 On the Stability of Displaced Two-Body Lunar Orbits

Jules Simo and Colin R. McInnes – University of Strathclyde, Scotland

In a prior study, a methodology was developed for computing and approximate large displaced orbits in the Earth-Moon circular restricted three-body problem (CRTBP) by the Moon-Sail two-body problem. It was found that far from the L1 and L2 points, the approximate two-body analysis for large accelerations matches well with the dynamics of displaced Earth orbits in relation to the three-body problem. In the present study, the linear stability characteristics of the families of periodic orbits are investigated.

08:50 AAS 10 - 182 Analytic Solutions of the Two-Body Problem

Julio C. Benavides and David B. Spencer – The Pennsylvania State University

The N-body problem is defined and its equations of motion are introduced along with the equations of motion for the two-body problem. Time dependent series solutions of the two-body problem are discussed. A new time transformation based on these series solutions is introduced and used to develop a time-dependent; analytic; first-order solution of the two-body problem. A process of deriving higher-order; time-dependent; analytic solutions of the two-body problem is also introduced. These analytic solutions are shown to be capable of describing complete, two-body trajectories with good accuracy and with far fewer function evaluations than are required by numerical integration.

09:15 AAS 10 - 183 In Plane Correction of an Approximate Planar Periodic Orbit about the Larger Primary

Mohammed Ghazy and Brett Newman – Old Dominion University

An approximate planar solution to the circular restricted three body problem is analytically corrected for the in plane motion, the special case of small mass parameter and motion of the third body near the first primary is considered. The correction process is done iteratively through adding small correction terms of order of magnitudes less than the base solution. Variation equations of the correction variables are found to be linear differential equations with periodic coefficients. These equations are solved using the perturbation method and stability of motion is investigated using Floquet theory.

09:40 Break

10:05 AAS 10 - 184 Long-Term Evolution of Trajectories Near the Smaller Primary in the Restricted Problem
Diane Craig Davis and Kathleen C. Howell – Purdue University

In the problem of three bodies, the gravity of the larger body affects orbits near the smaller primary and can cause escape from its vicinity. However, a collection of orbits remains bounded for extended periods of time. Predicting the long-term behavior of a trajectory given its initial state is challenging; an understanding of the larger primary's gravity in terms of quadrants can be combined with Poincaré maps to yield useful information about the evolution of various orbits. Classifying various categories of escape and captured orbits with respect to their initial conditions facilitates the selection of orbits with desired characteristics.

10:30 AAS 10 - 185 Repeating Orbits in a Three Body System with Zero Mass Parameter
Mohammed Ghazy and Brett Newman – Old Dominion University

In a three body problem when the mass parameter is approximated to be zero the problem is treated as a two body problem in a rotating coordinate system. Yet, the Jacobi integral equation is still applicable and different values of the Jacobi constant determine boundaries within which repeating orbits exist around the larger primary. It is proven that cusps in these orbits are formulated when a third body touches a corresponding zero velocity curve. Characteristics of direct and retrograde repeating orbits are analyzed. Conditions under which loops in the repeating orbits exist are discussed.

10:55 AAS 10 - 186 Analytic Solutions of the N-Body Problem
Julio C. Benavides and David B. Spencer – The Pennsylvania State University

The N-body problem is defined and its equations of motion are introduced. A new time transformation based on two-body problem series solutions is introduced and used to develop a time-dependent; analytic; first-order solution of the N-body problem. A process of deriving higher-order; time-dependent; analytic solutions of the N-body problem is also introduced. These analytic solutions are used to investigate non-periodic trajectories in the restricted three-body problem and are shown to be capable of describing complete, N-body trajectories with good accuracy and with far fewer function evaluations than are required by numerical integration.

11:20 AAS 10 - 187 N-Gon Minimum Energy Solutions of the Planar N-Body Problem
T. A. Bauer – Twelve Enterprizes

Mathematical method calculating planar n-body radii, mass and angular velocity particle distributions around a central body as structured in concentric n-gons is considered. This procedure derives perturbations between orbiting particles as formulated by n-gon synodic relations and n-body equations of motion. Infinite differentially rotating conservative dynamical particle systems result, where it is of interest to find the minimum energy solution to determine unique n-gon radii, mass and angular velocity distributions.

Session 12: Planetary Missions

Chair: Matthew Berry – Analytical Graphics, Inc.

08:00 AAS 10 - 188 Failure Bounding and Sensitivity Analysis Applied to Monte Carlo Entry, Descent, and Landing Simulations

John A. Gaebler and Robert H. Tolson – North Carolina State University; Juan R. Cruz – NASA Langley Research Center

Three methods that provide statistical insights are applied to an entry, descent, and landing simulation. Failure domain bounding reduces the computational cost to generate additional failed cases for study while increasing the accuracy of the failure probability approximation. Sobol's variance based sensitivity analysis allows an engineer to identify which input will have the greatest impact on reducing the uncertainty on an output. Probabilistic sensitivity analysis uses Leibniz rule to calculate certain sensitivities at a reduced computational cost. The advantages and disadvantages of each method will be discussed in terms of the insights gained vs. the computational cost.

08:25 AAS 10 - 189 Mission Design of Solar Polar Region Observer Equipped with Solar Electric Propulsion

Yasuhiro Kawakatsu, Hitoshi Kuninaka, and Kazutaka Nishiyama – Japan Aerospace Exploration Agency, Japan

A study on the post-HINODE Solar Observation Mission has been started in the Solar physics community. One candidate of the mission targets on the observation of the solar polar region from the orbit largely inclined with the ecliptic plane. Following the paper presented in the previous meeting, this paper focuses on the mission design option which uses the solar electric propulsion (SEP). The design is refined and optimized based on the further analyses on the sensitivity to parameters and the additional consideration of practical constraints. The newly obtained mission baseline and its features are discussed as well.

08:50 AAS 10 - 190 Numerical Simulations of the Radio Science Experiment of the Mission BepiColombo to Mercury

Manuela Marabucci and Luciano Iess – University of Rome La Sapienza, Italy

The Mercury Orbiter Radio Science Experiment (MORE) of the ESA mission BepiColombo will provide an accurate estimation of Mercury's gravity field by means of highly stable, multi-frequency radio links in X and Ka band. Thanks to a plasma noise cancellation system, two-way range rate accuracies of about 3 micron/s are expected at nearly all solar elongation angles. We report on numerical simulations of the MORE experiment and provide an estimate of the attainable accuracies in the determination of the spacecraft orbit and the harmonic coefficients of the gravity field.

09:15 AAS 10 - 191 The Mission Assessment Post Processor (MAPP): A New Tool for Performance Evaluation of Human Lunar Missions

Jacob Williams and Shaun M. Stewart – ERC, Incorporated; Elizabeth C. Davis – Jacobs Technology; David E. Lee, Gerald L. Condon, and Timothy F. Dawn – NASA Johnson Space Center; Juan Senent – Odyssey Space Research

Performance evaluation of human lunar missions is a difficult problem, since it is a function of a complex set of interdependent parameters (such as departure epoch, Earth-Moon geometry, flight time, entry return constraints, etc.). A new tool, the Mission Assessment Post Processor (MAPP) has been developed in order to provide a global view of the mission space and statistical sensitivities for all on-orbit mission phases. MAPP enables an assessment of the integrated performance over the operational lifetime of a lunar architecture. Mission design and vehicle sizing results will be shown for the Constellation lunar architecture.

09:40 Break

10:05 AAS 10 - 192 Mars Atmosphere and Volatile EvolutioN (MAVEN) Mission Design
David Folta – NASA Goddard Space Flight Center

The MAVEN mission was selected as the second in the low-cost Mars Scout mission series. MAVEN will determine the role that loss of volatiles to space has played through time from a highly inclined elliptical orbit. The launch period opens November 18, 2013 with arrival September 16, 2014. After achieving a 35-hr capture orbit, maneuvers will reduced the period to 4.5-hrs with periapsis near 150 km and maintained within a nominal density corridor. MAVEN will also execute "deep dip" campaigns, with periapsis at an altitude near 125 km. This paper presents the unique mission design challenges of the MAVEN mission.

10:30 AAS 10 - 193 Numerical Simulations of the Gravity Science Experiment of the Juno Mission to Jupiter
Stefano Finocchiaro and Luciano Iess – University of Rome La Sapienza, Italy

The Gravity Science Experiment of the Juno mission will investigate Jupiter's interior structure through an accurate determination of the gravity field. The onboard radio system enables a highly stable, two-way, Ka-band radio link, providing high quality range-rate data. This work reports on numerical simulations of the gravity experiment, in particular on the attainable accuracies in the determination of the even-zonal harmonics, k2 and k3 Love numbers, and the principal axis of inertia.

10:55 AAS 10 - 194 LAPLACE: An Update of the Science Phases around Callisto and Ganymede
Arnaud Boutonnet, Johannes Schoenmaekers, and Paolo de Pascale – European Space Agency, ESOC

Laplace is a mission towards Jupiter and its moons Callisto and Ganymede. The original baseline plans a pseudo-orbiter strategy around Callisto and a capture into eccentric, then circular orbit around Ganymede. The paper will present an innovative method to design the Callisto phase. It is based on a reduced set of discrete parameters to describe the swing-bys and the resonances involved in the pseudo-orbiter strategy. The results are presented against a new option: the gravitational capture. For Ganymede the highly unstable polar eccentric orbit constrains its duration. Another option, based on a periodic inclined orbit, is analyzed against the baseline.

11:20 AAS 10 - 195 Trajectory Design to Enable an Enceladus Plume Sample Return Mission
Nathan Strange and Damon Landau – Jet Propulsion Laboratory

Saturn's moon Enceladus has an active region at its south pole which produces plumes of water ice. This plume provides an opportunity to obtain a sample of an icy satellite's interior from a simple flyby. However, Saturn is 19 times as far from the Earth as Mars, which makes finding a plume sample return trajectory within a reasonable flight time challenging. This paper discusses two options for free return trajectories and their undesirable characteristics and then presents an alternative approach where the spacecraft enters and then leaves Saturn orbit propulsively. This alternate approach makes a plume sample return feasible by achieving collection speeds less than 6 km/s and a round-trip flight time less than 14 years.

Session 13: Trajectory Solution Techniques

Chair: Anastassios Petropoulos – Jet Propulsion Laboratory

13:30 **AAS 10 - 196** **Shape-Based Approximation Method for Low-Thrust Interception and Rendezvous Trajectory Design**
Bradley Wall, Bradley Pols, and Brandon Lanktree – Embry-Riddle Aeronautical University

Mission design utilizing low-thrust propulsion requires a method for approximating the spacecraft's trajectory. This method can be used for providing an initial guess used in direct optimizers. Such optimizers are more likely to converge when the initial guess satisfies the equation of motion constraints and terminal boundary conditions. A shape-based method is derived here that is capable of determining near-optimal solutions. Additionally, a throttle parameter and thrust acceleration are determined that satisfy the equations of motion. Using a genetic algorithm, it is possible to find solutions within a few percent of optimal for both rendezvous and intercept trajectories.

13:55 **AAS 10 - 197** **Solving Initial Value Problems by the Picard-Chebyshev Method with NVIDIA GPUs**
Xiaoli Bai and John L. Junkins – Texas A&M University

Combining the classical Picard method with Chebyshev polynomials, we can solve a large number of initial value problems using parallel computation. We develop a matrix-vector form of Picard-Chebyshev method and implement it using a NVIDIA graphics card. The algorithm is developed through CUDA with the CUBLAS toolbox. Experimental results show that comparing with the ODE45 algorithm implemented in MATLAB, the speedup from using Picard-Chebyshev method is about a factor of one hundred. Comparing with a CPU version of the same algorithm implemented in C, the speedup from using one NVIDIA graphics card is about a factor of two hundred.

14:20 **Break**

14:45 **AAS 10 - 198** **A GPU Accelerated Multiple Revolution Lambert Solver for Fast Mission Design**
Nitin Arora and Ryan P. Russell – Georgia Institute of Technology

The Lambert algorithm acts as an enabler for a large variety of mission design problems. Often an overwhelmingly large number of Lambert solutions are needed to globally search the design space, making the process computationally very expensive. We propose a multi-revolution Lambert solver accelerated by a Graphics Processing Unit (GPU) to combat this expensive combinatorial problem. The implementation builds from the concepts of parallel heterogeneous programming utilizing both the CPU and GPU in tandem to achieve multiple orders of magnitude in speedup on a single desktop computer. Example grand tour design problems are used to demonstrate the potential speedup.

15:10 **AAS 10 - 199** **Relative Performance of Lambert Solvers 1: 0-Revolution Methods**
Glenn E. Peterson, Eric T. Campbell, and Alisa M. Hawkins – The Aerospace Corporation; Jorge Balbas – Cal State University Northridge; Samuel Ivy, Ekaterina Merkurjev, Tavis Hall, and Paulina Rodriguez, University of California Los Angeles; Eric D. Gustafson – University of Michigan

Lambert's problem is a classic two-point boundary value problem to determine the spacecraft's conic trajectory from position P1 on an initial orbit to position P2 on a second desired orbit in a specified time. The current research, performed in coordination with UCLA's Institute of Pure and Applied Mathematics, examines the performance of various Lambert methodologies. This selection of methods (Battin, Herrick, Nelson and Zarchan, Gooding, Kriz, and Thorne) is not meant to be comprehensive but rather a representation of the types of approaches used. Results in the form of accuracy, computational speed, and limitations will be presented.

Session 14: Spaceflight Safety

Chair: Lauri Newman – NASA Goddard Spaceflight Center

13:30 AAS 10 - 203 A Discussion on the Hazards on the Embratel's (Star One) Satellites and Others in the Geostationary Orbit

Jorge Martins do Nascimento – Instituto Nacional de Pesquisas Espaciais, Brazil

The aim of this paper is to present a discussion on the hazards on the EMBRATEL's (Star One) satellites and others in the geostationary orbit. This work also comments on the satellites of the National Oceanic and Atmospheric Administration (NOAA) called GOES - Geostationary Operational Environmental Satellites of the series (GOES 1 AKM and GOES 5), COSMOS 1888, ECHOSTAR 2 and SL-12RB2. This work considers them because in the simulation period considered they presented close approaches with BRASILSAT/StarOne active and inactive satellites.

13:55 AAS 10 - 202 Survey of Orbit Non-Linearity Effects in the Space Catalog

Sergei Tanygin and Vincent T. Coppola – Analytical Graphics, Inc.

Improving space situational awareness and conjunction analysis in particular has taken on a new urgency due to a series of recent events. We provide "the best case scenario" metric for determining the prediction window beyond which the first order probability computations become inaccurate even if the initial state vector and the propagation dynamical model are known perfectly. We will use the space catalog data to compute acceptable prediction windows for all objects, trending of non-linear effects for various classes of orbits, and the degree of non-linearity at the time of closest approach for reported conjunctions.

14:20 Break

Session 15: Attitude Sensors Data Processing

Chair: Jon Sims – Jet Propulsion Laboratory

13:55 AAS 10 - 205 Forty-Nine Biased Star Positions from ICESat Flight Data

Noah Smith, Sungkoo Bae, and Bob Schutz – University of Texas at Austin

Approximately 1% of the 10,000 stars measured by the ICESat star trackers are believed to have position biases on the order of tens of arcseconds caused by near-neighbor stars. The trackers are common models, a Goodrich HD-1003 and two Ball CT-602. Empirical biases are given for 49 stars, including four Aura onboard catalog stars. A survey was performed to detect and characterize biased stars by treating each observed star as a target, predicting the tracker measurements of the target, and then comparing the observations and predictions. Five million passes of 10,472 stars were processed, giving almost complete sky coverage.

14:20 Break

14:45 AAS 10 - 206 Recursive Star Identification with the K-Vector ND

Ben Spratling, IV and Daniele Mortari – Texas A&M University

After lost-in-space star-identification is performed and an estimate of the space-craft's attitude is available, the identification of the rest of the stars, and detection of non-stars, from the original image is sometimes desired. The resulting database search is quickly searched with an oct-tree; however the K-Vector ND index-based range search algorithm is shown to perform asymptotically faster. The author presents two possible applications of the K-Vector ND to the recursive search problem and analyzes the relative performance. The selected algorithm is shown to execute in fewer than 1,000 clock cycles per star.

15:10 AAS 10 - 207 Star-ND: Multidimensional Star-Identification

Ben Spratling, IV and Daniele Mortari – Texas A&M University

For the lost-in-space case of star-identification used for autonomous attitude determination, one bottleneck is the performance of the database search. Previously, the K-Vector ND was found to perform much faster on uniformly distributed databases than other search algorithms. The presenter presents new star pattern parameters which achieve a nearly-uniformly distributed database. Practical issues arise, and techniques for mitigating these problems are presented. The resulting new star-ID technique is analyzed for its performance and found to be nearly two orders of magnitude faster than cutting edge-algorithms.

Session 16: Attitude Dynamics and Control – II

Chair: Dennis Byrnes – Jet Propulsion Laboratory

13:30 AAS 10 - 208 On the Discrepancy Between the Intended and the Actual Cutoff Frequency in Repetitive Control

Mehmet Can Isik and Richard W. Longman – Columbia University

Repetitive control can in theory completely eliminate the influence on a feedback control system of periodic disturbances of known period. On spacecraft it can isolate fine pointing equipment from the effects of slight imbalance in reaction wheels or CMGs. A zero-phase low-pass filter is needed to make RC robust to model errors at high frequencies. Previous work showed for iterative learning control that when one applies such a cutoff at the needed frequency for stability, the learning cuts off at a lower frequency. This phenomenon is studied here for repetitive control considering a series of general design methods.

13:55 AAS 10 - 209 Rhumb-Line Attitude Maneuver Calibration for Spinning Satellites

Jozef C. van der Ha – Kyushu University, Japan

The paper presents an efficient calibration technique for rhumb-line attitude control maneuvers of spin-stabilized satellites. This technique has actually been employed successfully during the initial operations of the CONTOUR satellite in its Earth-orbiting phase in August 2002. Two dedicated calibration maneuvers were performed for CONTOUR based on the very accurate Sun-aspect angle measurements. The first calibration maneuver achieved the thrust-level calibration and the second maneuver aimed at calibrating the rhumb angle. As a result of these two calibration maneuvers, the 180 deg flip maneuver could reach its target attitude to within 2 degrees.

14:20 Break

14:45 AAS 10 - 210 Simplified Singularity Avoidance Using Variable Speed Control Moment Gyroscope Null Motion

Jay McMahon and Hanspeter Schaub – University of Colorado

Singularity avoidance in VSCMG systems can require significant computation to determine null motion steering commands. This paper presents a less complicated method of determining commands while achieving similar performance as current methods. This method is based on tracking the range of the transverse axes. The new approach does not require any knowledge of the rotor speeds in order to create singularity avoidance null motion steering commands. The performance using this simpler singularity cost function is essentially identical to previously published methods. The main benefit of this new method for CMG singularity avoidance using VSCMG.

15:10 AAS 10 - 211 The Sequential Optimal Attitude Recursion Filter

John A. Christian and E. Glenn Lightsey – University of Texas at Austin

A new attitude filter called the Sequential Optimal Attitude Recursion (SOAR) Filter is developed. This routine is based on a sequentialization of the Wahba Problem that has been extended to include non-attitude states. The algorithm can accept either individual unit vector measurements or quaternion measurements. This new algorithm is compared with existing attitude filtering routines, including the Multiplicative Extended Kalman Filter, Filter QUEST, REQUEST, and Optimal-REQUEST.

Session 17: Trajectory Design & Optimization – II

Chair: Yanping Guo – Applied Physics Laboratory

08:00 **AAS 10 - 212** **A New Approach to Design a Repeat Ground Track Orbit for the Local Reconnaissance Mission**

Hae-Dong Kim – Korea Aerospace Research Institute; Hyochoong Bang – Korea Advanced Institute of Science and Technology; Hak-Jung Kim – Korea Aerospace Research Institute, Republic of Korea

For specific mission such as the local reconnaissance mission, a new approach using a hybrid genetic algorithm that consists of coarse targeting and fine targeting is introduced to resolve the proposed problem quickly and demonstrated its feasibility as a preliminary result. The proposed approach relies upon coarse search process using a rough solution by analytical scheme and fine search process using a result from the coarse search process. Both of targeting processes are based on a genetic algorithm. The effectiveness of the proposed approach comparing to simple genetic algorithm is consequently demonstrated in terms of computational speed.

08:25 **AAS 10 - 213** **Determination of Fundamental Low-Thrust Control Frequencies for Fitting Sequences of Orbital States**

Jennifer Hudson – University of Michigan; Daniel J. Scheeres – University of Colorado

Determination of an effective low-thrust control law that connects a series of orbital states is studied using an averaged method based on Fourier series representation of the thrust control. Time-variation of the control law is introduced through segmentation of an orbital targeting problem into multiple two-point boundary value problems and optimization of the control law for each segment. Least-squares analysis is also used to efficiently calculate the low-thrust transfer that minimizes a general thrust-based cost function through a set of states. Applications of these methods to low-thrust mission design and space situational awareness are discussed.

08:50 **AAS 10 - 214** **Equations of Motion of a Launcher Using a Full Quaternion**

Alexandre Vachon and André Desbiens – Université Laval, Canada; Éric Gagnon – Defence Research and Development Canada-Valcartier, Canada

The 3 degrees of freedom equations of motion are used to extrapolate the state of a launcher and to calculate its final orbit. These equations can be obtained by two common approaches, using either Cartesian or polar coordinates. However these two schemes have problems when comes the time to implement them into an onboard computer; the first request too much computational load and the second does have discontinuities. By combining explicit fictitious forces with the full quaternion, one is able to obtain a set of equations in which the previous problems do not appear. This paper will present these developments.

09:15 **AAS 10 - 215** **Optimal Orbit Design for Regional Coverage Using Genetic Algorithm**

Ahmed Gad and Ossama Abdelkhalik – Michigan Technological University

This paper presents an optimization technique for the problem of initial orbit design for regional coverage. The problem of orbit design to cover given set of ground sites, within a constraint time frame, is addressed. The objective is to calculate a repeated ground track orbit such that the spacecraft's field of view covers each of the sites, at least once, within a given time frame. The development in this paper takes into consideration the J2 perturbations. A Genetic Algorithm (GA) technique is developed for optimization. GA is used to maximize the number of covered ground sites and minimize the mission duration.

09:40 **Break**

10:05 **AAS 10 - 216** **Porpoise Floating Launch Sounding Rocket**
Andrew E. Turner – Space Systems/Loral

Project Porpoise involves an experimental rocket to be launched from a floating condition in the ocean, which allows for soft water-landing, rapid recovery and re-flight of the vehicle. Floating launch avoids the restrictions of land-based rocket ranges or the need to include parachutes in all flights. Multiple test flights each day will permit experience to be gained rapidly and applied immediately to improve the vehicle. The paper will include trajectory analysis for sample test flights for Porpoise to a variety of altitudes.

10:30 **AAS 10 - 217** **Solving CMG-Driven Vehicle Reorientations Using Optimal Control Methods**
Christopher Ranieri – The Aerospace Corporation

Time optimal vehicle slews are solved with optimization theory instead of feedback control laws. The results presented were found using the Sparse Optimal Control Software (SOCS). Optimal slews published by Naval Postgraduate School are used as a benchmark and equivalent or slightly better results were found in comparison. Additionally, multiple slew sequences are solved as a single problem, incorporating various dwells between slews. This analysis explores the benefits of CMG motion during dwells where they can reorient while imposing no net torque. The appropriate formulations for the problem's various cost functions, states, and constraints to yield better convergence are presented.

10:55 **AAS 10 - 218** **Using Multi-Complex Variables for Automatic Computation of High-Order Derivatives**
Gregory Lantoine and Ryan P. Russell – Georgia Institute of Technology; Thierry Dargent – Thales Alenia Space

The computations of the high-order partial derivatives in a given problem are in general tedious or not accurate. A new method for calculating exact high-order sensitivities using multi-complex numbers is presented. The mathematical theory behind this approach is revealed, and an efficient procedure for the automatic implementation of the method is described. Several applications are presented to validate and demonstrate the accuracy and efficiency of the algorithm. Our multi-complex method is shown to have many advantages over traditional approaches, and it is therefore expected to be useful for any algorithm exploiting high-order derivatives, such as second-order NLP solvers.

11:20 **AAS 10 - 219** **Optimal Pathways for Sequences of V-infinity Leveraging Maneuvers**
Ryan Woolley and Daniel J. Scheeres – University of Colorado at Boulder

V-infinity leveraging maneuvers are an effective means to reduce total Delta-V requirements to achieve orbit about a planetary satellite. They can be used to incrementally decrease the V-infinity, leading to eventual capture at the cost of added flight time. This work seeks to characterize optimal sequences of fly-bys and leveraging maneuvers with the aid of a graphical tool depicting resonance contours vs. V-infinity magnitude and direction. Preliminary results indicate that non-tangential maneuvers are more efficient than tangential sequences of equivalent flight times. It was also found that powered fly-bys are not helpful for V-infinity > 0.17.

Session 18: Orbital Perturbations

Chair: Thomas Eller – Astro USA, LLC

08:00 **AAS 10 - 220** **Fast Computation of Frozen, Inclined, Low Lunar Orbits in a High Degree Selenopotential**
Martin Lara – Real Observatorio de la Armada, Spain

The averaged equations of a high degree Selenopotential are used to find lunar frozen orbits at altitudes below 100 km. Despite the large expressions to handle, their arrangement as Clenshaw sums allows for fast and efficient evaluation, thereby making feasible the fast generation of frozen orbits' eccentricity-inclination diagrams. Simple inspection of these diagrams shows that circular frozen orbits only occur close to the known inclinations of 27, 50, 76 and 86 deg. In addition, the averaged equations provide an estimation of the period that is good enough for mapping frozen orbits into their partner periodic orbits of the non-averaged problem.

08:25 **AAS 10 - 221** **Analytic Expansions of Luni-Solar Gravity Perturbations Along Rotating Axes for Trajectory Optimization: Part 1: The Dynamic System**
Jean A. Kechichian – The Aerospace Corporation

An analytic form of the accelerations due to the luni-solar perturbations resolved along the rotating Euler-Hill frame is devised by using the expansion method. The addition of higher order terms to the main gravity gradient term is carried out to the third order. The nodal precession as well as the perigee advance of the lunar orbit is taken into account analytically by using the analytic lunar theory of de Pontécoulant. The analytic description of the luni-solar motion removes the need for an ephemeris generator leading to self-contained software for rapid and efficient optimal trajectory generation through iterations.

08:50 **AAS 10 - 222** **Displaced Solar Sail Orbits: Dynamics and Applications**
Jules Simo and Colin R. McInnes – University of Strathclyde, Scotland

We consider displaced periodic orbits at linear order in the circular restricted Earth-Moon system, where the third massless body is a solar sail. These highly non-Keplerian orbits are achieved using extremely small sail acceleration. Prior results have been developed by using an optimal choice of the sail pitch angle, which maximize the out-of-plane distance. In this paper we will use solar sail propulsion to provide station-keeping at periodic orbits around the libration points using small variations in the sail's orientation. Applications include continuous line-of-sight communications with the lunar poles.

09:15 **AAS 10 - 223** **Effects of Density Variations in the Upper Atmosphere on Satellite Trajectories**
Andrew Schaeperkoetter – Texas A&M University; Craig McLaughlin – University of Kansas

The density of the upper atmosphere varies rapidly. Understanding and being able to predict the density is crucial to being able to accurately determine the position of spacecraft. This paper seeks to understand how accurately the parameters sinusoidal density waves need to be estimated to have some desired accuracy. Furthermore, this paper seeks to compare the HASDM and POE techniques to the density estimated using an accelerometer onboard CHAMP. This study found that HASDM was more accurate initially, but if the bias is removed, POE is more accurate generally, revealing that POE can more accurately pick up variations in density.

09:40 **Break**

10:05 **AAS 10 - 224** **Solar Radiation Pressure Induced Resonance in Satellite Orbit with a Tumbling Spacecraft**

C. C. Chao – The Aerospace Corporation

An analytical investigation of the resonance effects caused by spacecraft tumbling and solar radiation pressure was performed for three types of orbits, GEO, GPS and high LEO. In each case, significant intrack deviations are induced when the simulated tumbling motion has the same rate as the orbit rate. The intrack deviations may range from 30 km to 400 km after 30 days depending on orbit type, spacecraft area-to-mass ratio and the variation of area-to-mass ratio. The results from analytic approximation were verified by numerical integration. The understanding of this phenomenon would be important for missions with spacecraft having large area-to-mass ratio and spin rate at or near orbital rate.

10:30 **AAS 10 - 225** **Efficient Parallelization of Nonlinear Perturbation Algorithms for Orbit Prediction with Applications to Asteroid Deflection**

Brian Kaplinger and Bong Wie – Iowa State University

Orbit determination and control problems are sometimes solved using linearized methods, even though nonlinear effects often dominate the system. This paper addresses ways to parallelize algorithms for nonlinear relative motion. Three applications are discussed: an outgassing comet, a "gravity tractor" spacecraft, and a fragmented asteroid. These scenarios show the ability of the model to handle undetermined initial conditions, time dependent nominal orbits, and multiple body interaction. Efficient algorithms for these problems emphasize the achievement of cutting-edge and verifiable results for asteroid deflection/fragmentation research using limited or budget-allocated computer resources.

10:55 **AAS 10 - 226** **Thermal Radiation Effects on Deep-Space Trajectories**

Jozef C. van der Ha – Kyushu University, Japan; Daniele Stramaccioni – European Space Agency / ESTEC, Netherlands

The precise navigation of deep-space (or interplanetary) spacecraft requires precise modeling of all forces affecting the orbital motion. In addition to solar radiation forces, thermal radiation effects introduce another source of small forces that may induce appreciable perturbations for deep-space trajectories. For satellites (like ROSETTA) with large solar arrays, a straightforward thermal balance analysis for the solar arrays provides valuable insights into the nature and magnitude of the acceleration induced by thermal radiation. The paper presents a straightforward but comprehensive analytical model for the calculation of thermal radiation accelerations on deep-space satellites. The model is illustrated by means of the in-orbit thermal properties and attitude pointing characteristics of ROSETTA during its cruise phase.

11:20 **AAS 10 - 227** **Lorentz Augmentation of Gravity-Assist Flybys with Electrostatically Charged Spacecraft**

George E. Pollock, Joseph W. Gangestad, and James M. Longuski – Purdue University

The Lorentz force may improve the effectiveness of gravity-assist flybys of celestial bodies with magnetic fields. Analytical theory is developed to assess the utility of the Lorentz force to increase the turn angle and the orbital energy of a hyperbolic flyby—without propellant cost. Lorentz-augmented gravity-assist mission applications are presented for missions beyond Jupiter. A Jupiter flyby with a specific charge of 0.03 C/kg can increase the jovicentric v-infinity by 2.8 km/s. With a specific charge of 2 C/kg, a Lorentz-augmented gravity-assist at Jupiter may enable a spacecraft to reach a distance of 250 AU within 20 years.

Session 19: Attitude Dynamics and Control – III

Chair: Sergei Tanygin – Analytical Graphics, Inc.

08:00 AAS 10 - 228 Hypersphere Stereographic Orientation Parameters

Jeff Mullen and Hanspeter Schaub – University of Colorado at Boulder

Hypersphere Stereographic Orientation Parameters (HSOP) are a new attitude parameter set that encompasses both the Modified Rodrigues Parameters (MRP) and Asymmetric Stereographic Orientation Parameters (ASOP). This paper presents the general mapping from HSOPs to EPs, to the direction cosine matrix, to the shadow set, as well as derives the HSOP kinematic differential equation. A remarkable truth is presented where the HSOP differential kinematic equations, as well as the shadow set coordinate mapping, have the same algebraic form as the MRPs. Thus, the HSOPs can exploit the same elegant control formulations that make use of particular algebraic MRP differential equation properties.

08:25 AAS 10 - 229 Inertial Sensors Performance Modeling by Means of Kalman Filters

Sergei A. Jerebets – Jet Propulsion Laboratory

An adequate description of the behavior of a real dynamical system such as an inertial sensor requires a complex mathematical analysis. It is often beneficial to apply some approximation and still obtain a satisfactory result at acceptable cost and in reasonable time. To gain better insight into inertial sensors performance characteristics, several polynomial Kalman filters were designed. Two sets of states were created for the filters to estimate. Those sets included sensor biases, scale factors and cross-coupling errors. A comparison was made between filter's order and its corresponding convergence efficiency as well as the quality of the estimates.

08:50 AAS 10 - 230 Vision-Based Dynamic Estimation for Thermally Induced Motion of Solar Array Paddle

Takanori Iwata – Japan Aerospace Exploration Agency, Japan

Thermally induced dynamics of solar array paddles is the most characteristic phenomena in on-orbit motions of satellites. The disturbances caused by this motion give significant adverse effects on satellite attitude and pointing. Despite its interdisciplinary nature, thermally induced dynamics of solar array paddle has been studied in various aspects. However, a direct measurement of paddle's deflection has not been performed and is difficult. This paper presents an approach to overcome the difficulty using monitor camera images and to obtain the estimation of paddle's deflection caused by thermally induced dynamics and results obtained by applying this approach to flight data.

09:15 AAS 10 - 231 Estimation of Solar Radiation Pressure Parameters for Solar Sail Demonstrator IKAROS Considering Attitude Dynamics

Yuya Mimasu and Jozef C. van der Ha – Kyushu University, Japan; Tomohiro Yamaguchi – Graduate University for Advanced Studies, Japan; Ryu Funase, Yuichi Tsuda, Osamu Mori and Jun'ichiro Kawaguchi – Japan Aerospace Exploration Agency, Japan

Solar sailing is one of the promising propulsion concepts for future deep space exploration missions. The Japan Aerospace Exploration Agency (JAXA) is now developing the spinning solar sail spacecraft IKAROS1 (Interplanetary Kite-craft Accelerated by Radiation Of the Sun). One of the most significant tasks to achieve the solar-sail mission in terms of navigation objectives is the estimation of the thrust force induced by the photons. This amounts to the establishment of the precise Solar Radiation Pressure (SRP) model. The SRP model needs to be calibrated by means of the observed on-orbit data.

09:40 **Break**

10:05 **AAS 10 - 232** **Fault Tolerant Attitude Control during Formation Flying**
Junquan Li and Krishna Dev. Kumar – Ryerson University, Canada

The authors propose an adaptive fuzzy terminal sliding mode control algorithm for attitude tracking of multiple picosatellites during formation flying. The relative attitude of the leader and follower picosatellites under gravity gradient torque and external periodic disturbances is controlled by four reaction wheels. This method can accommodate faults rapidly without controller reconfiguration. The numerical simulations (under the faults like sensor jam, wheel failure, wheel jam and wheel degradation) demonstrate the effectiveness of the proposed controllers.

10:30 **AAS 10 - 233** **Understanding and Improving Repetitive Control Robustness by Cost Function Averaging Over Model Distributions**
Yunde Shi and Richard W. Longman – Columbia University; Minh Q. Phan – Dartmouth College

Repetitive control (RC) can be used in active vibration isolation mounts that aim to cancel the influence of spacecraft vibrations on fine pointing equipment. It can cancel the influence of slight imbalance in momentum wheels, reaction wheels, and CMGs. A series of publications have demonstrated that designing RC using a cost function that averages over the distribution of uncertainty in one's model can significantly improve stability robustness to imperfect knowledge of the system model. This paper first develops an understanding in the frequency domain of how this robustification is achieved, and then investigates methods of further improving the performance.

10:55 **AAS 10 - 234** **Developing Iterative Learning Control Laws that Converge to Well Behaved Model Pseudo Inverses for Systems with and Unstable Inverse**
Yao Li and Richard W. Longman – Columbia University

Iterative learning control (ILC) adjusts the command to a feedback control system aiming to converge to zero error in a repeated tracking command. Spacecraft applications include repeated scanning with precision fine pointing instruments. Obtaining zero tracking error is equivalent to inverting the system, and most systems fed by a zero order hold have an unstable inverse. Earlier work by the authors established how to ask for zero error at fewer time steps and make the inverse well behaved. This paper develops methods to use this information to produce iterative learning control laws.

11:20 **AAS 10 - 235** **A Multiplicative Residual Approach to Attitude Kalman Filtering with Vector Measurement**
Renato Zanetti – The Charles Stark Draper Laboratory

Using direction vectors of unit length as measurements for attitude estimation in an extended Kalman filter inevitably results in a singular measurement covariance matrix. Singularity of the measurement covariance means no noise in one component of the measurement. Singular measurement covariances can be dealt with the classic Kalman filter formulation so long as the estimated measurement covariance is non-singular in the same direction. Unit vector measurements violate this condition since both the true measurement and the estimated measurement have perfectly known lengths. Minimum variance estimation for the unit vector attitude Kalman filter is studied in this work. An optimal multiplicative residual approach is presented. The proposed approach is compared with the classic additive residual attitude Kalman filter.

Session 20: Orbit Determination

Chair: John Seago – Analytical Graphics, Inc.

08:00 AAS 10 - 236 Orbit Determination using Prescribed Orbits
Reza Raymond Karimi and Daniele Mortari – Texas A&M University

A novel angles-only orbit determination technique based on prescribed orbits is presented. This approach does not require the exact solution of the Keplerian two-body problem. The solution is approximated by polynomials or any other functions best representing the orbit. The fact that the assumed solution should satisfy both two-body problem equation and the geometry of the problem is the foundation of the presented technique. The developed method is capable of using multiple observations. Seven scenarios were studied and the results showed our method as a valid alternative of the available methods of orbit determination.

08:25 AAS 10 - 237 Orbit Determination with the Cubed Sphere Gravity Model
Brandon A. Jones, George H. Born, and Gregory Beylkin – University of Colorado at Boulder

The cubed sphere model provides rapid evaluation of the gravity acceleration for astrodynamics applications. This paper discusses orbit determination improvements when utilizing this model. Updates were made to the model improve computational efficiency, including a comparison of the different formulations of the spherical harmonics to select a base model. This orbit determination study utilized orbits comparable to the GRACE, OSTM/Jason-2, and GPS satellites, with various data type combinations simulated. Results demonstrate close agreement with spherical harmonics based solutions, but with reduced computation requirements. The reduced evaluation time allows for improved filter accuracy with no change in filter execution time.

08:50 AAS 10 - 238 Modifications to the Gooding Algorithm for Angles-Only Initial Orbit Determination
Troy A. Henderson and Daniele Mortari – Texas A&M University

The Gooding algorithm is currently the most widely used angles-only method for estimating the orbit of a spacecraft. Two modifications to Gooding's angles-only initial orbit determination algorithm are presented. The first method is an extension to N measurements, whereas the state of the art algorithm is restricted to three measurements. The second modification is an optimization method which searches in the neighborhood of the output of the classical Gooding algorithm for a more optimal orbit estimation. The theory is developed and examples are given.

09:15 AAS 10 - 239 Detection of Non-linearity Effects During Orbit Estimation
James Woodburn and Sergei Tanygin – Analytical Graphics, Inc.

The application of linear methods to the inherently non-linear problem of orbit determination requires a linearization be performed. The orbit determination problem is never perfectly linear and while the effects of higher order terms are often negligible there are cases where linearity assumptions are violated. We examine several such cases in the framework of the extended Kalman filter and evaluate the effectiveness of an analytical measure of linearity which can be applied in conjunction with the forward running filter. Upon detection of non-linear conditions in the filter, corrective actions can be taken.

09:40 Break

10:05 AAS 10 - 240 Ensemble Kalman Filter Application to Large Constellation Ephemeris Estimation

C. F. Minter – National Geospatial-Intelligence Agency

Many tracking systems estimate ephemerides for large constellations in near-real time. As the constellation size increases, the state size and number of computations required in the Kalman filter also increase, which can make a simultaneous solution for the constellation impractical. Estimating each satellite's ephemeris individually may not be ideal. The ensemble Kalman filter is particularly adept at solving nonlinear systems with large state sizes. Results show the ensemble Kalman filter has increased efficiency and accuracy since it avoids the large matrix multiplications found in the traditional extended Kalman filter and preserves nonlinear model characteristics when propagating the state covariance matrix.

10:30 AAS 10 - 241 Analysis of Geosynchronous Elements for Dynamic Modeling and Application to Orbit Estimation

Jill Tombasco and Penina Axelrad – University of Colorado at Boulder

Geosynchronous orbits are designed to exhibit repeatability in an Earth-fixed orientation; this unique property can be exploited by selecting appropriate elements to represent the distinct resonant dynamics of the geosynchronous orbit. The purpose of this study is to investigate the usefulness of the synchronous elements for geosynchronous orbit estimation, the suitability of approximating the equations of motion for small eccentricity and inclination values, and general perturbation modeling for the synchronous elements as compared to Keplerian and Cartesian coordinates. Synchronous variational equations are developed via Poisson brackets; numerical propagation studies assess the precision and accuracy of the dynamic models. The feasibility of modeling realistic satellite dynamics is assessed by fitting to multiple nights of optical data.

10:55 AAS 10 - 242 Solar Sail Force Modeling and its Estimation Approach of Solar Power Sail Spacecraft IKAROS

Tomohiro Yamaguchi – Graduate University for Advanced Studies, Japan; Yuya Mimasu – Kyushu University, Japan; Yuichi Tsuda, Hiroshi Takeuchi, Ryu Funase, Osamu Mori, and Makoto Yoshikawa – Japan Aerospace Exploration Agency, Japan

This paper investigates the solar sail modeling and its estimation approach of solar power sail spacecraft IKAROS. Estimation of solar sail force model in space is the key factor for successful solar sail navigation because the solar sail have large uncertainty due to the flexible membrane. Since the sail wrinkles after the deployment and its surface will suffer from degradation, the solar sail force model is difficult to develop before the launch. In this paper, a practical analysis of estimating the parameter of generalized sail model from radiometric measurements is investigated.

Session 21: Near Earth Object Missions

Chair: David Spencer – Penn State University

13:30 **AAS 10 - 243** **Analysis of Manned Missions to Near Earth Asteroids**
Jessu Gil-Fernandez, Mariella Graziano, and Raul Cadenas – GMV, Spain

Manned missions to NEA are increasingly interesting for scientific, exploration and outreach reasons. Human-rated constraints are the key requirements for mission feasibility analysis. The system constraints are applied to a systematic trajectory search in a 30-year launch window. The candidate missions are further analyzed in terms of safety, mainly backup optical navigation system performances, and terminal relative navigation, mainly target detectability. After this first assessment, the resulting missions are feasible candidates in terms of system design and man-rated safety requirements.

13:55 **AAS 10 - 244** **Characterization of a Small Body via Slow Flybys**
Yu Takahashi and Daniel J. Scheeres – University of Colorado at Boulder

Recent scientific interest in small solar system bodies has spurred a number of mission studies, actual missions and planned future missions. One of the crucial tasks that a spacecraft must carry out on arrival to a small body is to characterize the body's total mass, spin state, and higher order gravity fields. In this paper we propose and analyze a method for carrying out this determination through a series of relatively slow flybys of the body, and probe the level of characterization that can occur using this approach and whether it could eliminate the need for a dedicated orbital phase.

14:20 **AAS 10 - 245** **Minimum Delta-V Launch Windows for Post 2029 Deflection of Asteroid Apophis**
Sam Wagner and Bong Wie – Iowa State University

For this paper a fictional scenario is assumed in which Apophis passes through the keyhole on April 13th, 2029, and is on a collision course with the Earth in 2036. Several launch dates must be determined that are compatible with an Interplanetary Ballistic Mission (IPBM) system already designed that is capable of delivering up to a 1500 kg nuclear explosive device (NED) with a total delta-V of 3.5 km/s from a geostationary transfer orbit (GTO). Quick rendezvous, multiple orbit, and gravity assisted missions will be explored to determine launch dates from Apophis in the 2029-2036 range.

14:45 **AAS 10 - 246** **Mission Design for Jupiter Trojans Rendezvous Mission**
Triwanto Simanjuntak – Graduate University for Advanced Studies, Japan; Masaki Namakiya and Yasuhiro Kawakatsu – Japan Aerospace Exploration Agency, Japan

Trojan asteroids exist in nearby of triangular Lagrangian points of the Sun-Jupiter system and are believed to contain primitive information on the early formation of our Solar System. Additionally their origin is also unclear. Considering these significances, we report in this paper mission analysis on the Trojans rendezvous mission. The mission design includes the selection of the target Asteroids and the design of the nominal mission sequence. We studied three types of trajectories, direct transfer, using gravity assists of Mars, Jupiter and also employed low-thrust propulsion to each type in finding reasonable time and delta V transfer among selected Asteroids.

15:10 **Break**

15:35 **AAS 10 - 247** **Orbital Strategies for Missions to Binary Near-Earth Asteroids**

Carlos Corral van Damme, Jesús Esteban Donés, and Mariella Graziano – GMV, Spain

Binary systems are fairly common among the population of Near Earth Asteroids, and may be the target of future space missions. The full dynamics of the problem of one spacecraft orbiting a binary system of small, irregular asteroids must be considered for the design of the orbital operations for a real space mission. In this paper, a parametric analysis of the main variables characterizing binary asteroid systems is performed to define a set of reference scenarios. Several orbital strategies (orbits around the Lagrangian points, formation flying, close controlled orbits), are examined in terms of required Delta-V and achieved coverage.

16:00 **AAS 10 - 248** **Surface Impact or Blast Ejecta Behavior in a Small Binary Asteroid System with Application to In-situ Observation**

Eugene G. Fahnestock – Jet Propulsion Laboratory; Daniel D. Durda – Southwest Research Institute; Kevin R. Housen – The Boeing Company; Daniel J. Scheeres – University of Colorado at Boulder

We study behavior of ejecta particles liberated from near-equatorial surface locations on a small binary near-Earth asteroid's primary by energetic events. We propagate full-two-body-problem dynamics of the binary itself and particle dynamics in close proximity. The latter includes full binary gravity, solar gravity gradient, and SRP effects; for ejecta launch time, location, and initial velocity distributions matching a realistic model of crater excavation physics, and for an empirically informed particle size distribution. We obtain ejecta outcomes, time history in reaching those outcomes, surface spatial distribution of impacting ejecta, and quality metrics for post-event nearby spacecraft-based crater optical observations.

16:25 **AAS 10 - 249** **Target Asteroid Selection for Human Exploration of Near Earth Objects**

Sam Wagner and Bong Wie – Iowa State University

In recent years NASA has performed sever studies to determine the feasibility of sending a crewed mission to an NEO using technology developed for under the Constellation project. However, these studies have focused primarily on the feasibility of such a mission. A full search of the NEO database and accompanying mission analysis for each possible target asteroid will be performed for this paper. The primary mission will be a short 90 day spaceflight, however mission up to 180 days will be considered as well. Only asteroids with close flybys in the 2020-2030 ranges, corresponding to expected lunar mission dates.

16:50 **AAS 10 - 250** **Tether Assisted Near Earth Object (NEO) Diversion**

Mohammad Jalali Mashayekhi and Arun K. Misra – McGill University, Canada

Potential earth impact threats by asteroids have motivated researchers to find effective NEO diversion techniques. There are several means to perturb the motion of an asteroid, proposed in the literature. One of the effective non-nuclear techniques is attachment of a tether and ballast to the asteroid to alter its trajectory. In this paper the effect of cutting the tether at proper time is examined. The instant of cutting the tether significantly affects the final orbit of the asteroid and thus the resulting diversion. It is shown that by cutting the asteroid at proper time a larger diversion can be achieved in a shorter time.

Session 22: Spacecraft Guidance, Navigation and Control – II

Chair: Don Mackison – University of Colorado

13:30 **AAS 10 - 251** **Covariance Analysis of the Minimum Model Error Estimator**

Manoranjan Majji, John L. Junkins, and James D. Turner – Texas A&M University

Minimum model error estimation has been an important smoothing approach for the state and parameter estimation of nonlinear dynamical systems. The analyst typically obtains the best estimates of the state trajectory and the time varying model error term as a byproduct of the measurement data processing using the minimum model error estimator. However, the lack of covariance information associated with the state estimation error is a particular setback that has prevented estimation theorists from adopting this procedure widely. In this paper, we derive expressions governing the covariance of the state estimation error for minimum model error estimation framework.

13:55 **AAS 10 - 252** **Admissible n-Impulse Orbit Transfer and Rendezvous Solved Using a Learning Optimization Algorithm**

Troy A. Henderson, Daniele Mortari, Martìn E. Avendaño, and Ron D. Denton – Texas A&M University

The n-impulse orbit transfer and orbit rendezvous problems are constructed for use with evolutionary algorithms (EAs), where the total delta-v of the maneuver is minimized constrained by a maximum allowed time of flight and maximum allowable delta-v per impulse. New, novel constraints on the delta-v are first derived to make the n-impulse problem more computationally tractable, and then the construct for using EAs is developed. In this paper, a specific optimization technique, called the Learning Approach to Sampling Optimization, is tested and compared to the more traditional genetic algorithm.

14:20 **AAS 10 - 253** **Reduced Complexity Gravity Modeling for Rapid Design Environments**

Kyle J. DeMars, Paige S. Felker, and Robert H. Bishop – University of Texas at Austin

In developing enabling technologies to achieve precision guidance, navigation, and control for lunar landing and operations, we must visit the issue of environment modeling. Current state-of-the-art gravity field models generally reach degree and order 160 to 360 (requiring the storage and implementation of approximately 26,000 to 130,000 spherical harmonics coefficients). These models represent global, high-fidelity models of gravity fields suitable for accurately predicting trajectories anywhere within the influence of the gravitating body. However, the disadvantage is that they are computationally expensive, restricting their full use in simulation. To this extent, we study the problem of determining reduced complexity gravity realizations.

14:45 **AAS 10 - 254** **Analysis of Relative GPS Navigation Techniques**

Matthew Fritz – Texas A&M University; Renato Zanetti – The Charles Stark Draper Laboratory; Srinivas R. Vadali – Texas A&M University

Relative global positioning system (GPS) navigation is currently used for autonomous rendezvous and docking of two spacecraft as well as formation flying applications. GPS receivers' measurements are used by the navigation subsystem to determine estimates of the current states of the spacecraft. The success of autonomous proximity operations in the presence of an uncertain environment and noisy measurements is highly dependent on the navigation accuracy. This paper presents the comparison of four Kalman filter architectures to be used for relative GPS navigation. A trade study is performed with the advantages and disadvantages of the four different Kalman architectures used for relative GPS navigation presented and compared.

15:10 **Break**

15:35 **AAS 10 - 255** **TableSatII for NASA's Magnetospheric MultiScale (MMS) Mission - A Problem in Orbit and Attitude Determination and Control**
David Waterhouse, Michael Dunstan, Megan Kramer, Jeffrey Kite, Daniel Castelli, and May-Win Thein – University of New Hampshire

The NASA Magnetosphereic Multiscale (MMS) Mission is a constellation mission consisting of four spin-stablized satellites flying in a tetrahedron-shaped formation and is to be launched in 2014. The authors aim to design and fabricate the MMS TableSat Generation II (TSat II), spacecraft prototypes with limited 5-DOF motion, in order to analyze the MMS spacecraft dynamics, particularly the Spin-plane Double Probe (SDP) and Axial Double Probe (ADP) booms. The goal of this part of the research is to design a control algorithm for autonomous tetrahedral formation flying and to observe the resulting TSat II dynamic responses.

16:00 **AAS 10 - 256** **Autonomous GNC for Descent and Landing on Small, Irregular Bodies**
Jesus Gil-Fernandez and Mariella Graziano – GMV, Spain

Future missions to asteroids demand soft, pinpoint landing (few meters dispersion). The GNC system during descent and landing is autonomous, mainly constrained by cost and technological maturity, and must be robust to large uncertainties (asteroid characteristics). The selected sensors provide the necessary observables and the navigation process them to provide reliable estimates of the spacecraft complete state (absolute and surface-relative navigation). A safe descent profile is defined by a set of waypoints and timing. Guidance generates the reference maneuvers and trajectory and control computes small actions to cancel current deviations. Monte Carlo simulations prove that GNC performances meet the requirements

16:25 **AAS 10 - 257** **Lunar Landing and Ascent Trajectory Guidance Design for the Autonomous Landing and Hazard Avoidance Technology (ALHAT) Program**
Thomas Fill – Charles Stark Draper Laboratory

The ALHAT (Autonomous Landing and Hazard Avoidance Technology) project is developing technology for autonomous lunar landing with the capability to detect and avoid surface hazards, and enable “anytime, anywhere” safe and precise landings. A GNC (Guidance, Navigation, and Control) system has been designed to support these goals through simulation, testing, and evaluation of the technology design. A guidance implementation has successfully supported the initial design analysis cycle in various simulation test beds. The design provides a single algorithm set for both descent to and ascent from the lunar surface. This paper provides a description of the ALHAT guidance algorithm design.

16:50 **AAS 10 - 258** **Optimal Guidance for 3D Lunar Ascent**
David G. Hull – University of Texas at Austin

The minimum-time controls (thrust pitch and yaw) for the three-dimensional transfer of a rocket from one state to another over a flat moon are used to develop guidance laws for vehicle operation over a spherical moon. After assuming small out-of-plane motion (small yaw), three in-plane (pitch) control laws are developed. The three laws are employed in the sample and hold guidance of a lunar ascent vehicle. All three laws satisfy the final conditions and give essentially the same pitch and yaw control histories. Since the zeroth-order law can be obtained completely analytically, it merits serious consideration for ascent guidance.

Session 23: Satellite Relative Motion – II

Chair: Craig McLaughlin – University of Kansas

13:30 AAS 10 - 259 A Relative Satellite Motion Model for Chief and Deputy with Slightly Eccentric Orbits

Kirk W. Johnson and Douglas D. Decker – Air Force Institute of Technology; Thomas Alan Lovell – Air Force Research Laboratory

This study develops parameters to describe one satellite's motion relative to another whose orbit has small but non-negligible eccentricity; these parameters yield significant geometrical insight and operational efficacy. Both satellites are required to remain close to a "virtual chief" whose orbit elements are identical to the actual chief's, but with zero eccentricity. The known Hill-Clohessy-Wiltshire motion of both satellites relative to the virtual chief is then transformed into chief-centered coordinates. This paper describes the resulting linearized equations of motion and their closed-form solution. Such a parameterized model is needed for rendezvous and proximity operations involving non-circular chief orbits.

13:55 AAS 10 - 260 Attitude Synchronization of the Spacecraft Formation Flying via the SDRE Controller Using Reaction Wheels

Junoh Jung – Yonsei University, Republic of Korea; Insu Chang – University of Illinois; Sang-Young Park and Kyu-Hong Choi – Yonsei University, Republic of Korea

The objective of the study is to develop a decentralized control algorithm for attitude synchronization of the spacecraft formation flying using Reaction Wheel Assembly (RWA). For the control, the absolute and relative dynamics with RWAs are formulated, which are used to construct the feedback controllers. The State-Dependent Riccati Equation (SDRE) technique is used to regulate state errors. The stability region is estimated by a newly suggested method. The reliability of the proposed control law is validated by using a new system which contains a Hardware-In-the-Loop Simulator (HILS) and virtual systems. The experimental results show effectiveness of the proposed control law.

14:20 AAS 10 - 261 Constrained n-impulse Periodic Close Encounters

Daniele Mortari, Jeremy Davis, Ron D. Denton – Texas A&M University

An orbit transfer strategy is proposed to provide periodic close observations of target satellites under various constraints. The constraints are time-invariant (maximum observation distance; observation time in minutes/day; maximum time for the first observation; maximum time interval between subsequent observations), and time-depending (illumination; encounters over specific Earth regions). The orbit transfer is impulsive with bounded value for each impulse as well as for the n-impulse orbit transfer cost. Examples are provided for LEO-to-LEO and GEO-to-GEO cases. Optimization is currently performed using Genetic algorithms while a Learning-Adaptive global optimization technique is in progress.

14:45 AAS 10 - 262 Distance Preserved Satellite Clusters

Yu Ning, Martìn E. Avendaño, and Daniele Mortari – Texas A&M University

The problem of creating a cluster of satellites such that the distances among satellites whose orbits have tiny eccentricity maintain constant is considered. The motions of satellites are described by relative orbital elements. Three kinds of relative positions of relative orbits are involved: with same plane, with same center, and totally different. The situation of same center is the most complicated one, but it has the character of continuity. Some particular situations are much easier. The stable keeping under J3 perturbation is analyzed. An illustrative example is included, which demonstrates the effectiveness of design method and the characters of cluster.

15:10 **Break**

15:35 **AAS 10 - 263** **Eaglet: A Geosynchronous Orbit Formation Flying Concept**
Andrew E. Turner – Space Systems/Loral

This paper develops the concept of flying a small spacecraft, referred to as Eaglet, in formation with a larger geosynchronous (GEO) spacecraft which supports its operation. The means by which Eaglet actively maintains position relative to the primary craft, which could be a commercial GEO spacecraft, are discussed. Even more importantly, the means by which Eaglet passively avoids collision and rapidly departs from the vicinity of the primary craft in the event of a contingency are explored. Eventual disposal of Eaglet into a graveyard orbit to prevent the introduction of new debris into the GEO arc is also discussed.

16:00 **AAS 10 - 264** **Optimal Impulsive Satellite Transfers Using Second-Order Solutions of Relative Motion**
Weijun Huang – University of Missouri

The "Primer Vector" technique is a well-known technique to solve an optimal transfer problem. But in order to use it, a dynamic equation and its costate dynamic equation need to be solved. This paper analytically deduced the Second-Order solutions of the dynamic equation and the costate dynamic equation for relative motion. These Second-Order Solutions are implemented in the "Primer Vector" technique to solve an optimal fuel, fixed-time, two-burn transfer problem. Numerical Test showed that the accuracy is very high even for the satellites with large relative distance.

16:25 **AAS 10 - 265** **Passively Safe Relative Motion Trajectories for On-Orbit Inspection**
Liam M. Healy and C. Glen Henshaw – Naval Research Laboratory

A spacecraft designed for close (< 10 m) inspection of a customer spacecraft incurs a significant risk of collision. By minimizing thrusting, the risk is also minimized because only collision-free relative motion trajectories are used during the non-thrusting periods. Relative orbital elements, an analog to orbital elements, together with a simulation of coverage over the host spacecraft are used to design such trajectories. Orbit segments are then defined and an algorithm for the coverage of a sphere from each segment presented. Desire for coverage of specific points on the customer governs a trajectory plan design.

16:50 **AAS 10 - 266** **Spacecraft Relative Motion Propagation using Euler Parameters**
Giulio Bau – University of Padova, Italy; Claudio Bombardelli and Jesus Pelaez – Technical University of Madrid, Spain; Enrico Lorenzini – University of Padova, Italy

A new formulation of the spacecraft relative motion for a generic orbit is presented based on the orbit propagation method proposed by Pelaez in 2006. We formulate the relative dynamics starting from a general form of the Clohessy-Wilthshire equations, where the orbital elements appear through the rotation matrix between the mobile and the inertial reference frame. The equations are than rewritten in function of the Pelaez variables in the special perturbation method. When compared with traditional relative motion proposed in the past the method offers better performance in terms of accuracy and computation speed.

Session 24: Space Structures Dynamics and Control

Chair: Chris Ranieri – The Aerospace Corporation

13:30 **AAS 10 - 268** **Dynamic Modeling of the Tethered Coulomb Structure**
Carl R. Seubert and Hanspeter Schaub – University of Colorado at Boulder

The Tethered Coulomb Structure (TCS) concept utilizes electrostatic forces to repel a formation of spacecraft nodes that are connected with fine, light-weight tethers creating a near rigid and potentially large structure. Simulations of the complex relative motion of each node under the small Coulomb and tether forces are conducted for any TCS shape and size. Of particular interest is the analysis showing the nodes motion under differential gravity and differential solar radiation pressure while in geostationary orbit. By inclusion of nodal attitudes the coupling between rotational motion and overall TCS motion from tether torques is shown. This paper demonstrates to what extent the low-mass tethered structure becomes rigid and stabilized under the inflationary Coulomb forces.

13:55 **AAS 10 - 269** **Performance Analysis of Bare Electrodynamic Tethers as MicroSat Deorbiting Systems**
Claudio Bombardelli, Jose Manuel Nuñez-Ayon and Jesus Peláez – Technical University of Madrid, Spain

It has recently been proposed to use bare electrodynamic tethers (EDTs) in connection with nanosatellites, either to provide a cheap test of OML current collection theory or to devise a lightweight deorbiting system for cubesats experiments. In the present article we investigate the orbital evolution of small satellites (1- 5 kg) equipped with electrodynamic tethers of different lengths (100-1000 m) and for different orbital conditions. Tether integration in the microsatellite system and tether deployment is also addressed. Results show that a small dedicated experiment involving one or two cubesat(s) is feasible in favorable conditions with tether length of 100-200m.

14:20 **AAS 10 - 270** **Space Debris Removal with Bare Electrodynamic Tethers**
Claudio Bombardelli and Jesus Peláez – Technical University of Madrid, Spain

Electrodynamic tethers (EDT´s) have been proposed as one tool for space debris removal thanks to their inherently propellantless modality of operation. For the tether current collection the bare tether concept has been shown to offer the best performance in terms of deorbiting capability per unit of tether mass. The design of the bare tether has not been optimized and often the simulation results are not reproducible. In this article we consider optimally sized bare electrodynamic tethers with tape cross section attached to existing space debris provided by the DISCOS database of the European Space Agency.

14:45 **AAS 10 - 271** **Validation of Tethered Satellite System Computational Models**
Joshua R. Ellis and Christopher D. Hall – Virginia Tech

We present a method of validating computational models for the dynamics of tethered satellite systems. As experimental data for tethered satellite system dynamics is largely unavailable, the validation procedure utilizes what we term a "top-level" computational model. This top-level computational model is assumed to approximate the behavior of the actual physical system with sufficient accuracy, and is therefore used in place of experimental data for the purposes of validation. The validation procedure is applied to two sets of results obtained from lower-level computational models to demonstrate its utility and the necessity of validating results obtained from simplified system models.

15:10 **Break**

15:35 AAS 10 - 272 Relative Equilibria of a Moon-Tethered Spacecraft

Alexander A. Burov – Dorodnicyn Computing Center of the RAS, Russia; Oleg I. Kononov – Lomonosov Moskow State University, Russia; Anna D. Guerman – University of Beira Interior, Portugal

We study relative equilibria of a space station connected to the Moon surface by a tether. The station is supposed to be a rigid body; we take into account its dimensions. The equations of motion are deduced supposing that both the Earth and the Moon move in a circular orbit about the center of mass of the system. The relative equilibria of the system are examined using the Routh function. We find particular solutions of the equilibrium equations that correspond to the possible nominal motions of the space station. We study stability of these equilibria.

16:25 AAS 10 - 267 Attitude Control of Multiple Rigid Body Spacecraft with Flexible Hinge Joints

Burak Akbulut – Turkish Aerospace Industries, Turkey; Kemal Özgören and Ozan Tekinalp – Middle East Technical University, Turkey

Control algorithm is developed for a satellite with flexible appendages to achieve a good pointing performance. Detailed modeling activity was carried out that consists of sensor and actuator models, disturbances and system dynamics. Common hardware found in the spacecraft such as reaction wheels, gyroscopes, star trackers, etc. were included in the model. Furthermore, the Newton-Euler method is employed for the derivation of multi-body equations of motion. Evaluation of the pointing accuracy with proper pointing performance metrics such as accuracy, jitter and stability during slew maneuvers are obtained through simulations. Control strategies are proposed to improve pointing performance.

16:50 AAS 10 - 274 Rigid Body Attitude Stabilization with Unknown Time-varying Delay in Feedback

Apurva Chunodkar and Maruthi Akella – University of Texas at Austin

We consider the problem of stabilizing attitude dynamics with an unknown time-varying delay in feedback. Upper-bounds on the time-varying delay magnitude and its rate of change are assumed to be known. The attitude stabilization objective is achieved by further generalizations to the complete type Lyapunov-Krasovskii (L-K) functional framework. The nonlinear time-delay system is partitioned into a nominal linear time-delay system with perturbations arising from nonlinearities and time-varying delay by using model transformation. A complete-type L-K functional is constructed for the nominal system and after performing robustness analysis, sufficient conditions which give a region of attraction estimate are provided.

AUTHOR INDEX

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RECORD OF MEETING EXPENSES

20th AAS/AIAA Space Flight Mechanics Meeting
San Diego Marriott Mission Valley Hotel, San Diego, California
14-17 February 2010

Name:_______________________________ Organization: _______________________________

Category	Early Registration (through 15 Jan 2010)	Late Registration
Full - AAS or AIAA Member	$510	$560
Full - Non-member	$595	$645
Retired*	$130	$180
Student*	$130	$180

Registration Fee: ___________________

Conference Proceedings (Hard Cover)[1] ___ @ $240 ___________________

Extra CD Conference Proceedings[1] ___ @ $40 ___________________

Special Event Guest Ticket ___@ $50 ___________________

Special Event Child Ticket ___@ $25 ___________________

TOTAL: ___________________

Recorded by: __________________________________

[1] Digital Proceedings on Compact Disk (CD) are provided after conference at no extra cost for full registrants

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Conference Satisfaction Survey

The organizing committee 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.

  ○ Very Poorly ○ Poorly ○ Average ○ Good ○ Very Well

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

  ○ Very Poor ○ Poor ○ Average ○ Good ○ Excellent

- Approximately how many conference of this type do you attend annually?

  ○ Maybe 1 ○ 1-2 ○ 3-4 ○ 4-5 ○ >5

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

  ○ 1 Unsatisfied ○ 2 ○ 3 ○ 4 ○ 5 Satisfied

Registration

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

  ○ 1 Unsatisfied ○ 2 ○ 3 ○ 4 ○ 5 Satisfied

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

  ○ 1 Unsatisfied ○ 2 ○ 3 ○ 4 ○ 5 Satisfied

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

  ○ 1 Unsatisfied ○ 2 ○ 3 ○ 4 ○ 5 Satisfied

Venue

- Overall, how satisfied were you with the conference location?

  ○ 1 Unsatisfied ○ 2 ○ 3 ○ 4 ○ 5 Satisfied

Technical Content

- How satisfied were you regarding the overall technical content?

  ○ 1 Unsatisfied ○ 2 ○ 3 ○ 4 ○ 5 Satisfied

- How satisfied were you with the printed materials received?

  ○ 1 Unsatisfied ○ 2 ○ 3 ○ 4 ○ 5 Satisfied

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

  ○ Too Long ○ Just Right ○ Too Short ○ Don't Care

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

  ○ Too Long ○ Just Right ○ Too Short ○ Don't Care

- How many presentations did you attend?

  ○ <10 ○ 10-20 ○ 21-30 ○ 31-40 ○ >40

- 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 do you prefer most?

  ○ Increase Meeting Length ○ Hold More Than 3 Concurrent Sessions ○ Shorten Presentation Length ○ Reject More Papers

Social Events

- How satisfied were you with the receptions?

  ○ 1 Unsatisfied ○ 2 ○ 3 ○ 4 ○ 5 Satisfied

- How satisfied were you with the offsite event?

  ○ 1 Unsatisfied ○ 2 ○ 3 ○ 4 ○ 5 Satisfied

- How do you feel about how many social events are held?

  ○ Too Few ○ Just Right ○ Too Many ○ Don't Care

Additional Survey Comments

- General

- Registration

- Venue

- Technical Content

- Social Events