Conference Program

American Astronautical Society

AIAA
The World's Forum for Aerospace Leadership

24th AAS/AIAA Space Flight Mechanics Meeting

January 26 – 30, 2014 | Santa Fe, NM

AAS General Chair
Donald Mackison
University of Colorado

AIAA General Chair
Ossama Abdelkhalik
Michigan Technological University

AAS Technical Chair
Roby S. Wilson
Jet Propulsion Laboratory

AIAA Technical Chair
Renato Zanetti
Johnson Space Center

Front Cover Image:

The Mars Atmosphere and Volatile Evolution Mission (MAVEN) successfully launched on November 18, 2013. MAVEN is the first spacecraft devoted to exploring and understanding the Martian upper atmosphere. The trip to Mars takes 10 months, and MAVEN will go into orbit around Mars in September 2014. Credit: NASA Goddard Space Flight Center

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24TH AAS/AIAA SPACE FLIGHT MECHANICS MEETING
CONFERENCE INFORMATION

REGISTRATION

Registration Site (https://www.xcdsystem.com/aas2014)

In order to encourage early registration, we have implemented the following conference registration rate structure: **Register by 5 Jan 2014 and save $100!**

Category	Early Registration (through 5 Jan 2014)	Late Registration
Full - AAS or AIAA Member	$530	$630
Full - Non-member	$630	$730
Retired*	$165	$190
Student*	$165	$190
Extra Dinner Event Ticket	$48	$48
Extra Dinner Event Child Ticket (6-11 yrs)	$25	$25

**does not include proceedings CD*

The reception is included for all registrants. The dinner event on Tuesday evening is included with all full registrations. The dinner event on Tuesday evening is free for children under the age of 6.

A conference registration and check-in table will be located on the Mezzanine Level of the La Fonda on The Plaza Hotel and will be staffed according to the following schedule:

- Sunday Jan. 26 3:00 PM - 6:00 PM
- Monday Jan. 27 7:30 AM - 2:00 PM
- Tuesday Jan. 28 8:00 AM - 2:00 PM
- Wednesday Jan. 29 8:00 AM – 2:00 PM
- Thursday Jan. 30 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
Sunday 26 January	3pm	6pm	Registration	Mezzanine
	6pm	9pm	Early Bird Reception	La Terraza Room

Day	Start	End	Function	Room
Monday 27 January	6:45am	8am	Speakers Breakfast	La Terraza Room
	7:30am	2pm	Registration	Registration Desk
	8am	12:00pm	Session 1: Space Situational Awareness I	North Ballroom
	8am	12:00pm	Session 2: Rendezvous and Proximity Operations I	South Ballroom
	8am	12:00pm	Session 3: Astrodynamics Algorithms	Stiha Room
	8am	12:00pm	Session 4: Low Energy Trajectory Design	Santa Fe Room
	9:40am	10:00am	Morning Break	Mezzanine
	Noon	1:30pm	AAS/AIAA Joint Technical Committee Lunch	New Mexico Room
	1:30pm	5:30pm	Session 5: Spacecraft Autonomy	North Ballroom
	1:30pm	5:30pm	Session 6: Navigation	South Ballroom
	1:30pm	5:30pm	Session 7: Trajectory Design I	Stiha Room
	1:30pm	5:30pm	Session 8: Asteroid Retrieval and Mitigation	Santa Fe Room
	3:30pm	3:50pm	Afternoon Break	Mezzanine

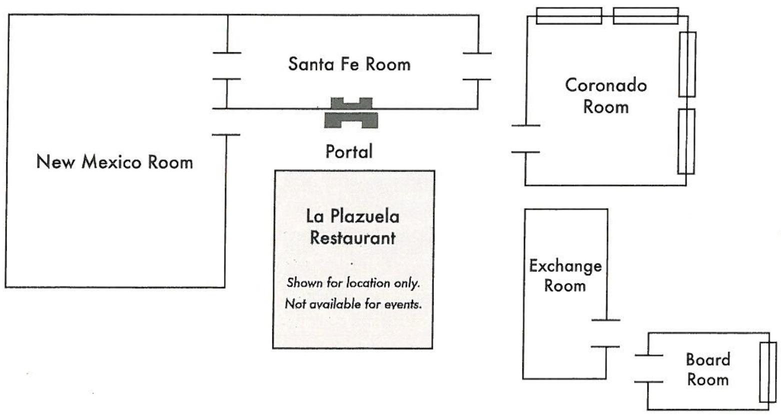
Day	Start	End	Function	Room
Tuesday 28 January	6:45am	8am	Speakers Breakfast	La Terraza Room
	8am	2pm	Registration	Registration Desk
	8am	12:00pm	Session 9: Orbit Determination I	North Ballroom
	8am	12:00am	Session 10: Attitude Determination and Sensors	South Ballroom
	8am	12:00pm	Session 11: Low-Thrust Trajectory Design	Stiha Room
	8am	12:00pm	Session 12: Orbital Debris	Santa Fe Room
	9:40am	10:00am	Morning Break	Mezzanine
	Noon	1:30pm	AIAA Astrodynamics Technical Committee Lunch	New Mexico Room
	1:30pm	5:30pm	Session 13: Space Situational Awareness II	North Ballroom
	1:30pm	5:30pm	Session 14: Estimation	South Ballroom
	1:30pm	5:30pm	Session 15: Small Body Proximity Operations	Stiha Room
	1:30pm	5:30pm	Session 16: Trajectory Design II	Santa Fe Room
	3:30pm	3: 50pm	Afternoon Break	Mezzanine
	6:00pm	7:00pm	Awards Ceremony and Dirk Brouwer Award Lecture	Lumpkins Ballroom
	7pm	11pm	Dinner Buffet	La Terraza Room

Day	Start	End	Function	Room
Wednesday 29 January	6:45am	8am	Speakers Breakfast	La Terraza Room
	8am	2pm	Registration	Registration Desk
	8am	12:00am	Session 17: Rendezvous and Proximity Operations II	North Ballroom
	8am	12:00am	Session 18: Spacecraft Guidance and Control	South Ballroom
	8am	12:00pm	Session 19: Spacecraft Dynamics	Stiha Room
	8am	12:00pm	Session 20: Earth Missions	Santa Fe Room
	9:40am	10:00am	Morning Break	Mezzanine
	Noon	1:30pm	AAS Space Flight Mechanics Committee Lunch	New Mexico Room
	1:30pm	3:30pm	Session 21: Optical Navigation	North Ballroom
	1:30pm	3:30pm	Session 22: Space Environment	South Ballroom
	1:30pm	3:30pm	Session 23: Orbit Determination II	Stiha Room
	1:30pm	3:30pm	Session 24: Aeronomy Special Session	Santa Fe Room
	4:00pm	5:30pm	Session 25: ASTRIA Special Session	Lumpkins Ballroom
	3:30pm	3:50pm	Afternoon Break	Mezzanine
	5:30pm	6:30pm	Conference Administration Subcommittee	Santa Fe Room
	5:30pm	6:30pm	Technical Administration Subcommittee	Exchange Room
	5:30pm	6:30pm	Website Administration Subcommittee	Stiha Room

Day	Start	End	Function	Room
Thursday 30 January	6:45am	8am	Speakers Breakfast	La Terraza Room
	8am	10am	Registration	Registration Desk
	8am	12:00pm	Session 26: Dynamics And Control Of Large Space Structures & Tethers	North Ballroom
	8am	12:00am	Session 27: Attitude Dynamics and Control	South Ballroom
	8am	12:00pm	Session 28: Lunar Mission Design	Stiha Room
	9:40am	10:00am	Morning Break	Mezzanine

La Fonda on The Plaza Hotel Layout

First Floor Meeting Facilities

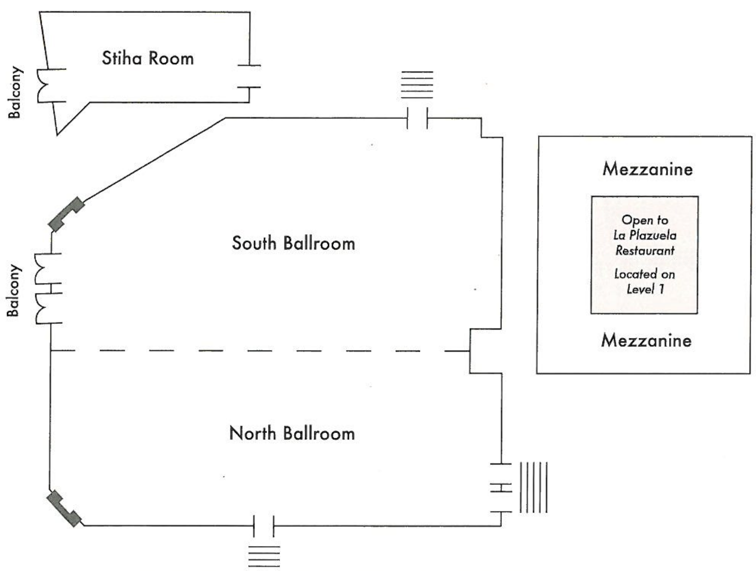


The **New Mexico Room**, with its hand-carved beamed ceiling and beautiful tin-and-glass chandeliers, was the hotel's original ballroom in the 1920s. It has retained an authentic, Old World ambience that guests appreciate. At 2,460 square feet, it can accommodate 180 for a sit-down banquet and 225 for a reception. And the **Portal** entrance, with its soaring fireplace and inviting furnishings, creates a lovely cocktail/reception area.

The **Santa Fe Room** is a jewel offering a 25' high cathedral ceiling, hammered-tin chandeliers, a carved tile wood-burning fireplace, and unique 1920s artwork. The room is intimate and charming and has 1,275 square feet that can accommodate 80 for a sit-down banquet, 100 for a reception or up to 120 for a meeting. Bridal couples often hold their ceremony in the Santa Fe Room and celebrate with a reception in the adjoining New Mexico Room.

The **Coronado**, **Exchange** and **Board Rooms** are ideal for breakout meetings and small group functions. All three feature windows or natural light from our dramatic Lobby skylights.

Second Floor Meeting Facilities

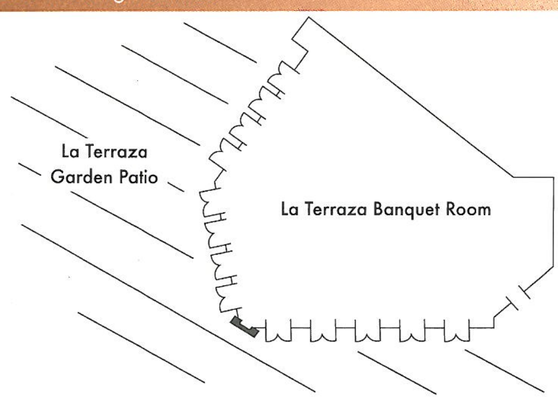


The **Lumpkins Ballroom** offers 6,560 square feet of space, accommodating up to 750 for a reception and as many as 550 for a sit-down luncheon or dinner, and the room is easily divided in half. Hand-wrought chandeliers, two fireplaces and a balcony add to the room's charm. The Ballroom opens to a beautiful, sky lighted Mezzanine.

The **Mezzanine**, just off the Ballroom, works beautifully for registration, coffee breaks, continental breakfasts and pre-dinner receptions. It is filled with natural light from the skylights above and overlooks the charming La Plazuela restaurant. Additionally, Vladan Stiha's striking painted panels of Native Americans grace the walls.

The **Stiha Room** is conveniently situated next to the Ballroom. It is often the site for small meetings, meals and executive retreats.

Third Floor Meeting Facilities



La Terraza is known as one of Santa Fe's most unique and luxurious banquet rooms, offering breathtaking views of the surrounding mountains and the iconic St. Francis Cathedral Basilica. This lovely space has an Italian marble floor, handsome copper and tin chandeliers, and french doors that fold open, bringing in the natural light and extending the space onto the lush **La Terraza Garden Patio**. A hand-sculpted kiva fireplace is an enchanting focal point, even in the summer. La Terraza offers 2,295 square feet of space, accommodating 180 for a sit-down banquet or 225 for a reception. One side of the Garden Patio is tented from spring through fall, which further expands its capacity.


Photo © Robert Reck

SPECIAL EVENTS

EARLY BIRD RECEPTION

Sunday, 26 January	6 – 9:00 pm
Location:	La Terraza Room

AWARDS CEREMONY AND DIRK BROUWER AWARD LECTURE

Tuesday, 28 January	6 – 7:00 pm (ceremony and lecture)
Location:	Lumpkins Ballroom

A Navigator's Journey

The tale of a professor's program of research and teaching is told through the stories of the people, programs, and places stretching across time from early Space Shuttle rendezvous missions to plans for precision fast-to-flight entry, descent, and landing navigation with hazard detection and avoidance. Central to the story is the Kalman filter. The fundamental linear Kalman filter equations are well known with stability and performance guarantees under the assumptions of the underlying theory. The reality of nonlinearities, model uncertainties, measurement errors with unknown or undesirable noise characteristics, and other deviations from the linear theory transform the implementation of practical navigation algorithms based on the Kalman filter to an exercise of blending theory and art that leads to fascinating teaching opportunities within a rigid research environment. This short talk will highlight the link between practical estimation algorithms and methods as applied to on-orbit relative navigation in the early Space Shuttle era and the more complex entry, descent, and landing navigation challenges posed by the Morpheus vehicle, and how NASA missions influenced one professor's ambition to inspire students to explore.

DIRK BROUWER AWARD HONOREE

Dr. Robert H. Bishop is the Dean of Engineering at Marquette University and holds a faculty position in the Department of Electrical and Computer Engineering. Previously he held the position of Chairman of the Department of Aerospace Engineering and Engineering Mechanics at The University of Texas at Austin where he held the Joe. J. King Professorship and was a Distinguished Teaching Professor. Prior to academia, he was a member of the technical staff at the Charles Stark Draper Laboratory. Dr. Bishop is currently working advanced navigation algorithm development with fast-to-flight characteristics and integrated navigation and guidance for planetary precision landing. He was selected twice as a Faculty Fellow of the NASA Jet Propulsion Laboratory and as a Welliver Fellow of the Boeing Company. He co-authors one of the world's leading textbooks in control theory, and has authored two other textbooks, edited two handbooks, and authored/co-authored over one hundred and twenty-five journal and conference papers. He received the John Leland Atwood Award by the American Society of Engineering Educators and the

American Institute of Aeronautics and Astronautics that is given periodically to “a leader who has made lasting and significant contributions to aerospace engineering education."

Dr. Bishop is a Fellow of the American Institute of Aeronautics and Astronautics and a Fellow of the American Astronautical Association. He holds a PhD in electrical and computer engineering from Rice University and both an MS and BS in aerospace engineering from Texas A&M University.

DINNER BUFFET

Tuesday, 28 January	7:00 - 11:00 pm
Location	La Terraza Room, La Fonda on The Plaza Hotel

All conference registrations will receive an event ticket. Adult guest tickets will be available prior to January 23, 2014 for $48 each. Tickets for children from 6-12 are available for $25. Children under 6 are free. If interested in guest tickets prior to January 23, 2014, please order them online from the conference registration website ***(https://www.xcdsystem.com/aas2014).***

Conference Location

La Fonda on the Plaza

100 E. San Francisco St.
Santa Fe, NM 87501

505.982.5511 (voice)
800-523-5002 (Toll-free)
505.988.2952 (fax)
http://www.lafondasantafe.com/

La Fonda on the Plaza is a Santa Fe landmark, just steps away from history and art museums, a variety of galleries and shops, historic churches and, of course, the Plaza. The historic inn's Pueblo-style architecture features thick wood beams, latilla ceilings and carved corbels. Special touches such as hand-crafted chandeliers, tin and copper lighting fixtures, and colorful tiles add character and charm. Beautiful hand-carved and hand-painted furniture and displays by local artists create a rich ambience. La Fonda has always been a local gathering spot and a hub of activity.

The Conference rate for the conference is $88/night plus applicable taxes. Taxes include Santa Fe Lodger's Tax of 7% and the New Mexico Gross Receipts Tax of 8.1875% per room. Please request the AAS/AIAA Space Flight Mechanics Meeting rate (AAS/AIAA or #725938). The deadline for securing the conference rate at the hotel is Monday, December 30, 2013.

Complimentary internet access in guest rooms and meeting space is available to all conference attendees.

Other Accommodation Options

- Inn and Spa at Loretto
  211 Old Santa Fe Trail
  Santa Fe NM 87501
  505-988-5531
  Reservations: 866-582-1646
  AAS/AIAA conference Group rate: $88.00/night
  Overnight parking: $10.00
- Hotel Santa Fe
  Reservations: (855) 825-9876
  Rate: $106/night
- Eldorado Hotel & Spa
  309 W. San Francisco, Santa Fe, NM 87501
  (800) 955-4455
  (505) 988-4455
  Rate: $123/night
- La Posada de Santa Fe Resort & Spa
  330 East Palace Avenue
  Santa Fe, NM 87501
  Reservations: 855-278-5276
  Santa Fe Tel: 505-986-0000
  AAS/AIAA conference Group rate: $88.00/night (code: **GAASOFL**)
  Overnight parking: $10.00
- Inn of the Governors
  Reservations: (800) 234-4534
  Rate: $119/night
- Rosewood Inn Of the Anasazi
  113 Washington Ave., Santa Fe, NM 87501
  T: +1 505 988 3030
  Reservations: 888 767 3966
  Rate: $219/night

TRANSPORTATION INFO

Airports Serving Santa Fe Area

- Santa Fe Municipal Airport (SAF) is about 15 minutes driving from the hotel
- Albuquerque International Sunport (ABQ) is about 65 miles away from the hotel - about 70 minutes driving.
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Ground Transportation

- Whether you fly to SAF or ABQ airports, there is a shuttle service to/from the hotel: Roadrunner shuttle and charter. Roadrunner shuttle online reservation is available at: http://www.rideroadrunner.com/
- If you fly to ABQ airport, there is another shuttle service: Sandia Shuttle Express. Sandia shuttle online reservation at:http://www.sandiashuttle.com/newreservations.html. Sandia shuttle phone reservation at: 888-775-5696. Use the reference AAS/AIAA to receive the group discount
- The parking fees at the hotel is $15/night

DRIVING DIRECTIONS

Directions from I-25 and Albuquerque Airport:

Santa Fe is approximately 60 miles north of Albuquerque. As you leave the airport, take the Sunport exit to I-25 North. When you reach Santa Fe, take Exit #284 (Old Pecos Trail). At the stop sign at the top of the hill, turn left.

Overview of the conference hotel area

Proceed north to the third traffic light and bear right to stay on Old Pecos Trail into town. Old Pecos Trail becomes Old Santa Fe Trail which dead ends into La Fonda at Water Street. Go around the hotel by turning left on Water, then making an immediate right. At the traffic light at San Francisco Street, turn right again – away from the Plaza and toward the St. Francis Cathedral Basilica. Proceed to the hotel's parking garage at the end of the block, on the right side of the street.

From the Santa Fe Municipal Airport:

Santa Fe Municipal Airport
121 Aviation Dr, Santa Fe, NM 87507

1.	Head **north** on **Aviation Dr** toward **Hart Rd** About 3 mins	go 1.2 mi total 1.2 mi
2.	Take the 2nd right onto **Paseo Real**	go 0.1 mi total 1.3 mi
3.	Take the 1st left onto **NM-599 N/Veterans Memorial Hwy** About 10 mins	go 10.0 mi total 11.3 mi
4.	Keep right at the fork, follow signs for **US-84/US-285 S/Santa Fe** and merge onto **US-285 S/US-84 E/N St Francis Dr** About 1 min	go 1.1 mi total 12.4 mi
5.	Take the exit on the left toward **Museum**	go 0.3 mi total 12.7 mi
6.	Merge onto **N Guadalupe St** About 2 mins	go 0.8 mi total 13.5 mi
7.	Turn left onto **W San Francisco St** Destination will be on the right About 2 mins	go 0.3 mi total 13.8 mi

La Fonda on the Plaza
100 E San Francisco St, Santa Fe, NM 87501

ARRIVAL INFORMATION

Check-In and Checkout

- Check-in: 3:00 PM
- Check-out: 12:00 PM

Parking

Valet parking is available at a rate of $15/night plus tax. Overnight guests at the conference hotel are guaranteed parking in the hotel garage; Day attendees – based on availability in the hotel garage. Public and city parking is also available near the conference hotel, as shown in the map below. The Cathedral Lot, Water Street Lot and Archdiocese Lot are recommended (in order of being close to La Fonda, starting at one block away to two blocks away). Each lot is $2.00 per hour, $10.00 maximum. The Cathedral and Archdiocese Lots are Open 24 hours / 7 days week. The Water Street Lot is open Monday through Saturday, 7 a.m. to 10:00 p.m, and Sunday, 7 a.m. to 9 p.m

RESTAURANTS

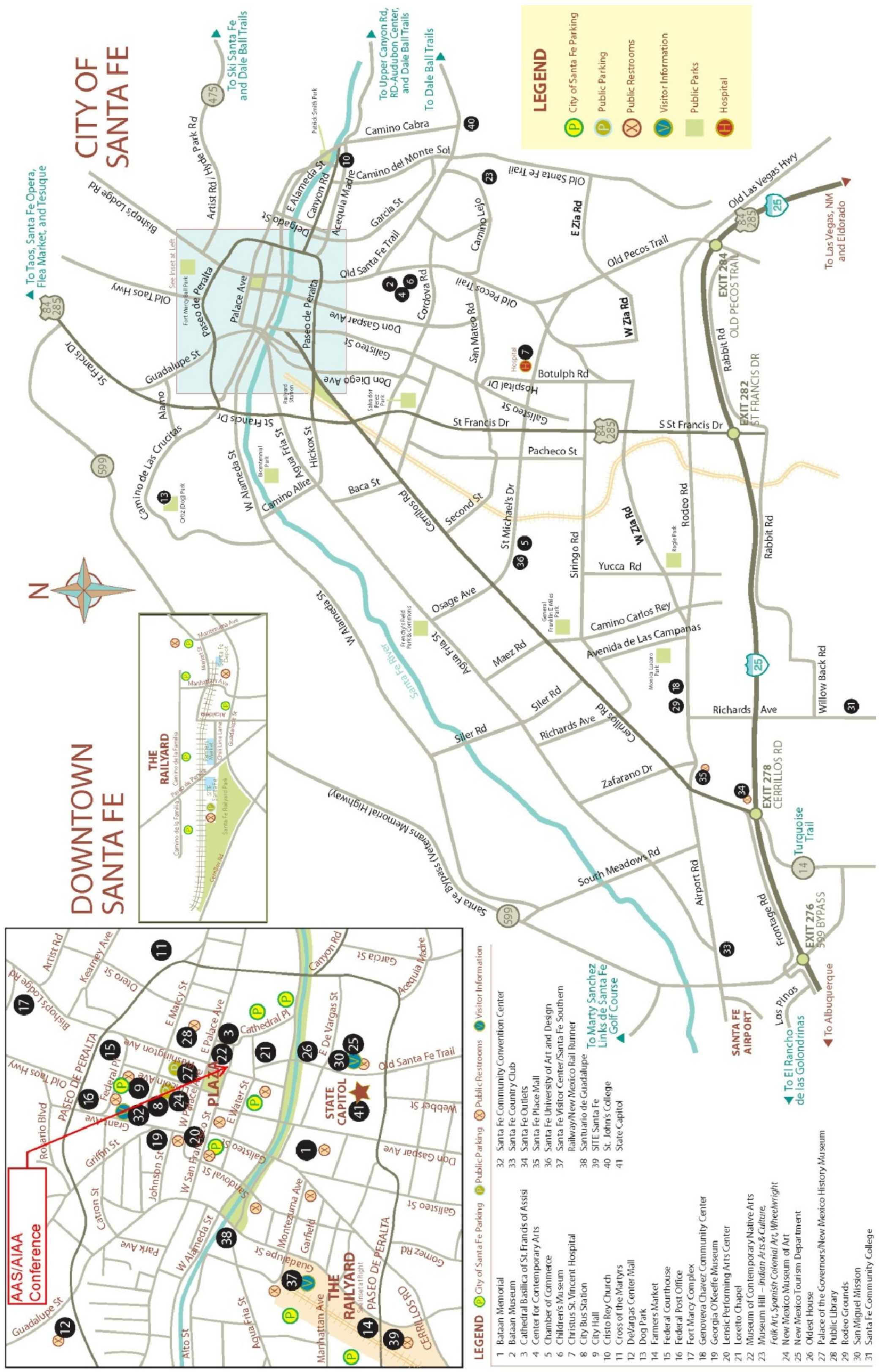
There are many options near the hotel. A handout will be given at the conference registration desk that has a list of local restaurants including more fine dining and upscale choices. For more information please visit http://santafe.org/.

RECREATION

A handout will be given at the registration desk that includes a has a very informative list for things to do in Santa Fe. For more information, please visit http://santafe.org/.

AREA MAP

Additional information and maps are located at http://santafe.org/



Additional Information

Speaker Orientation

On the day of their sessions, authors making presentations meet with their session chairs at 6:45 am. Breakfast will be served. Check the schedule at the beginning of the program for the location of the speaker's breakfast each morning. 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 16 minutes. An additional four 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 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 Astrodynamics Specialist Conferences. Electronic preprints are available for download at least 72 hours before the conference at https://www.xcdsystem.com/aas2014/ for registrants who use the online registration system. The hotel provides conference guests with complimentary 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 full registrants will receive a CD of the proceedings mailed to them after the conference (extra copies are available for $10 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 off the post-conference rate even if they delay their order until after the conference. Cost of Proceedings:

- Conference Rate **$290 domestic ($380 international)**
- Post-Conference Rate **$750** (approx.)
- Authors (post-conference) **$375** (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: www.writetrack.net/aiaa/

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

Journal of the Astronautical Sciences
Editor-in-Chief: Kathleen C. Howell
School of Aeronautics and Astronautics
3233 Armstrong Hall
Purdue University
West Lafayette, IN 47907
(765) 494-5786
howell@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.

Meetings

Committee seating is limited to committee members and invited guests. Committee and subcommittee meetings will be held according to the schedule at the beginning of the program.

SESSION 1 : SPACE SITUATIONAL AWARENESS I

Session Chair: Felix Hoots, The Aerospace Corporation

8:00 **AAS 14-201** **A Boundary Value Problem Approach to Too-Short Arc Optical Track Association**
Kohei Fujimoto, Texas A&M University; Kyle T. Alfriend, Texas A&M University

Given a short-arc optical observation with estimated angle-rates, the admissible region is a compact region in the range / range-rate space defined such that all likely and relevant orbits are contained within it. An alternative boundary value problem formulation has recently been proposed where range / range hypotheses are generated with two angle measurements as input. In this paper, angle-rate information is reintroduced as a means to eliminate hypotheses by bounding their constants of motion before a more computationally costly Lambert solver or measurement fitting algorithm is run.

8:20 **AAS 14-202** **Distant Periodic Orbits for space-based Near Earth Objects detection**
Camilla Colombo, Politecnico di Milano; Michele Stramacchia, Politecnico di Milano; Franco Bernelli-Zazzera, Politecnico di Milano

Space-based systems can integrate ground-based detection of Near Earth Objects (NEOs) that approach the Earth from the Sun direction. The feasibility of a constellation for NEOs detection from a family of Distant Periodic Orbits (DPOs) in the Sun-Earth system is studied. A map of DPOs around the Earth in the circular restricted three-body problem is constructed and the added coverage region within the exclusion zone of current Earth-based systems, when the spacecraft is at the inferior conjunction at a distance larger than the Earth L1 distance, is assessed. Then, a four-spacecraft constellation is designed.

8:40 **AAS 14-203** **Estimation for Satellite Collision Probabilities using Importance Sampling**
David Higdon; Earl Lawrence

Satellite paths are predicted using high fidelity computer models that propagate an object according to the effects of gravity and atmospheric drag. At any given time, the exact position and velocity of any satellite is uncertain; so is the state of the atmosphere. Hence the future path of the satellite is also uncertain. While the probability of a collision between two satellites can be computed, in principle, via Monte Carlo, the computational demands of the propagator make direct Monte Carlo infeasible. This talk surveys current approaches for estimating collision probabilities, and suggests an approach based on importance sampling.

9:00 **AAS 14-204** **Initial Orbit Determination, Data Association, and Admissible Regions of Space Objects using Magnetometers**
Marcus Holzinger, Georgia Institute of Technology

Magnetometer-based detection of space objects is motivated and challenges are discussed. Observable constants of motion with and without charge screening are derived in detail. Batch filtering methods are proposed to estimate the observable space object states. A novel application of various orbit constraints is used to generate admissible region boundaries for unobservable states, allowing initial orbit determination of space objects passing near magnetometers. Practical and operational issues are discussed, followed by suggested future research activities.

9:20 **AAS 14-205** **“Inverse Crime” and Model Integrity in Unresolved Space Object Identification**

Kamesh Subbarao, The University of Texas at Arlignton; Laura Henderson, The University of Texas at Arlington

The work done in the state estimation of orbital debris often uses synthetic light curves. These synthetic measurements are produced by a mathematical model that aims to describe the physical phenomena, that are then used in the estimation process. Thus, model integrity (the choice of an appropriate mathematical representation of the observed data) is critical to the success in showing observability of states/parameters in measurements. However, it is in the choice of the measurement model to generate the synthetic data and use of the of the same model in the inversion process (estimation), where one commits the ``inverse crime''.

9:40 **Morning Break**

10:00 **AAS 14-206** **Enabling the use of rotating platforms for orbit determination applications**

Brad Sease, Virginia Polytechnic Institute and State University; William Anthony, New Mexico State University; Brien Flewelling, Air Force Research Laboratory

Current methods for retrieving visual observations of on-orbit assets for the purpose of orbit determination are generally restricted to either fixed-stare observations or optical tracking based on a priori knowledge. To expand the range of operating modes, an alternative method is proposed to allow data collection from rotating platforms with limited a priori knowledge of a specific target. By intentionally generating a streaked star image and employing simple image processing techniques, it becomes possible to autonomously identify non-star behavior based on apparent motion. In this paper, a procedure is detailed and compared to fixed-stare observation methods.

10:20 **AAS 14-207** **Probability Of Correct And Wrong Detection Of Non-Resolved Objects Using Optical Sensors Under The Influence Of Clutter**

Carolin Frueh, Air Force Research Laboratory

For the multi-object tracking in a Bayesian framework, probabilistic expressions for the correct and false detection rate of objects are needed. The correct or incorrect detection of an object has three components. First, the trace the object leaves on the detector has to be recognized. Secondly, it has to be recognized correctly, as an object image and discerned from clutter (wrong detection). Furthermore, the detection has to be discriminated from other true object images and linked to the correct object. This paper addresses the first two issues and derives expressions for the false and correct probability of detection.

10:40 **AAS 14-208** **Collision Avoidance in Elliptical Formation Flying Based on Relative Orbit Elements**

Jianfeng Yin, China Academy of Space Technology; Yinrui Rao; Guo Zhong, Beihang University; Chao Han, Beihang University

In this article, a new collision avoidance model is developed based on relative orbit ele-ments. The propagation of the uncertainty estimate is studied using the unscented transform (UT) method to remove the nonlinearities. The propagation equations of the covariance matrix are derived. The collision probability model is established with the consideration of J2 perturbation. The role of the relative orbit elements is highlighted on configuration design and collision analysis. A new elliptical formation impulsive control strategy is proposed to reduce the collision probability to an acceptable level. Finally the proposed methods are validated by simulation through several typical examples.

11:00 **AAS 14-209** **Stochastic Optimization for Sensor Allocation Using AEGIS-FISST**

Islam Hussein, Applied Defense Solutions; Richard Erwin, Air Force Research Laboratory; Moriba Jah, Air Force Research Laboratory; Zach Sunberg; Suman Chakravorty

In this paper we use finite set statistics (FISST) to solve a two-object search, detection and tracking space situational awareness problem. Initially the system is only provided with prior (uncertain) information about the number of objects existing in the environment and their states. We seek an optimal automated approach for tasking a sensor to search for, detect and track the objects. We use FISST-based expected information gain as the objective function. Given the computational complexity of finding the optimal sensor action, we use a fast stochastic optimization receding horizon control approach to solve the optimal tasking problem.

11:20 **AAS 14-210** **Particle Filtering Light Curve Based Attitude Estimation For Non-Resolved Space Objects**

Richard Linares, University at Buffalo, State University of New York; John Crassidis, University at Buffalo, State University of New York; Moriba Jah, Air Force Research Laboratory

This paper discusses the development of a particle filter for attitude and angular rate estimation of a space object using light curve observations. The particle filter approach used is based on the generalized Rodrigues parameters (GRPs) local error representation. The global state used is the quaternion to avoid singularity in the attitude states. Uniform quaternions are generated to approximate a uniform distribution of rotation states. The approach is tested with simulation scenarios and evaluated based error performance and converge rate

SESSION 2: RENDEZVOUS AND PROXIMITY OPERATIONS I

Session Chair: Fernando Abilleira, Jet Propulsion Laboratory

8:00 **AAS 14-211** **Relative Orbital Motion and Angles-Only Relative State Observability in Cylindrical Coordinates**

David Geller, Utah State University; Thomas Lovell, Air Force Research Laboratory

The relative orbital equations of motion in cylindrical coordinates are rigorously derived in several forms including the linear-time-invariant differential equations of motion for a circular orbit chief. These equations are found to be very similar to corresponding equations in Cartesian coordinates (i.e., the standard Hill-Clohessy-Wiltshire equations). However, after developing the angles-only measurement equation in cylindrical coordinates, evidence of full-relative-state observability is found, contrary to the range observability problem exhibited in Cartesian coordinates. It is found that information about orbit curvature and dynamics is better preserved in the cylindrical coordinates formulation.

8:20 **AAS 14-212** **Initial Relative Orbit Determination Performance Analysis in Cylindrical Coordinates using Angles-only Measurements**

David Geller, Utah State University; Thomas Lovell, Air Force Research Laboratory

The initial relative orbit determination problem using angles-only measurements is valuable for proximity operations and the identification of unknown space objects in similar orbits. A preliminary relative orbit determination performance analysis is conducted utilizing the linearized relative orbit equations of motion in cylindrical coordinates. A geometric approach to the problem equivalent to computing the Cramer-Rao lower bound is used to estimate the expected performance. The results clearly show how orbit estimation performance is dependent on the geometry of the relative orbit and on the time interval between observations. Analysis is conducted for several common relative orbits.

8:40 **AAS 14-213** **A Non-Singular Keplerian Differential State Transition Matrix**

Stefano Casotto, Universita' di Padova

The Keplerian differential state transition matrix (KSTM) is constructed based on a well-known, but seldom used theorem from the theory of ordinary differential equations related to sensitivity to initial conditions. We provide a full three-dimensional KSTM, based on Keplerian elements, devoid of any singularity. We present analytical expressions for both the direct and the inverse KSTM in inertial coordinates, as well as in the local orbital (radial, transverse, and normal) coordinates. The new transition matrices is compared against some of the popular versions in current use and results are reported for a wide range of test cases and

9:00 **AAS 14-214** **Formation Flying and Relative Dynamics Under the Circular Restricted Three-Body Problem Formulation**

Fabio Ferrari, Politecnico di Milano; Michele Lavagna, Politecnico di Milano

Formation Flying can greatly answer complex mission goals at the cost of a challenging trajectory and stationkeeping design. The dynamics of a low-acceleration environment such as the one associated to the Circular Restricted Three-Body Problem, can be exploited to design spacecraft configurations, which satisfy relative position and velocity requirements. This work analyzes the effects of three-body dynamics on formations of spacecraft. Three-body environment is then analyzed while imposing some constraints to the relative dynamics of two spacecraft, with the perspective of providing a powerful tool to support refined mission analysis for future missions to be designed.

9:20 **AAS 14-215** **Relative Dynamics and Control of High Area-to-Mass Ratio Spacecraft Flying Around an Oblate Earth Exploiting Solar Radiation Pressure**

Giorgio Mingotti, Advanced Space Concepts Laboratory, University of Strathclyde; Colin McInnes, Advanced Space Concepts Laboratory, University of Strathclyde

Reconfiguration maneuvers for formation-flying are investigated in this paper, where micro-spacecraft with high area-to-mass ratio and small length-scale are considered. Assuming the exact J2 nonlinear relative dynamics, an optimal control problem is formulated to accomplish the maneuvers. A continuous control acceleration is applied to the system dynamics via a propellant-free approach, which exploits differential solar radiation pressure by means of electrochromic coating. A new class of space missions is enabled, based on swarms of micro-spacecraft with sensing, computing, bi-directional communicating and micro-power sources.

9:40 **Morning Break**

10:00 **AAS 14-216** **Inverse Transformation of Relative State Transition Matrix Based on Relative Orbit Elements**

Jianfeng Yin, China Academy of Space Technology; Yinrui Rao; Chao Han, Beihang University

A new set of relative orbit elements (ROEs) is used to derive a new elliptical formation flying model in previous work. In-plane and out-of-plane relative motions can be completely decoupled, which benefits elliptical formation design. In order to study the elliptical control strategy and perturbation effects, it is necessary to derive the inverse transformation of the state transition matrix based on relative orbit elements. Poisson bracket theory is used to obtain the linear transformations between the two representations: the relative orbit elements and the geocentric orbital frame. In this paper, the details of these transformations are presented.

10:20 **AAS 14-217** **Relative Position Control Of A Two-Satellite Formation Using The SDRE Control Method**

Ozan Tekinalp, METU Aerospace Engineering Dept.; Mohammad Mehdi Gomroki, METU Aerospace Engineering Dept.

The relative position control of a two-spacecraft utilizing coulomb forces as well as thrusters is addressed. The nonlinear control is realized through state dependent Riccati equation (SDRE) control method. To this end the equations of motion of the formation is properly manipulated to obtain a suitable form for SDRE control. The state-dependent coefficient (SDC) form is then formulated to include the non-linearities in the relative dynamics. The effectiveness of the controllers is demonstrated through simulations.

10:40 **AAS 14-218** **Use of Cartesian-Coordinate Calibration for Satellite Relative-Motion Control**

Andrew Sinclair, Auburn University; Ryan Sherrill, University of Florida and Air Force Research Laboratory; Thomas Lovell, Air Force Research Laboratory

The Cartesian state of the motion of a deputy satellite relative to a chief satellite can be propagated with either nonlinear or linearized dynamics. Linearized propagation of a calibrated Cartesian state has been observed to reduce linearization error compared to linearized propagation of the true Cartesian state. Control laws are often designed assuming linearized dynamics. Implementing these controllers in the presence of the nonlinear dynamics can lead to reduced performance. However, feedback of the calibrated state can provide improved performance and reduced fuel consumption compared to feedback of the true state.

11:00 **AAS 14-219** **Periodic Orbits in the Elliptical Relative Motion Problem with Space Surveillance Applications**

Ashley Biria, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin

Periodic orbits with respect to an object in an eccentric Keplerian reference orbit can be found in a variety of ways, including the use of Tschauner-Hempel equations, orbital element differences, and direct analyses of two orbits. This study proposes an alternative parameterization of the last approach, utilizing the inertial frame and simple geometrical constructs inherent to the relative motion problem. In this manner, an intuitive and straightforward characterization of periodic orbits is developed that retains the nonlinear dynamics. The resulting multi-dimensional space that defines the periodic orbits are explored. Applications focus on space object surveillance and circumnavigation orbits.

11:20 **AAS 14-220** **Future Exploration of Lamberts' Problem Using Relative Satellite Dynamics**

William Anthony, New Mexico State University

This paper represents a follow-on to previous work that investigated the Lambert problem, a well known spacecraft targeting problem, as a rendezvous problem, whereby a deputy satellite is to rendezvous with a fictitious chief. Two Lambert-like guidance algorithms based on relative motion models (one being the linear Hills-Clohessy-Wiltshire model, and the other a recent second-order closed-form solution) were presented and compared for accuracy. In this paper, the nature of the second-order algorithm is further explored, in terms of its multiple-root nature and limitations on its use.

11:40 **AAS 14-221** **Finite-Time Control For Body-Fixed Hovering Of Rigid Spacecraft Over An Asteroid**

Daero Lee, New Mexico State University; Amit Sanyal, New Mexico State University; Eric Butcher, New Mexico State University; Daniel Scheeres, University of Colorado

Finite-time hovering control scheme for body-fixed spacecraft hovering maneuver over an asteroid is presented in the framework of geometric mechanics. The configuration space for the spacecraft is the Lie group $\SE$, which is the set of positions and orientations of the rigid spacecraft in three-dimensional Euclidean space. Lyapunov analysis on the nonlinear state space of motion is used to verify finite-time convergence of the control law for the closed-loop system. Numerical simulation results demonstrate that the finite-time control scheme is superior to the asymptotic control scheme in terms of faster tracking results

Session 3: Astrodynamics Algorithms

Session Chair: Robert Melton, Pennsylvania State University

8:00 **AAS 14-222** **Framework for Performance Comparison of Lambert Algorithms**

Jaemyung Ahn, Korea Advanced Institute of Science and Technology; Sang-Il Lee; Joon Bang, Korea Advanced Institute of Science and Technology

This paper proposes a framework to compare the performances of different Lambert algorithms in a systematic way. Minimal parameters that can uniquely determine the iterator of each algorithm are identified then the cost to execute a single iteration of the algorithm is calculated. A set of experimental conditions whose single element can match a unique set of input parameters for each algorithm is constructed. Numerical experiments are conducted using the set, which provide the numbers of iterations for solved problem instances. The experiment results, combined with the cost per iteration, create the performance dominance map for considered algorithms.

8:20 **AAS 14-224** **Long-term orbital propagation through transfer maps and averaging semi-analytical approaches**

Roberto Armellin, University of Southampton; Alexander Wittig, Politecnico di Milano; Camilla Colombo, Politecnico di Milano; Pierluigi Di Lizia, Politecnico di Milano

Orbit perturbations are fundamental when analyzing the long-term evolution and stability of natural or artificial satellites. We propose the computation of transfer maps for repetitive dynamical systems as a novel approach to study the long-term evolution of satellite motion. We analyze the evolution of high area-to-mass ratio spacecraft under solar radiation pressure and J2, and the evolution of a Molniya-like spacecraft under luni-solar perturbations and Earth's oblateness. The results presented demonstrate the potentiality of the transfer maps for this problem. We highlight that it is possible to combine this approach with averaging methods.

8:40 **AAS 14-225** **An asymptotic solution for the main problem**

Jesus Pelaez, Technical University of Madrid (UPM); Hodei Urrutxua, Technical University of Madrid (UPM); Javier Herrera-Montojo, Technical University of Madrid (UPM)

An analytical solution of the main problem, a satellite only perturbed by the J2 harmonic, is derived with the aid of perturbation theory. The solution, which is valid for circular and elliptic orbits with generic eccentricity and inclination, describes the instantaneous time variation of all orbital elements. Its includes the secular variation of the elements and also the short periodic time dependence, which exhibit an interesting structure showing that the main frequencies involved in the elliptic case are the are the angular frequency of the orbit and its first five multiples

9:00 **AAS 14-226** **Asymptotic solution for the two body problem with radial perturbing acceleration**
Juan Luis Gonzalo, Technical University of Madrid (UPM); Claudio Bombardelli, Technical University of Madrid (UPM)

In this article, an approximate analytical solution for the two body problem perturbed by a radial, low acceleration is obtained, using a regularized formulation of the orbital motion and the method of multiple scales. The results reveal that the physics of the problem evolve in two fundamental scales of the true anomaly. The first one drives the oscillations of the orbital parameters along each orbit. The second one is responsible of the long-term variations in the amplitude and mean values of these oscillations. A good agreement is found with high precision numerical solutions.

9:20 **AAS 14-227** **EDromo: an accurate propagator for elliptical orbits in the perturbed two-body problem**
Giulio Bau, University of Pisa; Hodei Urrutxua, Technical University of Madrid (UPM); Jesus Pelaez, Technical University of Madrid (UPM)

EDromo is a special perturbation method for the propagation of elliptical orbits in the perturbed two-body problem. It relies on a time-element and seven regular elements, four of which are the components of a unit quaternion. The time-transformation adopted, the embedding of the total energy and the choice of a proper reference frame are the tools that lead to the regularization of the differential equations. The performance of EDromo has been analyzed by considering some typical problems in astrodynamics. In almost all our tests the method is the best among other popular formulations based on elements.

9:40 **Morning Break**

10:00 **AAS 14-228** **Efficient Kepler's Solution Via Blended Laguerre and Taylor's Series Approach**
Daniel Oltrogge, Analytical Graphics Inc

The solution of Kepler's equation is accomplished via a hybrid approach incorporating Laguerre Interpolation and a Taylor's series expansion. The resulting "corrective step without iteration" method uses only one trigonometric evaluation and directly yields the in-plane Euler rotation angles necessary to map orbit elements to orbital position. This is computationally efficient, with speed increases of between 50 and 400 percent. The achieved solution is accurate to 1.e-7 degrees, which translates to less than 10 cm at GEO altitude, making it suitable for in-line incorporation into semi-analytic orbit propagators.

10:20 **AAS 14-229** **Solutions of Multivariate Polynomial Systems Using Macaulay Resultant Expressions**
Keith LeGrand, Missouri University of Science and Technology; Kyle DeMars, Missouri University of Science and Technology; Jacob Darling, Missouri University of Science and Technology

Finding zeros of algebraic sets is a fundamental problem in aerospace engineering computation. Geometrically, this problem can often be represented by the intersection of multiple conic or quadric surfaces. A common example is GPS trilateration, which is geometrically the intersection of three spheres. In this work, several methods based on Macaulay resultant expressions are used to compute the solutions of a set of multivariate polynomial expressions. Both two- and three-dimensional algebraic sets are considered, and examples of several geometric systems are presented.

10:40 **AAS 14-230** **Application of the Stark Problem to Space Trajectories with Time-Varying Perturbations**

Noble Hatten, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin; Nicholas Bradley, The University of Texas at Austin

Three methods of obtaining solutions to the three-dimensional Stark problem one using Jacobi elliptic functions, one using Weierstrass elliptic and related functions, and one using F and G Taylor series extended to the Stark problem are applied to modeling the trajectory of a spacecraft in an inverse-square gravitational field subject to time-varying natural perturbations. Multiple ways of determining the Stark acceleration are examined. Accuracy, speed, and implementation details of all methods are compared.

11:00 **AAS 14-231** **Applications of Implicit Functions to Orbital Mechanics Problems**

Donghoon Kim, Texas A&M University; Daniele Mortari, Texas A&M University

Bezier curves are implicit functions able to describe complicated curves and surfaces. These functions are implicit polynomials ruled by control points and associated weights. Thanks to the flexibility of these functions, Bezier curves have found several applications in computer graphics. However, two distinct appealing features make these functions quite interesting of being investigated to find alternative approaches solving various orbital mechanics problems: 1) outstanding capability to simulate any trajectory and 2) capability to represent exact conic sections. In this paper, several analytical expressions of orbital mechanics problems are shown in term of Bezier curve parameter.

11:20 **AAS 14-232** **Multi-Segment Adaptive Modified Chebyshev Picard Iteration Method**

Donghoon Kim, Texas A&M University; John Junkins, Texas A&M University; James Turner, Texas A&M University

A Modified Chebyshev Picard Iteration method is the one of the computationally efficient method for solving initial value problems such as a two body problem. The cosine sampling, which is known as Chebyshev-Gauss-Lobatto node, is utilized to reduce the Runge's phenomenon. Since dense sample points are distributed at the beginning and ending locations, poor accuracy of solutions are expected during the propagation if an initial position is not located near the periapsis. This paper suggests a multi-segment method to obtain consistent accurate solutions regardless of initial positions by dividing the given orbit into two or three.

SESSION 4: LOW ENERGY TRAJECTORY DESIGN

Session Chair: Kathleen Howell, Purdue University

8:00 **AAS 14-233** **A Quick Search Method for Low-Energy Trajectory Options to Near Earth Objects**
Rodney Anderson, NASA / JPL-CalTech

In this study, the use of low-energy trajectories computed from the invariant manifolds of unstable periodic orbits is explored as a means to transfer from low-Earth orbit to Near Earth Objects. Previous work estimated the maneuvers required to reach these asteroids using planar assumptions, and various other studies have focused on returning an asteroid to Earth's vicinity. In this study, new asteroids are examined using the planar assumption, and three-dimensional effects are included for comparison with these results. Comparisons are made to results obtained using two-body techniques, and effects of using the ephemeris are studied.

8:20 **AAS 14-234** **Applications of Gravity Assists in the Bicircular and Bielliptic Restricted Four-Body Problem**
Kenta Oshima, Waseda University; Tomohiro Yanao, Waseda University

This study develops gravity assists in the Sun-Earth-Moon-spacecraft four-body system. We propose a method of searching nominal transfer trajectories between libration point orbits (analogues of Lyapunov orbits) of different energies without fuel consumption by utilizing the gravity assists and invariant manifolds of the libration point orbits in the bicircular model. Moreover, we extend the bicircular model to a bielliptic model by introducing eccentricities of celestial bodies. We then apply the similar method of gravity assist to the bielliptic model to construct transfer trajectories between libration point orbits of different energies without fuel consumption.

8:40 **AAS 14-235** **Flow Control Segment and Lagrangian Coherent Structure Approaches for Application to the Restricted Three-Body Problem**
Cody Short, Purdue University; Kathleen Howell; Daniel Blazevski, ETH Zurich; George Haller, ETH Zurich

Structures like Lagrangian Coherent Structures (LCS) are useful for describing the general flow of a particular system, including specific flow regions advantageous to desirable transport options. Application in a model like the Circular Restricted Three Body Problem (CR3BP) requires working with a minimum of four dimensions. Other complex models require even more dimensions. Satisfactory identification of LCS in such systems becomes increasingly challenging. Additional information available from the Cauchy-Green Strain Tensor (CGST) that helps isolate higher-dimensional LCS, and seed initial control segments for effective trajectory evolution, is explored in this investigation.

9:00 **AAS 14-236** **Improved Transfers to Earth-Moon L3 Halo Orbits**
Kathryn Davis, University of Colorado; Eric Butcher, New Mexico State University; Jeffrey Parker, University of Colorado; Masoud Deilami, New Mexico State University

This paper is a continuation of previous research where we improve two-impulse transfers from low-Earth orbit (LEO) to L3 libration point orbits (LPOs). The first maneuver is executed in LEO and the second maneuver, which is no longer constrained to be in the direction of the orbit's stable eigenvector, is an injection maneuver onto the LPO. The result is a reduction in the orbit injection maneuver from 130 m/s to 15 m/s, and a time of flight reduction from 44 days to 31 days.

9:20 **AAS 14-237** **F And G Taylor Series Solutions To The Circular Restricted Three Body Problem**
Etienne Pellegrini, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin

The Circular Restricted Three-Body Problem (CRTBP) is solved using an extension to the classic F and G Taylor series. The Taylor series coefficients are developed using exact recursion formulas, which are implemented via symbolic manipulation software. In addition, different time transformations are studied in order to obtain an adapted discretization for the CRTBP. The resulting propagation method is compared to traditional numerical integration methods.

9:40 **Morning Break**

10:00 **AAS 14-238** **Near Optimal Feedback Guidance Design and the Planar Restricted Three-Body Problem**
Joseph Dinius, University of Arizona; Roberto Furfaro, The University of Arizona; Francesco Topputo, Politecnico di Milano

In this paper, we present the application of the ZEM/ZEV guidance algorithm to the planar restricted three-body problem (PR3BP). The ZEM/ZEV guidance law as a feedback guidance strategy is presented and applied to the PR3BP. The fuel optimal solution to the PR3BP for a transfer from GTO to L1 in the Earth-Moon system is presented as a point for comparison. Comparisons are made between the fuel optimal and closed-loop trajectories, showing the near optimality of the closed-loop guidance approach. Challenges of the approach and strategies for implementation in spacecraft mission design are discussed.

10:20 **AAS 14-239** **Novel Solar Sail Mission Concepts for Space Weather Forecasting**
Jeannette Heiligers, Advanced Space Concepts Laboratory, University of Strathclyde; Colin McInnes, Advanced Space Concepts Laboratory, University of Strathclyde

This paper proposes several novel solar sail mission concepts for space weather forecasting. These include, among others, exploiting the invariant manifolds of solar sail Halo orbits around sub-L1 points, i.e. equilibrium points Sunward of the classical L1-point. By choosing the correct orbital geometry and manifold insertion point, particular manifolds stay close to the Sun-Earth line while travelling upstream of coronal mass ejections, thereby significantly increasing the warning time for solar storms over existing infrastructure at the classical L1-point. By assuming NASA's Sunjammer solar sail performance, these concepts are all feasible in the near-term.

10:40 **AAS 14-240** **[A Mission Profile Utilizing Sun-Earth Libration Points And Double Lunar Swingby Maneuvers For Efficient Travel To Multiple Solar System Destinations]**

Nathan Mogk, University of Arizona; David Dunham, KinetX, Inc.; Roberto Furfaro, The University of Arizona

This paper proposes a mission profile where a transfer vehicle is parked in a halo orbit near the Sun-Earth L1 libration point, then utilizes an unstable manifold trajectory to set up a double lunar swingby sequence, which will precess the line of apsides to align with the lowest energy transfer to a specified destination. This paper proposes a method of solving such trajectories to multiple destinations using a genetic algorithm approach to global optimization, and multiple-shooting to quickly identify a near-optimal solution for the chosen time and destination.

11:00 **AAS 14-241** **[Using Lunar Swingbys And Libration-Point Orbits To Extend Human Exploration To Mars]**

John Kidd, University of Arizona; Roberto Furfaro; David Dunham, KinetX, Inc.

For a viable program of exploration beyond the Moon international collaboration, like for the ISS, and reusable spacecraft will be needed. Additionally, using high-energy Earth orbits that can be drastically modified with lunar swingbys and small propulsive maneuvers, especially near the collinear Sun-Earth and Earth-Moon libration points will greatly reduce the propellant requirements of such missions. Specifically, the study will explore the use of highly-elliptical Earth orbits (HEOs) whose line of apsides can be rotated using lunar swingbys to achieve the escape vector necessary for such a mission.

11:20 **AAS 14-242** **Investigating the Optimization of Midcourse Maneuvers to Earth-Moon L2 Libration Orbit**

Jennifer Dowling, University of Colorado Boulder; Jeffrey Parker, University of Colorado

Baseline trajectories to an Earth-Moon L2 libration orbit for crewed missions have been created in support of an advanced Orion mission concept. Various transfer durations and orbit insertion locations have been evaluated. The trajectories often include a deterministic midcourse maneuver after a powered lunar flyby that decreases the overall change in velocity in the trajectory. This paper presents the application of primer vector theory to study the existence, location, and magnitude of the midcourse maneuver in order to understand how to build an optimal transfer to an L2 orbit.

SESSION 5: SPACECRAFT AUTONOMY

Session Chair: Fu-Yuen Hsiao, Tamkang University

13:30 **AAS 14-243** **Spinner Spacecraft Propulsion Model for MMS Flight Dynamics Applications**
Laurie Mann, NASA GSFC; Conrad Schiff, NASA GSFC; Henry Mulkey, NASA GSFC; Dean Chai, NASA GSFC

The Magnetospheric MultiScale Mission (MMS) consists of four spacecraft flying in highly eccentric orbits with the goal to further our understanding of Earth magnetic reconnection events. Throughout its two and a half year mission lifetime, the MMS spacecraft will perform about 200 maneuvers. This paper focuses on the flight dynamics propulsion model which is used to generate the Delta-V plan uploaded to the spacecraft. The purpose of this model is to ensure enough margins are allocated during the planning process so that the on-board controller does not significantly lag behind, potentially aborting the maneuver.

13:50 **AAS 14-245** **Orbit Control and Hovering In Asteroid Dynamical Environments using Higher Order Sliding Control Theory**
Roberto Furfaro, The University of Arizona

Close proximity operations around small bodies in general and asteroids in par-ticular are extremely challenging due to their uncertain dynamical environment. In this paper, we apply Higher Order Sliding Control (HOSC) theory to devise a class of 2-sliding homogeneous controllers that are suitable for autonomous or-bit control and hovering in highly uncertain dynamical environments typically founds around asteroids. The class of controllers that can be constructed using the theory are shown to be global finite-time stable against perturbations.

14:10 **AAS 14-246** **Fault Detection and Isolation Strategy for Redundant Inertial Measurement Units**
Renato Zanetti; Abran Alaniz, Draper Laboratory; Louis Breger, Draper Laboratory; Ian Mitchell, Draper Laboratory; Richard Phillips, Draper Laboratory

Aerospace vehicle are often required to be two-fault tolerant in order to be men rated. This paper presents a two-fault tolerant fault detection and isolation algorithm for a set of four redundant inertial measurement units (IMUs). The algorithm tests the IMU data twice after it is processed by two different infinite impulse response filters. The first filter has a lower cut-off frequency in order to detect biases and slowly growing biases. The second test is performed on the data filtered with a higher cut-off frequency in order to detect off-nominal abrupt changes in IMU errors.

14:30 **AAS 14-247** **Optimal Autonomous Pose and Trajectory Estimation for Lunar Orbiters Using Visible Camera**
Stoian Borissov, Texas A&M University; Daniele Mortari, Texas A&M University

This paper presents a method for optimal autonomous attitude and position (pose) estimation for spacecraft in lunar orbit, which may be used when a spacecraft loses communication with Earth. Using only on-board equipment, namely, a visible camera which has the capability of observing stars and the Moon's horizon in a single image, pose estimation is performed. The proposed method requires establishing the relative position between the Moon and stars using imaging. This information, along with spacecraft attitude, is enough for determining the pose of the spacecraft in inertial space.

14:50 **AAS 14-248** **Performance Evaluation of Artificial Neural Network-based Shaping Algorithm for Planetary Pinpoint Guidance**

Jules Simo, University of Strathclyde; Roberto Furfaro, The University of Arizona; Brian Gaudet, University of Arizona

Computational intelligence techniques have been used in a wide range of application areas. This paper proposes a new learning algorithm that dynamically shapes the landing trajectories, based on potential function methods, in order to provide computationally efficient on-board guidance and control. Extreme Learning Machine (ELM) devises a Single Layer Forward Network (SLFN) to learn the relationship between the current spacraft position and the optimal velocity field. Furthermore, the proposed efficient algorithm is tested in typical simulation scenarios which include a set of Monte Carlo simulation to evaluate the guidance performances.

15:10 **AAS 14-249** **Model Predictive Control And Extended Command Governor For Improving Robustness Of Relative Motion Guidance And Control**

Christopher Petersen, University of Michigan; Andris Jaunzemis, Georgia Institute of Technology; Morgan Baldwin, Air Force Research Laboratory; Marcus Holzinger, Georgia Institute of Technology; Ilya Kolmanovsky, University of Michigan

The paper describes two approaches to improving robustness of spacecraft relative motion guidance and control. The first approach is based on Model Predictive Control (MPC), and this paper demonstrates its capability for robust trajectory execution in a changing environment. The second approach uses an Extended Command Governor (ECG) that augments a nominal LQ controller. The ECG modifies commanded set-points to the inner loop LQ controller when it becomes necessary to avoid constraint violation. Simulations to compare the two approaches and experimental results, based on an omnibot system developed for validation of spacecraft relative motion control algorithms, are reported.

15:30 **Afternoon Break**

15:50 **AAS 14-250** **The Adaptive Entry Guidance Law Design Based on a New 3D Reachable Space Region Concept**

Erlong Su, Northwestern Polytechnical University; Jianjun Luo

A new three-dimension reachable space region concept for entry guidance subjects to path constraints is developed. The key factor is that this method transforms the path constraints such as heating rate, dynamic pressure and the g-load into control variable constraints which are bank angle and attack angle, obtaining a three-dimensional control variables space. Consequently the transformation can substantially simplify the complicity of entry guidance and trajectory design for without considering the path constraints. The adaptive guidance is also presented which can use the variables space to accomplish the design of entry guidance and terminal guidance integratively.

16:10 **AAS 14-251** **Semi-Analytical Guidance Algorithm for Autonomous Close Approach to Non-Cooperative Low-Gravity Targets**

Paolo Lunghi, Politecnico di Milano; Michele Lavagna, Politecnico di Milano; Roberto Armellin, University of Southampton

An adaptive guidance algorithm for close approach to and precision landing on uncooperative low-gravity objects (e.g. asteroids) is proposed. The trajectory, updated by means of a minimum fuel optimal control problem solving, is expressed in a polynomial form of minimum order to satisfy a set of boundary constraints from initial and final states and attitude requirements. Optimal guidance computation, achieved with a simple two-stage compass search, is reduced to the determination of two parameters, time-of-flight and initial thrust magnitude, according to additional constraints due to actual spacecraft architecture. A NEA landing mission case is analyzed.

16:30 **AAS 14-252** **Feedback And Iterative Learning Control With Disturbance Estimators**

Anil Chinnan, Columbia University; Minh Phan, Dartmouth College; Richard Longman, Columbia University

Iterative learning control (ILC) and feedback control (FBC) are fundamentally different in terms of their objectives and limitations. An iterative learning controller can compensate for unknown repeating errors and disturbances, but it is not suited to handle non-repeating errors and disturbances, which can be more effectively handled by a feedback controller. A combination of feedback and iterative learning controllers would be an ideal control strategy. This paper shows how a one-time step behind disturbance estimator and one-repetition behind disturbance estimator can be incorporated in such a feedback and iterative learning controller combination.

16:50 **AAS 14-253** **Idiosyncrasies In The Inverse Models Of Digital Skip Step Finite Time Systems**

Te Le, Columbia University; Richard Longman, Columbia University

Iterative learning control (ILC) iterates with the real world to find the command to a control system to produces zero tracking error for a specific trajectory. ILC can produce high precision tracking of fine pointing scanning maneuvers in spacecraft. Asking for zero error at sample times usually creates an unstable inverse problem. We use multiple zero order holds between addressed samples times to address this problem. But there are other anomalous singular values that cause difficulties to the inverse problem. These are seen to relate to zero error during transients. Suggestions of how to reduce their detrimental effects are given.

SESSION 6: NAVIGATION

Session Chair: Brian Page, KinetX Aerospace

13:30 **AAS 14-254** **Expected Performance of the Deep Space Atomic Clock Mission**
Todd Ely, NASA / JPL-CalTech; Jill Seubert, NASA / JPL-CalTech; Julia Bell, NASA / JPL-CalTech; David Murphy NASA / JPL-CalTech; Da Kuang, NASA / JPL-CalTech

The Deep Space Atomic Clock mission is developing a small, highly stable mercury ion atomic clock with an Allan deviation of less than 2e-14 at one day, with current estimates near 3e-15. This stability enables one-way radiometric tracking data with accuracy equivalent to or better than current two way tracking data; allowing a shift to a more efficient and flexible one-way deep space navigation architecture. The project is building a demonstration unit and payload that will launch in 2015 into Earth orbit. This study presents the preliminary estimates of the orbit and clock determination that the

13:50 **AAS 14-255** **The Evolution Of Deep Space Navigation: 1999-2004**
Lincoln Wood, NASA / JPL-CalTech

This paper is the third in a chronological sequence covering the evolution of deep space navigation from the early 1960s to the present. The time interval covered here extends from the 1999 launch of the Stardust spacecraft to comet P/Wild 2 through the arrival of the Cassini spacecraft at Saturn in 2004. The paper focuses on the observational techniques that have been used to obtain navigational information, propellant-efficient means for modifying spacecraft trajectories, and the computational methods that have been employed, tracing their evolution through eight planetary missions.

14:10 **AAS 14-256** **Navigation Filter Simulator Development For Small Body Proximity Operation**
Peter Lai, Globalstar Inc; David Bayard, NASA / JPL-CalTech

A simulator is developed to test a vision-based onboard navigation filter algorithm relevant to space exploration of small bodies such as asteroids and comets. The navigation filter algorithm was developed in earlier references and includes many data types relevant to small body proximity operations: Landmark Table, Paired Feature Table, and Range Measurement Table. The first two data types use vision-based camera measurements, while the third consists of multi-beam altimeter measurements. The paper presents the simulation architecture and test scenarios to validate the simulation code, along with the derivation of a range dependent measurement noise.

14:30 **AAS 14-257** **Extended and Unscented Kalman Filters for Spacecraft Close Proximity Relative Navigation**

Jacob Darling, Missouri University of Science and Technology; Kyle DeMars, Missouri University of Science and Technology; James McCabe, Missouri University of Science and Technology; Henry Pernicka, Missouri University of Science and Technology

Extended and unscented Kalman filters are implemented to estimate the relative position and velocity of a deputy spacecraft using two camera line-of-sight measurements from an inspector spacecraft. Additionally, the position, velocity, and attitude of the inspector spacecraft are estimated via dead reckoning of IMU data and external aiding from GPS and magnetometer measurements. Camera specifications, such as field-of-view and resolution, as well as camera baseline are investigated to determine their effects on each filter. The performance of the filters is compared through the achievable tracking accuracy.

14:50 **AAS 14-259** **Performance Evaluation of the Target-star Angles based Relative Navigation Method**

Kai Wang, Beihang University; Shijie Xu, Beihang University

This paper investigates the performance of a relative navigation method for far or medium range rendezvous. The measurement information contains target-star angels and relative range. To analyze the influence of the amount of reference stars, six groups of Monte Carlo simulations with different amounts of pseudo reference stars and different opening angles are undertaken. The error distributions of the relative bearings on the imag-ing sensor's focal plane are also computed. The comparison indicates that the relative navigation method using three reference stars has a better error distribution and therefore performs better than that using two stars.

15:10 **AAS 14-260** **Finite-Time Observer For Rigid Spacecraft Motion Over An Asteroid**

Daero Lee, New Mexico State University; Amit Sanyal, New Mexico State University; Eric Butcher, New Mexico State University; Daniel Scheeres, University of Colorado

A finite-time observer design for translational and rotational motion states of a rigid body modeled for a spacecraft and the parameters of an asteroid is presented. This nonlinear observer presents almost global finite-time convergence using the state measurements of the rigid spacecraft's pose and velocities. The finite-time convergence of the state and parameter estimations of the observer is verified using a Lyapunov analysis on the nonlinear state space of the motion. Numerical simulation results confirm this analytically obtained convergence property and the robustness in the presence of measurement noises and the noise in the dynamic model.

15:30 **Afternoon Break**

15:50 **AAS 14-262** **A Novel Angles-only Relative Navigation Algorithm for Autonomous Rendezvous with Space Non-Cooperative Target**

Baichun Gong, Northwestern Polytechnical University; Jianjun Luo; Jianping Yuan; Erlong Su

A novel angles-only relative navigation algorithm for rendezvous to non-cooperative target using GPS and CCD is presented in this paper. Recursive formulas of relative distance is derived from the differential between GPS positioning information at two different epochs based on triangle principle, aided by an initial imprecise relative distance from exterior. Then, the navigation model is established, and the PCSR-EKF filter is selected to process angles and relative distance to estimate the relative states. The proposed algorithm was tested by simulations, while its robustness to the error of initial relative distance was evaluated by Monte Carlo method.

16:10 **AAS 14-263** **Navigation Design and Analysis for the Orion Earth-Moon Mission**

Renato Zanetti; Christopher D'Souza, NASA - Johnson Space Center

This paper details the design of the cislunar optical navigation system being proposed for the Earth-Moon (EM) missions. In particular, it presents the mathematics of the navigation filter. It also presents the analysis that has been performed to understand the performance of the proposed system, with particular attention paid to entry flight path angle constraints and the DV performance.

16:30 **AAS 14-244** **Solar and Thermal Radiation Pressure Models & Flight Evaluation for IKAROS Solar Sail**

Jozef van der Ha, Consultant; Yuya Mimasu, Japan Aerospace Exploration Agency; Yuichi Tsuda, Japan Aerospace Exploration Agency; Osamu Mori, Japan Aerospace Exploration Agency

This paper gives an evaluation of the solar and thermal radiation accelerations acting on the IKAROS solar sail and spacecraft body during its operational mission from June to December 2010. In particular, the predicted temperatures are compared with actual in-flight measurements on the membrane and on the body. The results show fairly good correspondences in most cases, but also appreciable deviations have been observed. The results confirm that the magnitude of the thermal radiation perturbations on the trajectory is about one percent of the solar radiation and may be neglected in view of uncertainties in the solar radiation force.

Session 7: Trajectory Design I

Session Chair: Yanping Guo, Johns Hopkins University Applied Physics Laboratory

13:30 AAS 14-265 Forced Precession Orbit Departing from Keplerian Orbit under Continuous Normal Thrust

Jing Cao, Northwestern Polytecnical University; Jianping Yuan; Yong Shi; Jianjun Luo; Erlong Su Zhang Zhiguo, Tsinghua University

A novel non-Keplerian orbit termed forced precession orbit under continuous normal thrust is proposed motivated by the precession of gyroscope. The orbits departing from general Keplerian orbits are studied. With quaternion description, orbital motion in the circular case can be solved analytically, while it cannot in the elliptical case. Numerical analysis and Floquet theory are employed to capture the motion characteristics in the elliptical case. Results show that the forced precession orbit in the circular case is a displaced orbit, while that in the elliptical case exhibits a quasi-bird's nest geometry with upper and lower circular boundaries.

13:50 AAS 14-266 Optimal Impulsive Rendezvous with Terminal Tangent Burn Between Elliptic and Hyperbolic Orbits Considering the Trajectory Constraints

Wenbo Zhang, Beijing Institute of Technology; Yue Chen, Beijing Institute of Technology; Xin Sui; Ningfei Wang

The cycler orbit is an important trajectory for the human exploration of Mars, since it repeatedly encounters Earth and Mars on a regular schedule without stopping. The Aldrin cycler is the simplest circulating orbit between Earth and Mars. There are two types of spacecraft in the cycler architecture. One is the interplanetary transfer vehicle; the other is the "taxi" vehicle which travels between the surface of Earth or Mars and the transfer vehicle. Thus, the taxi must rendezvous with the transfer vehicle which is on a hyperbolic trajectory during the planetary flyby. The optimal problem that two or three impulsive rendezvous with terminal tangent burn between elliptic and hyperbolic Orbits are solved for cycler architecture.

14:10 AAS 14-267 Design of End-to-End Trojan Asteroid Rendezvous Tours Incorporating Potential Scientific Value

Jeffrey Stuart, Purdue University; Kathleen Howell; Roby Wilson, NASA / JPL-CalTech

The Sun-Jupiter Trojan asteroids are celestial bodies of great scientific interest as well as potential resources for long-term human exploration of the solar system. Previous investigations have addressed the automated design of end-to-end tours from the Earth to the rendezvous sequence within the asteroid swarm. The automated scheme is now expanded by incorporating a relative importance metric assigned to each asteroid such that potentials tours can be readily ranked by an overall accumulated merit. Computational aspects of the design procedure are automated such that end-to-end trajectories are generated with a minimum of human interaction.

14:30 **AAS 14-269** **Explore Europa by the Jovian Magnetic Lorentz Force**
Zhang Zhiguo, Tsinghua University; Gong Shengping; Li Junfeng

The Lorentz force is used to design Europa tour mission. A special bang-bang charge control is used to transfer the satellite from the L2 point of Jupiter-Gamymede to the new L2 point of Jupiter-Europa, and it takes less than 30 days to achieve the mission goal with q/m less than 0.5C/kg. A new strategy is used to solve the endgame problem at the new L2 point, where the satellite itself separates into two parts. One speeds up to form an eight-shaped Lissajous orbit, and the other is controlled to enter the Europa orbit.

14:50 **AAS 14-270** **Autonomous Trajectory Redesign for Phobos Orbital Operations**
Eric Trumbauer, University of California, Irvine; Benjamin Villac, University of California, Irvine

Orbital operations at Phobos will likely involve switching between different orbit families in an unstable environment. Due to the very rapid divergence from reference trajectories, autonomous action has been seen to be a necessary component of such a mission. A heuristic search and sequential convex programming based redesign tool adapted to this case is demonstrated to be able to re-plan or correct important transfers in a rapid and robust manner, even with very large perturbations to the expected initial conditions. Changes to earlier approaches are detailed, as well as challenges specifically posed by Phobos.

15:10 **AAS 14-271** **A Framework For Exporting Ballistic Orbits Across Dynamical Models. Application to Initial Guess Generation for High Fidelity Optimizers**
Benjamin Villac, University of California, Irvine

Many academic studies in spaceflight dynamics rely on simplified dynamical models, such as restricted three-body models or averaged equations of motion of an orbiter. To use the results generated in these models as good initial guesses for high-fidelity trajectory optimization tools, such as Mystic, these need to be transformed into more realistic models. This paper reviews and extends some of the approaches used in the literature to perform such a task, with a view toward automation for the case of ballistic orbits. Sample test cases are presented to illustrate the inherent trade-offs of such a process.

15:30 **Afternoon Break**

15:50 **AAS 14-272** **Automated Patch Point Placement for Spacecraft Trajectory Targeting**
Kathleen Howell; Amanda Haapala, Purdue University; Galen Harden; Belinda Marchand

The ultimate goal of autonomous, onboard trajectory design motivates this investigation. Given a dynamical environment consistent with the circular restricted problem, two types of differential correctors are employed with multiple-segment trajectories subject to continuity and other constraints. The relationship between Local Lyapunov Exponents (LLEs) and the convergence behavior of parallel shooting targeters is explored, then formalized in terms of an error prediction model. An automated patch point placement algorithm is developed and demonstrated in simple design examples. The placement algorithm is not limited to this framework, but is applicable for various dynamical and error models.

16:10 **AAS 14-273** **A Continuation Method to Transition Simplified Trajectories to Higher Fidelity Dynamical Models**

Nicholas Bradley, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin

A method is introduced to transition space trajectories from low to high fidelity dynamical systems, such as from patched conics or three-body models to full ephemeris models. The algorithm begins with a feasible trajectory in a simplified model and progressively re-converges in systems with incrementally higher fidelities. The intermediate models are related and made continuous and differentiable through the use of a continuation parameter that is linearly tied to various model parameters. Trajectories may include gravity assists and rendezvous with any number of target bodies, so the method is ideal for constructing tour missions to small bodies.

16:30 **AAS 14-274** **Three Problems in Space Flight Mechanics Solved Using the Multipoint Pontryagin's Maximum Principle**

Alan Zorn, Stanford University; Matt West, University of Illinois

A new result in nonlinear optimal control is used to solve three problems in space flight mechanics. Each problem has been previously solved by other au-thors using different methods. It is shown that our method provides a unified theory to solve these different problems. Our theory also suggests interesting and useful variations and extensions of these problems that have hitherto been posed or solved.

SESSION 8: ASTEROID RETRIEVAL AND MITIGATION

Session Chair: Anastassios Petropoulos, Jet Propulsion Laboratory

13:30 **AAS 14-275** **Interplanetary Superhighways: Cheaper Roads To Deflect Apophis**
Reza Raymond Karimi, Texas A&M University; David Hyland, Texas A&M University

The Apophis Exploratory and Mitigation Platform (AEMP) concept was developed as a prototype mission to explore and potentially deflect the Near Earth Asteroid (NEA) 99942 Apophis. Deflection from a potential 2036 impact will be achieved using a gravity tractor technique, while a permanent deflection, eliminating future threats, will be imparted using a novel albedo manipulation technique. This mission would serve as an archetypal template for future missions to small NEAs and could be adapted to mitigate other potential Earth-crossing objects. The trajectory of the spacecraft will be designed based on the interplanetary Superhighways concept.

13:50 **AAS 14-276** **What Does it Take to Capture an Asteroid? A Case Study on Capturing Asteroid 2006 RH120**
Hodei Urrutxua, Technical University of Madrid (UPM); Daniel Scheeres, University of Colorado; Claudio Bombardelli, Technical University of Madrid (UPM); Juan Luis Gonzalo, Technical University of Madrid (UPM); Jesus Pelaez, Technical University of Madrid (UPM)

The population of temporarily captured asteroids offers attractive candidates for asteroid retrieval missions. Once captured, these asteroids have lifetimes ranging from a few months up to several years in the vicinity of the Earth. One could potentially extend the duration of such temporary capture phases by acting upon the asteroid with slow deflection techniques. In this paper we present a case study on asteroid 2006 RH120, which is the single known member of this category, and study what it would have taken, in terms of thrust level and total delta-V, to prolong its temporary capture phase.

14:10 **AAS 14-277** **Asteroid Retrieval via Direct Launch and Solar Electric Propulsion**
Jacob Englander, NASA Goddard Space Flight Center; Eric Cardiff

This paper discusses a spacecraft design concept and mission optimization for missions to 12 different asteroids. Mission concepts with different electric propulsion systems were considered for optimization by the Evolutionary Mission Trajectory Generator (EMTG) code. The optimization was conducted to find the latest possible launch to reach said asteroids using engine models with both variable thrust and specific impulse. A range of propulsion systems, powers, launch vehicles, and target asteroids were studied. Results are presented for the required trajectories and the required propellant.

14:30 **AAS 14-278** **Comprehensive Modeling of the Effects of Hazardous Asteroid Mitigation Techniques**

Daniel Scheeres, University of Colorado; Claudio Bombardelli, Technical University of Madrid (UPM); Brandon Jones, University of Colorado, Boulder; Jay McMahon, University of Colorado

A plan and initial progress towards a program of fundamental research on the modeling of hazardous asteroid mitigation is described. This work focuses on computational modeling of outcomes from previously developed asteroid mitigation techniques. Our goal is to evaluate these techniques accounting for the expected and predicted range of asteroid geophysical and dynamical properties. This work defines a necessary and fundamental step for the design and evaluation of future mitigation experiments and attempts. It also enables the identification of necessary technology for the detection of mitigation outcomes to use as a fundamental metric in our models and evaluations.

14:50 **AAS 14-279** **Robust Deflection Strategies of Near Earth Asteroids under Uncertainties**

Mai Bando, Kyushu University; Yuki Akiyama; Shinji Hokamoto, Kyushu University

In this paper, an approach to optimize deflection mission of Near Earth asteroids under uncertainty is proposed based on control theoretical framework. By using the nonlinear mapping from initial deviation to the final deviation, the performance index J which is expressed as a function of the distance of the Earth in the Earth's closest approach time is minimized for the worst case initial condition. We also formulate the robust orbital transfer problem of kinetic impactor spacecraft where the initial state estimation error exists.

15:10 **AAS 14-280** **Asteroid Target Selection And Orbital Manipulation Innocuity For Deflection Demonstration Missions**

Joan Pau Sanchez Cuartielles, Department of Applied Mathematics I, Universitat Politecnica de Catalunya, Barcelona, Spain

With the possibility of near term asteroid deflection demonstration missions in mind, the paper seeks further insight into the optimality of the target selection: Instead of focusing on the asteroid's accessibility, the safety of its orbital manipulation is analyzed. It is generally stated that Amor asteroids are ideal targets for orbital manipulation demonstration missions because they do not cross the orbit of the Earth. This notion is revised by comparing accessibility, orbital likelihood of different NEO families and natural evolution of the asteroid's MOID, as well as the evolution as a consequence of the manipulation of its orbit.

15:30 **Afternoon Break**

15:50 **AAS 14-281** **Suborbital Intercept and Fragmentation of Asteroids with Very Short Warning Time**

Ryan Hupp, Asteroid Deflection Research Center, Iowa State University; Spencer Dewald, Asteroid Deflection Research Center, Iowa State University; Bong Wie, Iowa State University

The threat of an asteroid impact with a very short warning time is a very real danger, yet no countermeasures exist. The utilization of a modified ICBM to deliver a nuclear or kinetic payload on a suborbital interception trajectory is explored in the paper. This paper focuses on determining the trajectory needed to maximize the altitude of intercept. A hypothetical asteroid impact scenario is proposed as an example for calculating simplified trajectory models. It is shown that silo-based missiles with realistic burnout velocities can achieve meaningful intercept at reasonably high altitudes.

16:10 **AAS 14-283** **Low-Thrust Trajectory Optimization for Asteroid Redirect Missions**
Sam Wagner, Iowa State University; Bong Wie, Iowa State University

Recent advances in solar electric propulsion (SEP) systems are stimulating a renewed interest in low-thrust interplanetary missions. Such interest includes, NASA's Asteroid Redirect Mission (ARM), which is a robotic mission concept using an Asteroid Redirect Vehicle (ARV) equipped with a high-power (40-kW class) SEP system, with the goal of returning a small (~7m diameter, 500 ton) asteroids to cis-lunar space. This paper describes an efficient optimization algorithm that employs a hybrid optimization solver (Evolutionary combine with traditional calculus base programming), capable of optimizing both high and low thrust missions.

16:30 **AAS 14-284** **Capture and Storage Orbit Options for an Asteroid Redirection Mission**
Damon Landau, NASA / JPL-CalTech

Recent studies have demonstrated the feasibility of nabbing a 100t to 1000t asteroid and returning it to the vicinity of Earth with a 40kW solar electric propulsion system. Once near Earth, there are many options for how to gravitationally capture and store the object for eventual exploration by astronauts. The orbital families to be considered include Earth-Moon Lagrange points, Sun-Earth Lagrange points, weakly captured lunar and Earth orbits, elliptical orbits around Earth or the Moon, and Earth or lunar distant retrograde orbits. These options are compared on the basis propellant required, transfer time, orbital stability, and crew accessibility.

16:50 **AAS 14-285** **Nuclear Explosion Energy Coupling Models for Optimal Fragmentation of Asteroids**
Pavithra Premaratne, Iowa State University

This paper examines both Tillotson and Jones-Wilkins-Lee (JWL)based energy coupling models, that are often used by various hydro-codes for simulating the effects of high energy explosives. A subsurface nuclear explosion has been known to be 20 times more efficient than a contact burst. Both in-house and commercial AUTODYN hydro-codes are used to validate such a known high efficiency factor of subsurface nuclear explosions. Our preliminary study results indicate an energy coupling efficiency factor of only 10, which might have been caused by some inherent modeling deficiencies.

SESSION 9: ORBIT DETERMINATION I

Session Chair: Laureano Cangahuala, Jet Propulsion Laboratory

8:00 **AAS 14-286** **Second Order Nonlinear Initial Orbit Determination For Relative Motion Using Volterra Theory**

Brett Newman, Old Dominion Univ.; Ethan Pratt, Old Dominion University; Thomas Lovell, Air Force Research Laboratory

Application of Volterra multi-convolution theory to the nonlinear circular relative motion initial orbit determination problem is considered. A series of angular measurements locating the deputy with respect to the chief are coupled through geometry with an analytic second order solution for relative motion in terms of linear, quadratic, and bilinear combinations of the initial conditions. The resulting set of nonlinear measurement equations are analyzed and solved in various ways. Methods range from direct solution of the nonlinear equations to reformulation as an equivalent set of linear equations with constraints solved by matrix decomposition and computation of an unknown scaling

8:20 **AAS 14-287** **Sequential Orbit Determination Using Satellite Laser Ranging**

David Vallado, Center for Space Standards and Innovation; John H. Seago, Analytical Graphics, Inc.; James Woodburn, AGI; Florent Deleflie, IMCCE

Satellite Laser Ranging (SLR) is an extremely precise method of tracking satellites that is publicly available. The Orbit Determination Toolkit (ODTK) from Analytical Graphics Inc. (AGI) approaches precision orbit determination using a Kalman-like filter in combination with different methods of smoothing, an approach requiring parameters that are not generally specified by batch-type estimation. The relevant features accounted for in SLR orbit generation are summarized. ODTK ephemerides are then compared against definitive orbits from ILRS Analysis Centers to understand the accuracy achieved via the particular setup used, and statements are made concerning relative accuracy and the cause of any

8:40 **AAS 14-288** **Preliminary Determination of the Geocentric Earth Flyby Path of Asteroid 2012 DA14**

Roger L. Mansfield, Astronomical Data Service

A method of initial orbit determination (IOD) is presented for use with short arcs of deep-space, angles-only observations. It is then used to determine the Earth flyby path of the asteroid 2012 DA14 on 2013 February 15. The method uses all of the available observations in the arc, not just three, as with classical IOD methods. It is modular with respect to the Lambert solution, in that any of the Lambert solutions of Gauss, Battin, Gooding, or Der could be incorporated. But for the asteroid example at hand, a Lambert solution of Gauss, with some modifications, is employed.

9:00 **AAS 14-289** **Convergence Behavior of Series Solutions of the Lambert Problem**
James Thorne, IDA

Lambert's problem, to find the unique conic trajectory that connects two points in a spherical gravity field in a given time, is represented by a set of transcendental equations due to Lagrange. Power series have been published that reverse the functionality of the Lagrange equations to provide direct expressions for the unknown semi-major axis as an explicit function of time. The convergence behavior of the series solutions is examined over the range of possible transfer angles and flight times. The effect of arbitrary precision calculations is shown on the generation of the series coefficients.

9:20 **AAS 14-294** **Bezier Description of Space Trajectories**
Francesco de Dilectis, Texas A&M University; Daniele Mortari, Texas A&M University; Renato Zanetti

Bezier curves are highly versatile polynomial curves that can be used to estimate a spacecraft trajectory based solely on measurements taken with optic sensors mounted on board. These measurements, weighed accordingly to their accuracy, determine the control points of the curve via a least square best fitting approach. This approach has the advantage of being independent from the problem's physics, thus giving it great generality. Several types of trajectories are simulated, and artificial noise is superimposed to the measurements. The results are compared with an Extended Kalman Filter and Unscented Kalman Filter.

9:40 **Morning Break**

10:00 **AAS 14-290** **A New Approach To Gaussian Initial Orbit Determination**
Stefano Casotto, Universita' di Padova

Gaussian IOD is based on the sector-to-triangle ratio, which incorporates the dynamical information associated with Keplerian motion, generating highly nonlinear equations. These equations are usually separated into two sets and solved iteratively in a two-level scheme. A more straightforward attack on the solution is better sought by directly solving the full system of nonlinear equations. It will be shown how a 9D system of equations (nine equations in nine unknowns) can easily be established, and that further analysis reduces this system to a 6D system, and finally to a 5D system.

10:20 **AAS 14-291** **Space-Time Coordinate Systems In The High-Precision Orbit Prediction**
Lu Deng, Beihang University; Qinqin Luo; Hongli Zhang, Beihang University; Yinrui Rao; Chao Han, Beihang University

In the application of spacecraft, there are two basic coordinate systems: celestial system and geocentric system. With the rapid development of observation techniques, the model of these two basic coordinate systems has grown increasingly accurate in recent years. How to choose efficient coordinate systems and their conversion according to different mission requirement in the orbit prediction is a problem. This paper summarized concepts and conversion methods consist with the International Astronomical Union (IAU) and the International Earth Rotation Service (IERS), applied the corresponding conversion to orbit prediction and compared and analyzed the results conducted under J2000 and WGS-84.

10:40 **AAS 14-292** **Initial Relative Orbit Determination Using Multiple LOS Measurements and Gaussian Mixture Models**

Keith LeGrand, Missouri University of Science and Technology; Kyle DeMars, Missouri University of Science and Technology; Henry Pernicka, Missouri University of Science and Technology

Unobservability of space-based angles-only orbit determination can be mitigated by including angle measurements from a second optical sensor. Previous approaches have used stereoscopic angles to triangulate a second satellite's position. Due to triangulation nonlinearities, zero-mean Gaussian noise cannot be assumed. In this work, the uncertainty of both angle measurements is used to bound the possible positions of the second satellite. Uniform uncertainty is approximated over these bounded regions at two times using Gaussian mixtures. Linkage of the mixtures is performed using a Lambert solver to formulate a full state uncertainty for use in a Bayesian filter.

11:00 **AAS 14-293** **A Second Order Method for Initial Relative Orbit Determination Using Angles Only Observations**

Ethan Pratt, Old Dominion University; Thomas Lovell, Air Force Research Laboratory; Brett Newman, Old Dominion University

An analytical solution procedure for recovering a deputy satellite's initial Cartesian states relative to a chief satellite assuming planar motion and a circular chief orbit is investigated. Line-of-sight observations coupled with a second order solution for the deputy motion based on Volterra convolution theory leads to a set of nonlinear measurement equations. Relations are converted to a linear formulation with constraints, where a matrix decomposition and computation of an unknown scaling factor are required. Performance of the initial relative orbit determination procedure is evaluated with computer simulation.

11:20 **AAS 14-295** **Orbit Determination for the Low-thrust spacecraft**

Tsutomu Ichikawa, Japan Aerospace Exploration Agency (JAXA)

There are interplanetary mission by using continuously Low-thrust system instead of impulse thrust system. This paper is described Earth-based orbit determination capability for the low-thrust spacecraft in the light of recent developments both in a few station tracking concepts and in the thrust subsystem error modeling. Both suboptimal and optimal orbit determination performance are determined for a wide range of process noise parameter values. The tracking techniques are found to be extremely effective, reducing orbit determination errors by orders of magnitude over that obtained with conventional single-station tracking.

SESSION 10: ATTITUDE DETERMINATION AND SENSORS

Session Chair: Carolin Frueh, Texas A&M University

8:00 **AAS 14-297** **Mapping to Compensate Radial Geometrical Distortion in Pin-hole Cameras**
Daniele Mortari, Texas A&M University; Martin Avendano, University of Zaragoza

Geometrical radial distortion by a pin-hole camera is usually corrected by Brown's distortion model. This model approximates the correction of the radial distortion by a truncated polynomial in terms of radius. In this paper, an analysis of various mapping methods is provided and comparisons are made to quantify the best mapping for pin-hole cameras to identify lines and/or circles. Motivations come from the fact that many features extracting algorithms mistakenly use direct image coordinates and do not take into account the radial distortion.

8:20 **AAS 14-298** **Adverse Effects of Satellite Magnetic Field on Magnetometer Measurements and Methods of Compensation for Compact Satellites**
Sharan Asundi, Tuskegee University; Todd Bonalsky, NASA Goddard Space Flight Center; Paul Mason, NASA Goddard Space Flight Center

For pico and nanosatellites with magnetic actuators, their magnetic field distribution is changing and adversely affecting the magnetometers. This study investigates the design and compensation approaches to address these adverse effects. In particular, the use of a dual-magnetometer configuration to simultaneously acquire measurements, provide a continuous estimate of the Earth and satellite magnetic field, will be analyzed. The approach is based on the approximation that (i) the external field is spatially uniform and (ii) the magnetic field measurements due to the satellite vary, across these two magnetometers.

8:40 **AAS 14-299** **Approximate Constrained Time-Optimal Reorientation Maneuvers Using Covariance Matrix Adaptation-Evolutionary Strategy**
Robert Melton, The Pennsylvania State University

The CMA-ES method is applied directly to the constrained satellite reorientation problem. This method is shown to give a very good approximate optimal solution to the unconstrained problem. The paper examines the performance for the constrained problem, and considers a modification that removes the eigendecomposition step in the early stages of the iteration to achieve greater computational speed.

9:00 **AAS 14-300** **Gyro-Free Rigid Body Attitude Stabilization using only Vector Measurements on SO(3)**
Divya Thakur, The University of Texas at Austin; Maruthi Akella, The University of Texas at Austin

Attitude stabilization of a rigid body is considered for the case when only a set of unit vector measurements is available for feedback. In particular, we assume that no angular velocity information is available for control formulation. A novel control scheme is proposed for stabilizing the rigid body's orientation to the desired configuration by using vector measurements directly for feedback. The control law does not rely on the estimated attitude vector or rate gyro measurements, and is formulated on the special orthogonal group SO(3). Thorough convergence and stability analysis is provided and the results are validated with simulations.

9:20 **AAS 14-301** **RSO Attitude Estimation via LIDAR Altimetry and a Particle Filter**
Brian Gaudet, University of Arizona; Roberto Furfaro, The University of Arizona; Bogdan Udrea, Embry-Riddle Aeronautical University

Given a point cloud of an RSO and a spacecraft with a scanning LIDAR, we need to determine the relative position, velocity, attitude, and rotational velocity between the spacecraft and the RSO. For this initial work, we assume that the relative position and velocity are known, and use a Rao-Blackwellized particle filter to infer the relative attitude and rotational velocity. We demonstrate via simulation that this approach can accurately estimate a RSO's attitude.

9:40 **Morning Break**

10:00 **AAS 14-302** **Memory Adaptive k-vector**
Daniele Mortari, Texas A&M University

This paper present two new enhancements of the k-vector range searching technique. The first one shows how to implement the k-vector range searching technique with any size of available memory. This enhancement is particularly suitable for on-board space implementation where memory available is limited and for ground applications when the database is strongly nonlinear. The more memory is available the faster the k-vector is. The second new feature is related to database with invariant number of elements whose values are changing. Performance analysis for these two new techniques is provided.

10:20 **AAS 14-303** **Shape, Surface Parameter, and Attitude Profile Estimation using a Multiple Hypothesis Unscented Kalman Filter**
Jack Wetterer, Integrity Applications Inc; Bobby Hunt, Pacific Defense Solutions; Kris Hamada, Pacific Defense Solutions; John Crassidis, University at Buffalo, State University of New York; Paul Kervin, Air Force Research Laboratory

Multiple hypothesis testing using an underlying Unscented Kalman Filter (UKF) to estimate state parameters has been previously demonstrated where the state includes the attitude, angular rate, position, velocity, and surface parameters of the space object. This algorithm is extended to include multiple components, and multiple bandpasses. An example scenario is presented where the models are proxy geostationary Earth orbit (GEO) satellites with different bus configurations (e.g. cylinder vs. rectangular prism) and in different controlled states (e.g. nadir-tracking vs. inertial).

10:40 **AAS 14-304** **Assessment of the Adaptive Angular Velocity Estimator**
Francesco de Dilectis, Texas A&M University; Daniele Mortari, Texas A&M University

An angular velocity estimating technique for spacecraft with no gyros is discussed and compared with established estimators such as various Kalman filters. The technique is based on defining an Ortho-Skew matrix related to the orientation quaternion, and analyze the evolution of its eigenvalues. This estimator is tested against a simple single point technique, a standard Kalman filter and a Multiplicative Kalman Filter.

11:00 **AAS 14-305** **Catalog-free angular rate estimation and on-line detection of resident space objects**

Brad Sease, Virginia Polytechnic Institute and State University; Brien Flewelling, Air Force Research Laboratory; Yunjun Xu, University of Central Florida

Star tracker systems are typically limited by the angular rates at which they operate due to the tendency for stars to streak across the image plane. Due to this limitation, spacecraft relying primarily on feedback from a star tracker must either perform rate-limited maneuvers or rely on secondary sensor systems during the maneuver. Building on previous work which produced two attitude estimates from a single streaked star image, an algorithm is proposed which removes the need for a star catalog to provide rate-only estimates. Additionally, it becomes possible to identify some non-star behavior with minimal additional processing.

11:20 **AAS 14-306** **Application Of The Extended H Infinity Filter For Attitude Determination And Gyro Calibration**

William Silva, Instituto Nacional de Pesquisas Espaciais; Helio Kuga, Instituto Nacional de Pesquisas Espaciais; Maria Zanardi, Universidade Estadual Paulista

This work describes the attitude determination and the gyros drift estimation using the Extended H-infinity Filter for nonlinear systems. The application uses measurement data of a real satellite CBERS-2. The attitude dynamical model is described by nonlinear equations involving the Euler angles. Actually, the extended H-infinity filter provides a rigorous method for dealing with systems that have model and noise uncertainties. The results in this work show that one can reach accuracies in attitude determination within the prescribed requirements, besides providing estimates of the gyro drifts which can be further used to enhance the gyro error model.

11:40 **AAS 14-307** **Bilinear Observer/Kalman Filter Identification**

Francesco Vicario, Columbia University; Raimondo Betti, Columbia University; Richard Longman, Columbia University; Minh Phan, Dartmouth College

Bilinear systems can be viewed as a bridge between linear and nonlinear systems, providing a promising approach to handle various nonlinear identification and control problems, such as the satellite attitude control. This paper develops and demonstrates via numerical examples a method for bilinear discrete-time system identification in the presence of noise. The formulation relies on a stochastic bilinear observer with properties similar to the Kalman filter, and on a novel approach based on the estimate of the observer residuals. The resulting method represents the bilinear counterpart of the Observer/Kalman filter Identification (OKID) for linear systems distributed by NASA.

SESSION 11: LOW-THRUST TRAJECTORY DESIGN

Session Chair: Geoffrey Wawrzyniak, a.i. Solutions

8:00 **AAS 14-308** **Design resonant transfer orbit using Low-thrust v-infinity leveraging maneuver**
Shengping Gong, Tsinghua University; Zhang Zhiguo, Tsinghua University

Low-thrust is used to design the resonant leveraging transfer orbit in this paper. The resonant concept is updated as the orbit is not Keplerian orbit whose orbital parameters are changed with low-thrust continuously. Using a global search method we give the boundary conditions of leveraging maneuver and the indirect method through Pontryagin maximum principle is used to solve the low-thrust fuel optimal trajectories. The result indicates that low-thrust control maneuver is continuous thrust at apojove in many circles with less fuel consumption compared with the impulse maneuver in the same flight time.

8:20 **AAS 14-309** **Global Optimization of Low-Thrust, Multiple-Flyby Trajectories at Medium and Medium-High Fidelity**
Jacob Englander, NASA Goddard Space Flight Center; Donald Ellison, University of Illinois at Urbana-Champaign Aerospace Engineering Department; Bruce Conway, University of Illinois at Urbana-Champaign

Global optimization of low-thrust, multiple-flyby trajectories is one of the most challenging problems in interplanetary mission design. The challenge is to develop a method which can design a complex trajectory with little or no human oversight. In the last few years several authors have developed such methods. To date each of those methods required many simplifications of the low-thrust trajectory model in order to perform a global search. In this work a global optimization framework, the Evolutionary Mission Trajectory Generator (EMTG), is presented. A medium-fidelity model based on the well-known Sims-Flanagan transcription is

8:40 **AAS 14-310** **Analytical Partial Derivative Calculation Of The Sims-Flanagan Transcription Match Point Constraints**
Donald Ellison, University of Illinois at Urbana-Champaign Aerospace Engineering Department; Jacob Englander, NASA Goddard Space Flight Center; Martin Ozimek, The Johns Hopkins University Applied Physics Laboratory; Bruce Conway, University of Illinois at Urbana-Champaign

Many low-thrust trajectory optimizers make use of large-scale nonlinear programming (NLP) packages, such as SNOPT, to solve the parameter optimization problem resulting from a discrete transcription of a continuous optimal control problem. The algorithms used by these gradient-based optimizers rely on knowledge of the system Jacobian. While it is possible to calculate the Jacobian entries numerically using finite differencing, specifying them analytically results in more robust and efficient solver performance. We present methods for the calculation of exact analytical expressions for the partial derivatives of the match point constraints of the ``up-to-unit'' vector control variant

9:00 **AAS 14-311** **Automation of Multi-Revolution Low-Thrust Orbit Transfers Optimization via Differential Evolution**

Jose Manuel Sanchez Perez, ESA; Andrea Campa

This paper addresses the problem of many-revolutions low-thrust transfer in the two-body problem. The optimal control for the thrust direction is formulated as a two points boundary value problem applying Pontriagyn's principle. A novel technique has been developed using together averaging and continuation methods and the Differential Evolution algorithm in order to find automatically a sufficiently accurate initial guess that ensures the convergence of the optimization problem. This strategy has been successfully applied to several orbit transfers in order to solve the minimum-time problem and to obtain the Pareto front of minimum-propellant consumption problems.

9:20 **AAS 14-312** **Averaging Technic In T_3d An Integrated Tool For Continuous Thrust Optimal Control In Orbit Transfers**

Thierry Dargent, Thales Alenia Space

The averaging technique introduced in T_3D optimal control tool for satellite orbit transfer enable to solve orbit transfer problems with a large number of revolutions: minimum time transfer or minimum fuel transfer can be solved easily. The proposed technique keeps the time as independent variable and do not perform the classical exchange between time and longitude. This choice simplifies the link from averaged to non-averaged dynamics, it authorizes to perform rendezvous in mean longitude and it helps to exchange solution from averaged to non-averaged problem. Example will show the efficiency of the method on different satellite dynamics.

9:40 **Morning Break**

10:00 **AAS 14-314** **Low-thrust Trajectory Optimization in a Full Ephemeris Model**

Xingshan Cai

The low-thrust trajectory optimization with complicated constraints must be considered in practical engineering. This paper solves the fuel-optimal problem of low-thrust trajectory with complicated constraints in a full ephemeris model. First, it introduces the various perturbations, including a third body's gravity, the nonspherical perturbation and the solar radiation pressure in a dynamic equation. Second, it builds two types of equivalent inner constraints to describe the GA. At the same time, the present paper applies a suite of techniques, such as a homotopic approach, to enhance the possibility of convergence to the global optimal solution.

10:20 **AAS 14-315** **Preliminary Optimization Of Low-Thrust, Geocentric-to-Halo-Orbit, Transfers Via Particle Swarm Optimization**

Andrew Abraham, Lehigh University; David Spencer, The Pennsylvania State University; Terry Hart, Lehigh University

Particle Swarm Optimization (PSO) is used to optimize a low-thrust trajectory from a geocentric orbit to a Lagrange point orbit in the Earth-Moon system. Unlike a gradient based approach,this evolutionary PSO algorithm is capable of avoiding undesirable local minima. The PSO method is extended to a local version and uses a two dimensional search space that is capable of reducing the CPU run-time by an order of magnitude when compared with other published work. A technique for choosing appropriate PSO parameters is demonstrated and an example of an optimized trajectory is discussed.

10:40 AAS 14-317 Application of a Quaternion-Based Formulation to the Electric Orbit-Raising of GEO Satellites from High-Inclination Injection Orbits

Paola Libraro, Princeton University; Atri Dutta, Princeton University; Jeremy Kasdin, Princeton University; Edgar Choueiri, Princeton University

All-electric orbit-raising of GEO satellites allows for mass savings which can be used either to increase payload or reduce launch costs. We investigate the feasibility of injecting an all-electric satellite into a high-inclination orbit for two main reasons: lower radiation damage and higher solar exposure for the solar arrays (which reduces the time spent in eclipse and the mass requirements of an on-board energy storage system). We formulate the problem using a novel quaternion-based formulation of the eom and demonstrate the applicability of the novel set of nonsingular coordinates to the orbit-raising problem.

11:00 AAS 14-318 Classification of Time-Optimal Low to Medium-Acceleration Interplanetary Transfers

Jesse Campbell, University of California, Irvine; Benjamin Villac, University of California, Irvine

Anticipating advancements in low-thrust propulsion systems, this paper explores time-optimal interplanetary transfers made using constant acceleration, with magnitudes varying between today's best capabilities (e.g. NASA's NSTAR ion propulsion system, approximately 10^(-4) m/s^2) and local gravitational acceleration (approximately 10 m/s^2. Using optimal control methods, a database of trajectories is computed using two-dimensional polar coordinates and circular coplanar orbits, wherein various transfer families are identified and analyzed. Once classified, the database is interpolated to provide initial guesses for more realistic mission designs incorporating ephemeris data.

SESSION 12: ORBITAL DEBRIS

Session Chair: Thomas Starchville, The Aerospace Corporation

8:00 **AAS 14-319** **Prediction Accuracies of Draper Semi-analytical Satellite Theory in LEO and MEO Regime for Space Object Catalogue Maintenance**

Srinivas Setty, DLR/GSOC; Paul Cefola, University at Buffalo, State University of New York; Oliver Montenbruck, German Aerospace Center (DLR); Hauke Fiedler, German Aerospace Center (DLR)

In order to determine the obits of the tracked objects, and propagating and correlating them to maintain the space objects catalogue, it requires accurate and computationally efficient propagators. For this purpose, the Draper semi-analytical satellite theory which makes use of generalized method for averaging, is examined for its best possible fit with numerically generated orbits. Along with this, accuracy comparison with SGP4 theory and its computational efficiency are marked and presented.

8:20 **AAS 14-320** **Near-Earth orbit debris identification to secure future Earth-Moon trajectory mission**

Melissa Zemoura, Kyushu University; Toshiya Hanada, Kyushu University; Mitsunobu Okada, ASTROSCALE PTE. LTD.

This research aims to secure Earth-Moon travels for common people from 2045. Therefore, the capacity to predict the debris environment along this orbit is required. The idea is to identify the objects that may intersect the transfer orbit in 2045. Collision probability calculation gives the criterion to evaluate this degree of dangerousness in order to decide on the objects that must be removed. However, removal should be performed in advance, on the objects that generate the identified debris. Original debris removal baseline has been set as year 2020 to give enough time to conduct an effective debris remediation process.

8:40 **AAS 14-321** **Longitude-Dependent Effects of Fragmentation Events in the Geosynchronous Orbit Regime**

Paul Anderson, University of Colorado at Boulder; Hanspeter Schaub, University of Colorado

The effects of on-orbit fragmentation on localized debris congestion in each of the longitude slots of the geostationary (GEO) regime are investigated by simulating explosions of uncontrolled objects in various orbit configurations, including libration about one or both of the gravitational wells at 75E and 105W. Initial conditions are provided by publicly-available two-line element (TLE) sets, and fragmentation particulates are generated with the NASA Standard Breakup Model. Results indicate that long-term severity of fragmentation events is dependent on longitude at the epoch of fragmentation, which can spawn bi-annual "debris storms" in high-risk longitude slots.

9:00 **AAS 14-322** **Characterizing Localized Debris Congestion in the Geosynchronous Orbit Regime**
Paul Anderson, University of Colorado at Boulder; Hanspeter Schaub, University of Colorado

Forecasting of localized debris congestion in the geostationary (GEO) ring is performed to investigate how frequently near-miss events occur for each of the GEO longitude slots on a daily basis, and characterize the classes of uncontrolled objects that contribute the most to macroscopic debris congestion, both globally and in a longitude-dependent sense. The present-day resident space object (RSO) population is propagated forward in time to assess congestion conditions over a 5-year time frame, and the "congestion culprits" are identified to yield recommendations for active debris removal initiatives that seek to clean-up particular longitude slots.

9:20 **AAS 14-323** **Disposal Strategies for Spacecraft in Lagrangian Point Orbits**
Giuseppe Di Mauro, Dinamica Srl; Mirco Rasotto, Dinamica Srl; Roberto Armellin, Dinamica Srl; Pierluigi Di Lizia, Dinamica Srl; Markus Landgraf, European Space Agency

This work presents three different strategies for the disposal of Lagrangian Point Orbit (LPO) missions, which have been studied in the frame of the European Space Agency study "End-of-life disposal concepts for Lagrange-points and HEO missions". The first strategy concerns the injection into heliocentric graveyard orbits, the second option is to eliminate the spacecraft by an Earth's re-entry, and the third one analyzes a Moon's impact scenario. In this paper some optimized solutions for SoHO and Gaia missions are presented and ranked.

9:40 **Morning Break**

10:00 **AAS 14-324** **Analytical model for the propagation of small debris objects after a fragmentation event**
Francesca Letizia, University of Southampton; Camilla Colombo, Politecnico di Milano; Hugh Lewis, University of Southampton

Current debris environment models usually neglect fragments smaller than 10 cm in their predictions because of the high computational effort they add to the simulation, even if also small fragments can be dangerous to operational satellites. This work proposes an analytical method to describe the evolution of a cloud of fragments generated by a collision in Low Earth Orbit. The proposed approach considers the cloud globally and derives analytically its evolution in terms of density, under the effect of drag. As a result, the analytical approach allows representing small fragments and noticeably reducing the computational time.

10:20 **AAS 14-325** **End-of-life Earth re-entry for highly elliptical orbits: the INTEGRAL mission**
Camilla Colombo, Politecnico di Milano; Francesca Letizia, University of Southampton; Elisa Maria Alessi, IFAC-CNR; Markus Landgraf, European Space Agency

This article defines optimal strategies for the end-of-life Earth re-entry of spacecraft in highly elliptical orbits. The orbit evolution is computed through a semi-analytical averaging method, and the resonances between luni-solar perturbations and the Earth's oblateness are identified. A double-averaged approach and the theory on secular perturbations on highly inclined and eccentric orbits are applied. Then, numerical optimization is performed with a high-accuracy dynamics. The optimal maneuver and the true anomaly on the orbit where this is applied are computed for a wide range of end-of-life dates for INTEGRAL mission.

10:40 **AAS 14-326** **Orbital anomaly analysis to detect breakups in GEO**

Masahiko Uetsuhara, The Institute of Statistical Mathematics; Toshiya Hanada, Kyushu University

This study investigates abrupt orbital changes, i.e., orbital anomalies of the very old upper-stages Titan Transtages inserted into the geostationary orbit (GEO) region in 1960s and 1970s to find evidences of breakups. The product of the solar reflectivity (Cr) and the area-to-mass ratio (A/m) will be estimated before and after the orbital anomalies of the Transtages. To find evidences of breakups, characteristics of temporal distributions of CrA/m are compared between before and after the orbital anomalies. The known breakup of the Transtage 1968-081E will be utilized as the reference of the comparison study.

11:00 **AAS 14-329** **Satellite Breakup Debris Cloud Characterization**

Felix Hoots, Aerospace Corporation; Brian Hansen

A satellite breakup caused by a hypervelocity impact or explosion will create a large number of debris particles. Eventually these particles spread into a shell around the Earth and can be essentially characterized as an enhancement to the existing debris background. However, prior to this complete spreading, the particles can be described more as a cloud which poses an elevated risk to any spacecraft passing through the cloud. We provide a method to characterize the size, shape and density evolution of the cloud over time.

SESSION 13: SPACE SITUATIONAL AWARENESS II

Session Chair: Marcus Holzinger, Georgia Institute of Technology

13:30 **AAS 14-331** **Collision Avoidance Maneuvers Design Based on Multi-Objective Optimization**
Roberto Armellin, University of Southampton; Pierluigi Di Lizia, Politecnico di Milano; Alessandro Morselli

The possibility of having collision between a satellite and a space debris or another satellite is becoming frequent. The amount of propellant is directly related to a satellite's operational lifetime and revenue. Thus, collision avoidance maneuvers should be performed in the most efficient and effective manner possible. In this work the problem is formulated as a two-objective optimization. whereas the second one is the collision probability between the satellite and the threatening object in a given time window after the maneuver. This is to take into account that multiple conjunctions might occur in the short-term.

13:50 **AAS 14-332** **High Order State Updates For Estimation Of Nonlinear Dynamical Systems**
Manoranjan Majji, University at Buffalo, State University of New York; Renato Zanetti

This paper presents a systematic generalization of the linear update structure associated with the extended Kalman filtering for estimation of nonlinear dynamical systems. A minimum variance criterion is used as a cost functional to determine the optimal gains (to high order) required for the estimation process. Using the update structure, high order moment update equations are derived to incorporate the information from the measurements in the filtering process. Applications to the orbit determination of resident space objects (RSOs) for space surveillance and situational awareness are outlined.

14:10 **AAS 14-334** **Phylogenetic Taxonomy For Artificial Space Objects**
Carolin Frueh, Texas A&M University; Moriba Jah, Air Force Research Laboratory; Ernest Valdez, United States Geological Survey; Paul Kervin, Air Force Research Laboratory; Thomas Kelecy, Boeing LTS

As space gets more and more populated, a classification scheme based upon scientific taxonomy is needed to properly identify, group, and discriminate space objects. A phylogenetic taxonomy based on key features allows the establishment different object classes of operational and unoperational objects. Different probability of detection values and distinct hazard values for the different classes are derived. Minimal tree derived orbital element clustering, weighted by orbital element dynamics, is added as a level to the taxonomic system.

14:30 **AAS 14-335** **Collision Avoidance Maneuver Optimization**
Claudio Bombardelli, Technical University of Madrid (UPM); Javier Hernando-Ayuso, Technical University orf Madrid; Ricardo Garcia-Pelayo, Technical University orf Madrid

The paper present a high accuracy analytical method to optimize the thrust vector and orbit location of an impulsive collision avoidance maneuver. The optimization criterion consists of minimizing the maneuver cost in terms of delta-V magnitude in order to lower the collision probability below a desired threshold. The algorithm, whose accuracy is verified in representative mission scenarios, can be employed for collision avoidance maneuver planning with reduced computational cost when compared to fully numerical algorithms.

14:50 **AAS 14-336** **GPU Accelerated Conjunction Assessment: Parallel Construction of Ordered Binary Radix Trees for Collision Detection**

Abel Brown, a.i.solution, Inc; Michael Demoret, a.i. Solutions, Inc.; Jason Tichy, A.I. Solutions

The primary purpose of Conjunction Assessment (CA) is to prevent the intersection of objects in space. Typical scenarios involve satellites intersecting with space debris or a formation of satellites with each other. Traditional brute-force approaches scale poorly as O(N^2) and are thus not appropriate for operational scenarios or Monte Carlo simulations involving many objects. In this talk we explore bounding volume hierarchies, spatial partitioning, and present a massively parallel GPU implementation of Ordered Binary Radix Trees capable of collision detection over millions of objects in real-time. Applications to formation flight and space debris tracking are presented.

15:10 **AAS 14-338** **Astrometric And Photometric Data Fusion For Mass And Material Property Inference Under Uncertain Physics**

Richard Linares, University at Buffalo, State University of New York; Jack Wetterer, Integrity Applications Inc; Moriba Jah, Air Force Research Laboratory; John Crassidis, University at Buffalo, State University of New York

This paper studies the inference of space object mass, which is made possible due to the coupled influence of solar radiation pressure (SRP) acceleration on the orbit of satellites and their observed brightness. Based upon prior analysis, a characteristic albedo will be chosen and therefore, what will be recovered is a characteristic mass value. An unscented Kalman filter approach that includes Bi-directional Reflectance Distribution Function (BRDF) and mass parameters is used. The effect of this mis-modeling is managed using a process noise model to account for differences in the modeled acceleration and torque to allow for flexibility and

15:30 **Afternoon Break**

15:50 **AAS 14-339** **Photometric Data From Non-Resolved Objects For Space Object Characterization**

Richard Linares, University at Buffalo, State University of New York; Michael Shoemaker, Los Alamos National Laboratory; David Palmer, Los Alamos National Laboratory; David Thompson, Los Alamos National Laboratory; Josef Koller, Los Alamos National Laboratory

This paper uses light curve measurements to estimate the attitude and angular velocities of space objects with known shape. This paper focuses on rocket bodies in particular. A nonlinear least squares estimator is used to estimate the attitude and angular velocity of the space objects; both real data and simulated data scenarios are shown. A number of representative rocket body models are used for simulated data and real data examples. Good performance was shown for both simulated and real data cases.

SESSION 14: ESTIMATION

Session Chair: Kohei Fujimoto, Texas A&M University

13:30 **AAS 14-342** **application of High-OrDer stts Uncertainity Propagation on perturbed two-body problem**

Ahmad Bani Younes, Texas A&M University

We developed State-Transition-Tensor-Series (STTS) which is summarized by: (1) Computational differentiation that automatically builds exact partial derivative models; (2) Automatic development of state transition tensor series-based solution for mapping initial uncertainty models into instantaneous uncertainty models; and (3) Development of nonlinear transformations for mapping an initial probability distribution function into a current probability distribution function for computing fully nonlinear statistical system properties. The resulting nonlinear (pdf) represents a Liouiville approximation for the stochastic Fokker Planck equation. The STTS algorithm is applied on the perturbed two-body-problem, EGM 2008 200x200.

13:50 **AAS 14-343** **Coordinatization Effects On Non-Gaussian Uncertainty For Track Initialization and Refinement**

James McCabe, Missouri University of Science and Technology; Kyle DeMars, Missouri University of Science and Technology

A comparison between common coordinate systems used for state representation in orbital mechanics is presented for track initialization in orbit determination and follow-on tracking utilizing optical angles-only measurements. A Gaussian mixture parameterized probability density function representing uniform uncertainty across all possible Earth-bound constrained orbits is constructed. This distribution is mapped into each coordinate system, propagated forward in time, and refined via a Bayesian filter. Performance measures related to uncertainty characterization and algorithm efficiency are applied to judge the efficacy of the method in each coordinate system.

14:10 **AAS 14-344** **An automatic domain splitting technique to propagate uncertainties in highly nonlinear orbital dynamics**

Pierluigi Di Lizia, Politecnico di Milano; Roberto Armellin, University of Southampton; Alexander Wittig, Politecnico di Milano; Franco Bernelli-Zazzera, Politecnico di Milano; Martin Berz, Department of Physics and Astronomy - Michigan State University; Kyoko Makino, Department of Physics and Astronomy - Michigan State University

Nonlinear uncertainty propagation plays a key role in astrodynamics. Current approaches mainly refer to linearized models or Monte Carlo simulations. Differential algebra (DA) has proven to be an efficient compromise. However, the current implementation of the DA-based high-order uncertainty propagator fails in highly nonlinear dynamics. We solve this issue by introducing automatic domain splitting. During propagation, the polynomial of the current state is split in two polynomials when its accuracy reaches a given threshold. The resulting polynomials accurately track uncertainties, even in highly nonlinear dynamics. The method is tested on the propagation of 99942 Apophis post-encounter motion.

14:30 AAS 14-345 Adaptable Iterative and Recursive Kalman Filter Schemes
Renato Zanetti

Nonlinear filters are often very computationally expensive and usually not suitable for real-time applications. Real-time navigation algorithms are typically based on linear estimators, such as the extended Kalman filter (EKF) and, to a much lesser extent, the unscented Kalman filter. The Iterated Kalman filter (IKF) and the Recursive Update Filter (RUF) are two algorithms that reduce the consequences of the linearization assumption of the EKF by performing N updates for each new measurement, where N is the number of recursions, a tuning parameter. This paper introduces an adaptable algorithm to calculate N on the go.

14:50 AAS 14-346 Error Estimation and Control for Efficient and Reliable Orbit (and Uncertainty) Propagation
Jeffrey Aristoff, Numerica Corporation; Joshua Horwood, Numerica Corporation; Navraj Singh, Numerica Corporation; Aubrey Poore, Numerica Corporation

Several promising implicit-Runge-Kutta-based methods for orbit propagation have been developed in recent years. This paper elaborates on some of the unique features of the authors' implementation of Gauss-Legendre implicit Runge-Kutta (GL-IRK), and addresses a misconception regarding what it means to use error estimation and control, and how this feature leads to improved efficiency and reliability of orbit (and uncertainty) propagation. New capabilities are also introduced, including the ability to adaptively truncate the gravity model to meet a user-prescribed accuracy.

15:10 AAS 14-347 Orbital density determination from unassociated observations: uninformative prior and initial observation
Liam Healy, Naval Research Laboratory; Christopher Binz, Naval Research Laboratory

One view of the orbital environment is that object density is a function of phase space which evolves. Sensors, such as staring radars, that acquire information about the orbital environment in bulk but not associate observations or determine orbits of individual objects can be used to create and maintain this density information. We approach this problem as one of Bayesian inference. The choice of coordinatization used to represent phase space, the implications for the uniformative prior, and the effect of the initial observation on the object density probability are treated here.

15:30 Afternoon Break

15:50 AAS 14-349 Drag Coefficient Estimation Using Satellite Attitude and Orbit Data
David Spencer, The Pennsylvania State University; Christopher Hassa, The Pennsylvania State University; Sven Bilen, The Pennsylvania State University

Current spacecraft decay models assume a constant coefficient of drag value of 2.2. This is driven by the difficulty in accurately modeling the spacecraft's cross sectional area exposed to the direction of motion. This research discards the assumption of a constant coefficient of drag; instead, it uses attitude data from the Swift spacecraft to determine the cross sectional area and directly calculates the coefficient of drag over the nine years of orbital data. This method partially validates the NRLMSISE-00 atmospheric model and encourages a new look into the coefficient of drag value used to determine the decay

16:10 **AAS 14-351** **Estimation And Prediction For An Orbital Propagation Model Using Data Assimilation**

Humberto C. Godinez, Los Alamos National Laboratory; Matthias Morzfeld, Lawrence Berkeley National Laboratory

The estimation and prediction of satellite orbits is an important problem for our society. Orbit estimation presents a particularly challenging problem since the resulting models are non-linear and have non-Gaussian distributions. We present assimilation experiments with a two-dimensional orbital propagation model to study the efficiency of three data assimilation methods: ensemble Kalman filter (EnKF), Implicit Sampling filter (IS), and variational data assimilation (4D-Var). The frequency of assimilation, and number of particles/ensemble members are changed to test their robustness. The experiments show how EnKF suffers from filter divergence in most cases, while both 4D-Var and

SESSION 15: SMALL BODY PROXIMITY OPERATIONS

Session Chair: Chris Ranieri, The Aerospace Corporation

13:30 **AAS 14-352** **Body-fixed orbit-attitude hovering at equilibria near an asteroid using non-canonical Hamiltonian structure**
Yue Wang, Beihang University; Shijie Xu

The orbit-attitude hovering at relative equilibria near an asteroid is discussed, in which the spacecraft is modeled as a rigid body and both its position and attitude are kept stationary in the asteroid frame. A feedback control law is proposed to stabilize the relative equilibria to achieve the hovering based on the non-canonical Hamiltonian structure. The control law is consisted of potential shaping and energy dissipation. Potential shaping makes the relative equilibrium be a minimum of the Hamiltonian, and energy dissipation leads the motion to converge. The feasibility of our method is validated through a numerical simulation.

13:50 **AAS 14-353** **Solar Sailing Apophis Rendezvous Mission with Fuel-Fixed Delta-V**
Xiangyuan Zeng, Tsinghua University; Jing He; Junfeng Li; Gong Shengping; Xingshan Cai; Zhang Zhiguo, Tsinghua University

The Aten-type asteroid 99942 Apophis is adopted to illustrate the effect of fuel-fixed delta-V on solar sailing rendezvous missions. The hyperbolic excess velocities can be applied at either end point of the interplanetary trajectory with a predetermined maximum magnitude. A time optimal control model is constructed and solved with an indirect method, involving the solution to a two-point boundary value problem. Numerical simulations are performed with a near term ideal solar sail in a characteristic acceleration of 1 mm/s2. A number of mission scenarios are investigated with different hyperbolic excess velocities.

14:10 **AAS 14-354** **Asteroid Proximity Navigation using Direct Altimetry Measurements**
Jay McMahon, University of Colorado; Daniel Scheeres, University of Colorado

Altimetry has a long history of being used for science data and navigation in space missions, especially for missions to asteroids. In this paper we analyze the use of direct altimetry range measurements for navigation about an asteroid, as is planned during the touch-and-go portion of the OSIRIS-REx mission. This paper will investigate what information is contained in direct altimetry measurements, how this information can be used for proximity navigation around a small body, and the expected navigation accuracy that can be achieved. Ultimately, we analyze if this information provides robust and accurate proximity and landing operations.

14:30 **AAS 14-355** **High-altitude deployment of landers to asteroid surfaces using natural manifolds**
Simon Tardivel, University of Colorado Boulder; Daniel Scheeres, University of Colorado; Patrick Michel, Observatoire de la Cote d'Azur

A simple, reliable and safe strategy for deploying landers to any asteroid surface is described. The spacecraft cruises on a hyperbolic trajectory and releases a landing pod, devoid of any guidance, navigation and control system or actuators, from very high altitude above the asteroid, near saddle points of the amended gravity field. At release, the spacecraft gives the lander initial conditions such that the dynamical environment of the asteroid naturally leads the pod to the surface. The deployment region and favorable initial conditions are computed and discussed. Monte Carlo simulations verify the efficacy and the robustness of the presented strategy.

14:50 **AAS 14-356** **Trajectory Design About Binary Asteroids Through Coupled Three-Body Problems**
Fabio Ferrari, Politecnico di Milano; Michele Lavagna, Politecnico di Milano; Kathleen Howell

The study of the dynamical environment near an asteroid pair has become an extremely relevant topic to design trajectories for future missions design. This work analyzes the dynamical environment in the proximity of a binary system and develops some useful tools to design trajectories about the asteroid couple, exploiting convenient dynamical properties of three-body systems. It is here proposed to deal with the two asteroids dynamics by conveniently coupling two different Circular Restricted Three-Body Problems (CR3BP); the potential application of the methodology to an asteroid landing scenarios is discussed in deep.

15:10 **AAS 14-357** **Rosetta Lander Philae Mission: Flight Dynamics Studies For Landing Site Selection On Comet Churyumov-Gerasimenko**
Eric Jurado, Centre National d'Etudes Spatiales; alejandro Blazquez, Centre National d'Etudes Spatiales; Elisabet Canalias, Centre National d'Etudes Spatiales; Thierry Martin, Centre National d'Etudes Spatiales; Thierry Ceolin; Romain Garmier; Jens Biele, DLR; Koen Geurts, DLR/VEGA

In August 2014, the European mission Rosetta will reach its target comet Churyumov-Gerasimenko. It will deliver the Philae Lander on the comet nucleus surface in November 2014. This paper addresses Flight Dynamics analyses performed for preparing landing delivery. Different separation and descent scenarios are studied to maximize the reachable areas on the nucleus. Currently these studies are done with predicted comet models but will be refined using comet observation data. After landing, it will also be necessary to determine within a few hours where and how Philae has landed. Implemented technical solutions are also presented in this paper.

15:30 **Afternoon Break**

15:50 **AAS 14-359** **ZEM/ZEV Sliding Guidance for Asteroid Close-Proximity Orbital Transfer and Rendezvous**
Daniel Wibben, The University of Arizona; Roberto Furfaro, The University of Arizona

The Zero-Effort-Miss/Zero-Effort-Velocity with sliding mode guidance scheme is applied to the problem of orbital transfer and rendezvous during asteroid proximity operations. The guidance scheme used is a non-linear methodology which combines techniques from optimal and sliding control theory and has its roots in the generalized ZEM/ZEV feedback guidance with a sliding mode augmentation that provides robustness against unmodeled dynamics. In this paper, the focus is the application of the guidance scheme to several typical scenarios that can be encountered during the close-proximity operations phase of a robotic mission to a small asteroid.

16:10 **AAS 14-360** **Orbital Evolution and Environmental Analysis Around Asteroid 2008 EV5**

Pedro J. Llanos, G.M.V. Aerospace & Defence, S. A.; James Miller, Consultant; Gerald R. Hintz

The orbital evolution and environmental analyses around the target asteroid, 2008 EV5, for the ESA's Marco Polo R mission are assessed during the proximity operations to minimize the efforts towards the improvement of the GNC system. With this analysis, we will extend our knowledge in the decision-making when the spacecraft is flying under unknown environmental conditions, such as the solar radiation pressure and the gravitational harmonics due to the irregular shape of the body. Our analysis is compared with different asteroid shape models, such a parameterized model, an ellipsoid model and a high fidelity mascons shape model.

16:30 **AAS 14-361** **Frozen orbits at small bodies subject to solar radiation pressure and J2 perturbations**

Demyan Lantukh, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin; Stephen Broschart, NASA / JPL-CalTech

The combined effect on spacecraft orbits of significant solar radiation pressure and J2 perturbations is investigated using averaged disturbing potentials and the Lagrange planetary equations. Several frozen orbit families are identified, including stable low inclination orbits that are not stable when solar pressure is considered alone. The orbits found here are applicable to a common class of rapidly rotating and small asteroids whose spin pole is nearly normal to their orbital plane. Bennu, the target of the OSIRIS-REx mission, is an example. The stability characteristics of these orbits are presented and verified via simulation.

Session 16: Trajectory Design II

Session Chair: Ryan Russell, University of Texas at Austin

13:30 **AAS 14-363** **2016 Mars Insight Mission Design And Navigation**
Fernando Abilleira, NASA / JPL-CalTech; Tung-Han You, NASA / JPL-CalTech

Scheduled for a launch in the 2016 Earth to Mars opportunity, the Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight) Mission will arrive to Mars in late September 2016 with the primary objective of placing a science lander on the surface of the Red Planet followed by the deployment of two science instruments to investigate the fundamental processes of terrestrial planet formation and evolution. Achieving a successful landing has a significant number of key and driving requirements that InSight Mission Design and Navigation has addressed.

13:50 **AAS 14-364** **Robotic Mars Exploration Trajectories Using Hall Thrusters**
Theresa Kowalkowski, NASA / JPL-CalTech; Zachary Bailey, NASA / JPL-CalTech; Robert Lock, NASA / JPL-CalTech; Erick Sturm, NASA / JPL-CalTech; Ryan Woolley, NASA / JPL-CalTech

A variety of Mars exploration architectures for the latter part of this decade and early part of the next are under consideration at NASA, ranging from orbiters to landers to sample return mission scenarios. The use of solar electric propulsion, particularly Hall thrusters, is an attractive option because it can provide increased flexibility to mass growth; alternate launch opportunities; Mars orbit selection, adjustment and rendezvous capabilities; and uncertainty in launch vehicle performance. In this paper, we present Earth-to-Mars and Mars-to-Earth trajectory options using Hall thrusters for potential Mars exploration architectures.

14:10 **AAS 14-365** **Round-Trip Solar Electric Propulsion Missions For Mars Sample Return**
Zachary Bailey, NASA / JPL-CalTech; Erick Sturm, NASA / JPL-CalTech; Theresa Kowalkowski, NASA / JPL-CalTech; Ryan Woolley, NASA / JPL-CalTech; Robert Lock, NASA / JPL-CalTech ; Austin Nicholas, NASA / JPL-CalTech

Mars Sample Return (MSR) missions could benefit from the high specific im-pulse of Solar Electric Propulsion (SEP) to achieve lower launch masses than with chemical propulsion. SEP presents formulation challenges due to the cou-pled nature of launch vehicle performance, propulsion system, power system, and mission timeline. This paper describes a SEP orbiter-sizing tool, which models spacecraft mass & timeline in conjunction with low thrust round-trip Earth-Mars trajectories, and presents selected concept designs. A variety of sys-tem designs are possible for SEP MSR orbiters, with large dry mass allocations, similar round-trip durations to chemical orbiters,

14:30 **AAS 14-366** **Preliminary Mission Design For A Crewed Earth-Mars Flyby Mission Using Solar Electric Propulsion (SEP)**

Stijn Smet; Jonathan Herman, University of Colorado at Boulder; Jeffrey Parker, University of Colorado; Ron Noomen, Delft University of Technology

This paper discusses the preliminary design of a crewed Mars flyby mission using Solar Electric Propulsion (SEP), like Inspiration Mars, which currently only includes chemical propulsion. This mission relies on a very specific planetary alignment to achieve a feasible final payload mass, so the next launch window would only be in 2031.The research will investigate whether or not new launch windows can be opened up using SEP. Furthermore, this paper will assess if SEP could be used to open up new mission concepts like an additional Venus flyby to increase the science value of this mission.

14:50 **AAS 14-367** **Spacecraft Trajectory Design with Photonic Laser Propulsion in the Two-body Problems**

Fu-Yuen Hsiao, Tamkang University; Shih-Hao Liu

This paper studies the trajectory design of spacecraft propelled by the photonic laser propulsion (PLP) system under the environment of two-body problem. With repeated reflections of laser beam, PLP generates continuous and tremendous power by consuming very small energy. This paper mainly focuses on the trajectory design. Conventional two-point boundary value problems may not be suitable for this problem. An algorithm is proposed to determine initial conditions in the trajectory design. Linearization of the trajectory and "local time approximation" are employed to find required initial conditions. Numerical simulations are presented to demonstrate the algorithm and potential applications.

15:10 **AAS 14-368** **There And Back Again: Using Planet-Based Sep Tugs To Repeatably Aid Interplanetary Payloads**

Tim McElrath, NASA / JPL-CalTech; John Elliott, NASA / JPL-CalTech

Tugs using Solar Electric Propulsion can efficiently operate between planetary and heliocentric orbits, by delivering payloads to ballistic flybys between planets. By restricting the solar range, the tug power level and other spacecraft parameters can be optimized. Launching payloads together with the xenon needed to propel them allows the very long lifetime of modern Hall thrusters to be utilized. An Earth-based tug can use this technique every Earth-Mars synodic period, and it can also be used for payloads to other destinations, providing a significant performance improvement over direct launches.

15:30 **Afternoon Break**

15:50 **AAS 14-369** **Orbit Design And Navigation Though The End Of Messenger's Extended Mission At Mercury**

James McAdams, Johns Hopkins University Applied Physics Laboratory; Christopher Bryan, KinetX Aerospace, Inc.; Dawn Moessner, Johns Hopkins University Applied Physics Laboratory; Brian Page, KinetX Aerospace, Inc.; Dale Stanbridge, KinetX Aerospace, Inc.; Kenneth Williams, KinetX Aerospace, Inc.

MESSENGER became the first orbiter of Mercury on 17 March 2011. After one year in a near-polar, 200x500 km periapsis altitude by 12-h orbit with six orbit-correction maneuvers (OCMs), extended mission 1 lasted until 18 March 2012, including two mid-April 2012 OCMs that lowered orbit period to 8 h. Extended mission 2 began 18 March 2013, had November 2013 observations of comets Encke (~0.025 AU) and ISON (~0.242 AU) and plans four OCMs to target periods with little variation from 25-km and 15-km periapsis altitude until Mercury impact in March 2015.

16:10 **AAS 14-370** **Mission Analysis Update for the JUpiter ICy moon Explorer (JUICE)**

Arnaud Boutonnet, ESA / ESOC; Johannes Schoenmaekers, ESA / ESOC; Waldemar Martens, ESA / ESOC; Tomohiro Yamaguchi, GMV at ESA/ ESOC

This paper presents the mission analysis update for JUICE, an ESA mission to study Jupiter, its environment and its Galilean moons. The various phases of the tour are quickly recalled (Europa swing-bys, Jupiter high latitudes, low energy endgame, Ganymede in-orbit). The interplanetary phase was updated: extended launch date interval, increased list of planets sequences, enhanced trajectory structure. The navigation of the Jupiter tour is also shown with careful attention to Jupiter capture. Finally the planetary protection analysis is presented for Europa through two contributions: short term failure (e.g. safe mode) and long term failure (e.g. micrometeoroids)

16:30 **AAS 14-371** **Precise Determination of the Reachable Domain for a Spacecraft with a Single Impulse**

Wen Changxuan, Beijing University of Aeronautics and Astronautics; Xu Zengwen, Beijing University of Aeronautics and Astronautics; Zhao Yushan, Beijing University of Aeronautics and Astronautics; Shi Peng, Beijing University of Aeronautics and Astronautics

Reachable domain for a spacecraft with a single impulsive maneuver at an arbitrary maneuver point is investigated. The surface of the reachable domain is precisely calculated by evaluate the extreme values of the radius in any given direction. Since the radius is a function of two free variables, the extreme values can be specified through solving the equations of two partial derivatives. The conditions of solution existence are further discussed and are given as the proper choosing the direction vector. Simulations of the reachable domain are presented to demonstrate the proposed method and its accuracy.

16:50 **AAS 14-372** **Europa lander mission analysis: non-Keplerian approach for radiation exposure mitigation**

Lorenzo Ferrario, Politecnico di Milano; Michele Lavagna, Politecnico di Milano

According to recent analyses, Europa has been identified as one of the most promising candidates as a life-hosting celestial body thanks to the presence of a vast and oxygenated underground ocean. Many mission analyses have been designed to reach that moon, but none really mitigates the exposition to the harsh and radioactive environment of the inner Jovian magnetosphere. This paper shows how it is possible to reduce significantly that risk by exploiting a non-Keplerian trajectory based on two nested Circular Restricted 3 Bodies Problems with Ganymede and Europa, also increasing the flexibility of the mission.

17:10 **AAS 14-373** **Techniques for Designing Many-Revolution, Electric-Propulsion Trajectories**

Anastassios Petropoulos, NASA / JPL-CalTech; Gregory Lantoine, NASA / JPL-CalTech; Zahi Tarzi, NASA / JPL-CalTech; Thierry Dargent, Thales Alenia Space; Richard Epenoy, Centre National d'Etudes Spatiales

The problem of computing many-revolution, low-thrust orbit transfers around a central body is a difficult one; its study began at least as early as the 1950s and continues today. In this paper, we develop and compare several different approaches to optimising and designing such transfers around planets and large moons or asteroids. Electric propulsion can offer significant overall mass savings compared to chemical propulsion, which offers the motivation for studying its use in spite of the long transfer durations involved with spiral trajectories.

SESSION 17: RENDEZVOUS AND PROXIMITY OPERATIONS II

Session Chair: Roberto Furfaro, University of Arizona

8:00 **AAS 14-374** **Solution of Lambert's Problem for Higher-Order Satellite Relative Motion**

Keith LeGrand, Missouri University of Science and Technology; Kyle DeMars, Missouri University of Science and Technology

In classical orbital mechanics, the Lambert problem consists of computing the full state of an orbiting body given two positions and the time elapsed between them. Similar analytic methods exist for the relative motion problem, but rely on linearized equations of motion and matrix inversion. In this work, an analytic solution to the ``relative'' Lambert problem is derived using second-order Clohessy-Wiltshire equations and is applied directly in the relative frame. The problem is represented geometrically by the intersection of three quadric surfaces. The associated multivariate algebraic set is solved non-iteratively using Macaulay resultant expressions to high accuracy.

8:20 **AAS 14-375** **An Error Analysis For Relative Satellite Motion In Earth Orbit**

Jerel Nielsen, Utah State University; David Geller, Utah State University; Thomas Lovell, Air Force Research Laboratory

Relative acceleration as a function of deputy distance from chief is investigated. This acceleration is computed only for LEO (7000 km) and GEO (42000 km) orbits, where the GEO orbits have an inclination of zero. Error in the CW equations is also investigated. Errors due to CW approximations and relative accelerations due to a point-mass gravity model, J2, SRP, and 3rd-body perturbations are compared and plotted as a function of radial, cross-track, and along-track position.

8:40 **AAS 14-376** **Rendezvous and Proximity Operations At the Earth-Moon L2 Lagrange Point: Navigation Analysis for Preliminary Trajectory Design**

David Woffinden, Draper Laboratory; Kuljit Mand; Renato Zanetti; Pol Spanos, Rice University

NASA's current mandate for space exploration beyond low earth orbit has drawn attention to missions to the Earth-Moon L2 point. This special Lagrange point is located along the Earth/Moon radial line and is located on the distant side of the moon. It provides a strategic location for potential lunar landing missions, asteroid exploration programs, human trips to Mars, space telescopes, and other programs. One key capability that must be revisited and demonstrated in this unique environment is rendezvous and close proximity operations. This paper derives the necessary navigation requirements and sensor suites that support rendezvous and docking.

9:00 **AAS 14-377** **Hovering Formation Design and Control Based on Relative Orbit Elements**
Yinrui Rao; Jianfeng Yin, China Academy of Space Technology; Chao Han, Beihang University

A new set of relative orbit elements (ROE) is used for hovering formation design. A new impulsive control strategy for hovering formation along-track direction movement is proposed, and it has advantages of concise form and convenient implementation in engineering. Furthermore, to control the formation from any configuration to the designated hovering formation, a new strategy based on Lambert's Problem is established. Additionally, considering the impact of mea-surement errors and perturbations, a closed-loop impulsive feedback control law is derived as well. Several numerical simulations are presented to demonstrate the effectiveness of these proposed methods.

9:20 **AAS 14-378** **Touchless Electrostatic Three-Dimensional Detumbling of Large GEO Debris**
Trevor Bennett, University of Colorado; Hanspeter Schaub, University of Colorado

Touchless detumbling of space debris is investigated to enable orbital servicing or active debris removal. Using active charge transfer between a tug and debris object, the attitude control goal is to arrest the debris tumbling motion prior to making any physical contact. Prior work has identified the feasibility of electrostatic de-tumble for one degree of rotational freedom. This work extends the theory to three-dimensional tumbling motion. Using the previously developed Multi-Sphere modeling method for electrostatic forces and torques on non-spherical objects, Lyapunov control theory is used to demonstrate a stabilizing attitude control.

9:40 **Morning Break**

10:00 **AAS 14-379** **State Transition Matrix for Relative Motion Including Third-Body Perturbations**
Hui Yan, Texas A&M University; Srinivas R. Vadali, Texas A&M University; Kyle T. Alfriend, Texas A&M University

The paper extends the capability of the Gim-Alfriend STM by including third-body perturbation effects in the study of formation flying relative motion. The first several secular terms of the averaged disturbing potential are be included in the lunar perturbation model with nonsingular elements. The relative motion of the moon with respect to the Earth is incorporated using the lunar ephemerides data obtained from the Jet Propulsion Laboratory's HORIZONS website. The initial conditions or the initial osculating elements of the satellites are determined by a least squares method. The resulting solution is validated by GMAT.

10:20 **AAS 14-380** **Spacecraft Swarm Finite-Thrust Cooperative Control Protocol for Common Orbit Convergence**
Divya Thakur, The University of Texas at Austin; Sonia Hernandez, The University of Texas at Austin; Maruthi Akella, The University of Texas at Austin

A novel decentralized cooperative control protocol is proposed for the convergence of an autonomous spacecraft swarm to a common circular orbit using finite thrust. Guidance and consensus algorithms are implemented to drive agents to an orbit of prescribed semi-major axis and zero eccentricity, with the plane of orbital motion determined through consensus. The information network is assumed to be connected, undirected, and either acyclic or purely cyclic. The thrust limited guidance and consensus schemes are designed separately and readily combined for overall closed-loop stability. The convergence properties are rigorously analyzed and simulations are provided to validate results.

10:40 **AAS 14-381** **Relative Orbit Determination For Formation Flying Spacecraft Using Differenced Beidou Carrier Phase**

Shu Leizheng, Beihang University; Jianfeng Yin, China Academy of Space Technology; Yinrui Rao; Hongli Zhang, Beihang University; Chao Han, Beihang University

A reduced-dynamic approach is developed for precise formation flying relative orbit determination using the double-differenced carrier phase of China's Beidou navigation system as the main observable. The reduced dynamic technique combines the benefits of kinematic positioning techniques with those of a fully dynamic trajectory modeling to determine the relative orbit using an extended Kalman filter. In addition, the augmented filter state is estimated to compensate the incomplete dynamic model for better precision of the orbit solution. A simulated LEO scenario indicates that the filter provide better than 10 cm accuracy when using single-frequency measurements.

11:00 **AAS 14-382** **The elliptic rendezvous problem in DROMO formulation**

Jesus Pelaez, Technical University of Madrid (UPM); Javier Roa, Technical University of Madrid (UPM)

Linearizing the differential equations of relative motion is a common approach to define the orbit of the follower satellite. Its orbit is constructed through small variations of the elements of the leader orbit. Instead of a frozen-time formulation, we explore the performance of a frozen-anomaly transformation, based on DROMO formulation. Frozen-anomaly solution implies a time delay between leader and follower states. This delay is corrected via a second-order approximation, computed for every iteration, using the instantaneous values of position and velocity. Numerical results show significant error reductions when compared to previous linearized solutions.

11:20 **AAS 14-383** **Optimal Control of Two-Craft Electromagnetic Formation in Circular Orbit**

Xu Zengwen, Beijing University of Aeronautics and Astronautics; Shi Peng, Beijing University of Aeronautics and Astronautics; Zhao Yushan, Beijing University of Aeronautics and Astronautics

Optimal reconfigurations of two-craft electromagnetic formation in low earth circular orbit are discussed. Equations of motion for two-spacecraft electromagnetic formation are derived according to the motion of tethered satellite. Three optimality criteria considered are minimum time, minimum acceleration, and minimum electrical power consumption. Three examples are presented with different DOFs. The two-point-boundary-value problem is numerically solved via Gauss pseudospectral methods. A general framework of calculating control currents in electromagnetic coils according to the required control forces is presented. Analytical solutions of control currents for the case of two-craft are derived considering energy consumption equilibrium.

SESSION 18: SPACECRAFT GUIDANCE AND CONTROL

Session Chair: Angela Bowes, NASA Langley

8:00 AAS 14-385 Internal Moving Mass Actuator Based Angle of Attack and Angle of Sideslip Control for Mars Entry Missions

Brad Atkins, Virginia Polytechnic Institute and State University

An internal moving mass actuator (IMMA) control system is proposed for controlling angle of attack and angle of sideslip for Mars entry vehicle trajectory control. A general form of the vehicle attitude equation is derived for IMMAs that can translate and rotate within the vehicle. A Linear Quadratic Tracking controller is synthesized to meet desired angles of attack and sideslip. Simulation of the controller for Mars entry conditions is provided demonstrating the ability to meet angles of attack for range control. The full paper will describe the implementation of the controller to follow a target seeking guidance algorithm.

8:20 AAS 14-386 Optimal low-thrust transfer and guidance scheme for Geostationary orbit insertion

Hao Huang, Beihang University; Jian Li; Hongli Zhang, Beihang University; Yinrui Rao; Chao Han, Beihang University

Unsented Kalman filter (UKF) parameter estimation technique is used in solving two-point-boundary-value-problem for optimal low thrust transfers. A feedback guidance scheme is developed by tracking the orbital characteristics profiles re-sult from the open-loop transfer process. The control laws in each tracking circle are obtained by solving a time-fixed optimal control problem with UKF. The techniques proposed for orbit transfer and guidance scheme design are applied to two GEO insertion missions. The performance is demonstrated through simu-lations. Furthermore, the orbit perturbation and the eclipse effects are considered in the guidance scheme.

8:40 AAS 14-387 Near-Optimal Guidance For Precision Lunar Landing With A Combined Solid Rocket Motor And Liquid Propulsion System

Martin Ozimek, The Johns Hopkins University Applied Physics Laboratory; Timothy McGee, JHUAPL

Previous lunar missions, such as NASA's Surveyor program, have effectively utilized a solid rocket motor to accomplish a large portion of the Delta-V required for terminal descent, followed by dispersion-cleanup and soft-landing with a smaller liquid propulsion system. Additional complexity is encountered when precision landing guidance is desired, since steering is possible with both propulsion systems. This study presents a novel solution to this problem that addresses the need for rapid onboard computation and near-minimal liquid fuel usage. The minimum fuel guidance problem is strategically approximated in both phases to obtain a near-optimal algorithm.

9:00 **AAS 14-388** **Near-Optimal Feedback Guidance For Aeroassisted Orbital Transfer Via Spatial Statistical Prediction**

Pradipto Ghosh; Bruce Conway, University of Illinois at Urbana-Champaign

This work applies a newly-developed extremal-field implementation of dynamic programming to the computation of a guidance strategy for the heating-rate-constrained, minimum-energy-loss orbital inclination change of an Aeroassisted Transfer Vehicle. In this method, the spatial statistical point prediction method of universal kriging is used to compute approximate-optimal controls via multi-dimensional interpolation from a family of pre-computed extremals. The performance of the feedback controller is found to be very promising; initial atmospheric-entry errors due to simulated thruster misfirings are seen to be accurately corrected while closely respecting the algebraic state-inequality constraint.

9:20 **AAS 14-390** **Maneuver Performance Assessment of the Cassini Spacecraft Through Execution-Error Modeling and Analysis**

Sean Wagner, NASA / JPL-CalTech

The Cassini spacecraft has executed nearly 300 maneuvers since 1997, providing ample data for execution-error model updates. With maneuvers through 2017, opportunities remain to improve on the models and remove biases identified in maneuver executions. This manuscript focuses on how execution-error models can be used to judge future maneuver performance, while providing means for detecting performance degradation. Additionally, this paper describes Cassini's execution-error model updates in August 2012. An assessment of Cassini's maneuver performance through December 2013 is also presented.

9:40 **Morning Break**

10:00 **AAS 14-391** **Optimal Spin Rate Control of a Spinning Solar Sail for the Maximum-Radius Orbit Transfer Problem**

Go Ono; Yuya Mimasu, Japan Aerospace Exploration Agency; Jun'ichiro Kawaguchi, Japan Aerospace Exploration Agency

The spin-axis of a spinning solar sail rotates around an equilibrium direction near the Sun direction due to the influence of SRP, and it leads to a complexity in the attitude and orbit control. This motion is called an attitude drift motion, and can be controlled by the spin rate of a spacecraft. The objective of this paper is to derive an optimal spin rate control law of a spinning solar sail for the maximum-radius orbit transfer problem. An optimal control problem is solved analytically, and the validity of the analytical solution is verified with numerical calculation.

10:20 **AAS 14-392** **Continuous Thrust Stationkeeping In Earth-Moon L1 Halo Orbits Based On Lqr Control And Floquet Theory**

Eric Butcher, New Mexico State University; William Anthony, New Mexico State University; Morad Nazari, New Mexico State University

Stationkeeping strategies in Earth-Moon L1 halo orbits are proposed based on continuous LQR control and Floquet theory using periodic control gains. Two strategies are proposed. The first strategy is based on the time-varying linear quadratic regulator (LQR) where the periodic algebraic Riccati equation (ARE) is solved over one orbit to obtain the periodic control gains. The second control strategy involves use of Lyapunov-Floquet transformation (LFT) as well as LQR design for linear time-invariant (LTI) systems.

10:40 **AAS 14-393** **A Gas Bearing Platform Attitude Control For Assessment Of Aocs Systems**

Valdemir Carrara, Instituto Nacional de Pesquisas Espaciais; Helio Kuga, Instituto Nacional de Pesquisas Espaciais; Alexandre Oliveira, Instituto Nacional de Pesquisas Espaciais

Gas Bearing Platforms (GBP) have been used for over the past 50 years to simulate the free-of-torque space environment. To achieve the goal of developing a three-axis AOCS, a dumbbell type GBP was equipped with several sensors, actuators, and an on-board computer. Control algorithms for 3-axes attitude stabilization and control have been implemented in the computer envisaging performance analysis with realistic hardware-in-the-loop tests. This paper presents the GPB balancing process, the mass properties estimation process and some results coming from a basic GBP attitude control.

11:00 **AAS 14-394** **Statistical Fuel Budgets For Impulsive Guidance To Earth-Moon L1 Halo Orbits**

Eric Butcher, New Mexico State University; William Anthony, New Mexico State University; Jeffrey Parker, University of Colorado

A previously proposed impulsive guidance scheme to mitigate the effects of thrust magnitude and direction errors for manifold-based transfers from LEO or GEO to a Earth-Moon L1 halo orbit is investigated further. To numerically obtain the required statistical fuel budget for this guidance scheme, Monte Carlo simulations are performed for the guided transfer with Gaussian thrust error dispersions assumed in the manifold injection burn as well as the individual TCMs. The resulting statistics are compared with the analytical delta-v99 relation for statistical fuel budgets.

11:20 **AAS 14-395** **Design of the Attitude Control Subsystem of IITMSAT, a Geomagnetic-Field-Pointing Satellite**

Deepti Kannapan, University of California, Santa Barbara; Akshay Gulati, Indian Institute of Technology Madras; Gourav Saha, Indian Institute of Technology Madras; Sruteesh Kumar, Indian Institute of Technology Madras

The IITMSAT project is a student satellite initiative of the Indian Institute of Technology Madras. It is a nanosatellite with a scientific mission involving measuring proton and electron fluxes in the Earth's magnetosphere to characterize their interactions with electromagnetic waves. The scientific mission places requirements on the attitude control subsystem that the attitude be autonomously maintained such that one axis of the satellite tracks the geomagnetic field direction. This must be achieved using minimal hardware due to power and mass restrictions. A system to track the time-varying vector is designed by a combination of analytical and numerical techniques.

SESSION 19: SPACECRAFT DYNAMICS

Session Chair: Jay McMahon, University of Colorado

8:00 **AAS 14-396** **Comparing a High-Fidelity Radiation Pressure Model to Other Perturbations in Orbit Determination and Propagation**
Keric Hill, Pacific Defense Solutions, LLC.; Jack Wetterer, Integrity Applications Inc; Moriba Jah, Air Force Research Laboratory

A perturbation analysis was performed to determine the effect of physically consistent radiation pressure and brightness models on an orbit compared to other common perturbations. Accelerations due to radiation pressure were computed consistent with the Bidirectional Reflectance Distribution Function (BRDF) used to compute brightness. The position differences due to that and other perturbations were plotted as a function of time for various orbits using different satellite models. In a second set of comparisons, the initial conditions of each perturbed orbit were differentially corrected to match the baseline orbit using least-squares to illustrate orbit determination error due to dynamic mismodeling.

8:20 **AAS 14-397** **Comparison of Solar and Thermal Radiation Accelerations of Deep-Space Satellites**
Jozef van der Ha, Consultant

Precise navigation of interplanetary satellites requires high-fidelity modelling of non-conservative small forces like solar radiation pressure (SRP) and the re- emitted thermal radiation pressure (TRP) from the external satellite surfaces. The accelerations induced by TRP show a strong dependence on the orientations and temperatures of the satellite external surfaces and may act in a different direction than the SRP force. This paper summarizes the main SRP and TRP effects on present ESA deep-space missions like Rosetta, Mars Express, Venus Express, during their cruise phases and compares their magnitudes and directions. Also predictions are given for Bepi Colombo.

8:40 **AAS 14-398** **Saturated Attitude Control with Almost Global Finite-Time Stabilization**
Haichao Gui, Beihang University; Tingxuan Huang; Shijie Xu; Lei Jin, Beihang University

The problem of finite-time attitude stabilization of a rigid spacecraft is revisited. First, homogeneous system theory is utilized to design a simple proportional-derivative type saturated finite-time controller (SFTC) based on quaternion, which avoids the undesirable unwinding phenomenon. Strict proof shows that the quaternion-based SFTC ensures almost global finite-time stability of the resulting closed-loop systems. The proposed SFTC not only yields bounded control torques, but also possesses robustness to large inertia uncertainties of the spacecraft since they are independent of the spacecraft inertia. Numerical results demonstrate the effectiveness and superiority of the proposed controller.

9:00 **AAS 14-399** **An Energy-Matching Optimal Control Method for Consensus of Spacecraft Cluster Flight**

Liang Zhou, Northwestern Polytecnical University; Jianjun Luo; Bo Zhang, Northwestern Polytecnical University; Erlong Su

This paper presents an optimal control method for consensus of spacecraft cluster flight under a kind of energy matching condition. Firstly, the relationship between energy matching and spacecraft periodically bounded relative motion is analyzed. Then, the period-delayed errors are employed as states variable to establish the period-delayed errors dynamics model of a single spacecraft and the cluster. Next a novel spacecraft cluster feedback control law with coupling gain is designed.LQR based optimal control approach is used to determine the feedback control gain matrix.Finally the feasibility and effectiveness of this method is verified through numerical simulations.

9:20 **AAS 14-400** **A Unique Maiden Device For Propulsion And A Maiden Device For Lift**

Hsien-Lu Huang, Retired Engineer from NASA at age 85 in 2008

Based on the published findings of the Authors as shown in Reference 1, in this article two new unique maiden devices have been developed and described. One is for providing propulsion force, and the other is for providing lift force. Because the derivation is independent of the environment where the devices are in, these devices can be used in air, sea, land, and space. For easier demonstration, c feet long copper cylinder or c feet thick copper disk of b feet radius circular cross-section is used for both devices.

9:40 **Morning Break**

10:00 **AAS 14-401** **A General Dynamics Model For Spacecraft With Variable Speed Control Moment Gyroscopes**

Sasi Prabhakaran Viswanathan, New Mexico State University; Amit Sanyal, New Mexico State University; Frederick Leve, Air Force Researcb Laboratory/Space Vehicles Directorate

An attitude dynamics model of spacecraft with variable speed control moment gyroscope (VSCMG), is obtained using the framework of geometric mechanics. This attitude dynamics formulation relaxes some standard assumptions, that are made in the prior literature on control moment gyroscopes and provides a general and rigorous dynamics model. These dynamics equations show the complex nonlinear coupling between the internal degrees of freedom associated with the VSCMG and the spacecraft base body attitude degrees of freedom. A control scheme using n VSCMGs in polyhedron formation for pointing attitude maneuvers in the absence of external torques, is presented.

10:20 AAS 14-402 Analysis on dynamic characteristics and control capabilities of Titan Aerobot considering fluid inertia force

Zhibin Li, Beijing Institute of Control Engineering; He WANG; Minghang LI; Shaoping Shen

Considering influence from fluid inertia force, comparative analysis is made on Titan Aerobot. Firstly, a Titan atmospheric environment model, including the wind field model, is built. Secondly, the consistency method is employed to build dynamic model, to deduce aerodynamic parameters and fluid inertia force expression of Langley Aerobot and JPL Aerobot. Thirdly, influence from atmospheric environment and internal structure on dynamic characteristics of airships has been analyzed, concluding that fluid inertia force has remarkable influence. Fourthly, control effect of ballonets, empennage and propellers on flight path and attitude motion of airships is analyzed. Finally, two Titan Aerobot plans are compared.

10:40 AAS 14-403 Incorporating Physical Considerations In The Design Of Repetitive Controllers

Jianzhong Zhu, Columbia University; *Richard Longman, Columbia University*

Repetitive control (RC) can be used in spacecraft for vibration isolation of fine pointing equipment from vibration sources, e.g. reaction wheels, CMG's. RC can in theory completely eliminate periodic disturbance influence. Effective RC design methods create FIR compensators mimicking the inverse system frequency response. The gains can become large and ill conditioned. This paper develops design guidelines that acknowledge a series of physical considerations including: noise amplification for fast sample rates, the need for a learning cutoff, the discrepancy between intended and actual cutoff frequency, robustness to model error and the implication for cutoff of the compensator frequency

11:00 AAS 14-406 Elevating Ordinary Differential Equations to the Complex Domain - A Simple Cookbook Example

Alan Zorn, Stanford University; Donald Hitzl, Lockheed Palo Alto Research Lab (Retired); Frank Zele, Lockheed Martin Advanced Technology Center

A very simple first-order ordinary differential equation is elevated to the complex domain. The analytic solution is immediately available. However, the analytic solution can also be obtained by integrating the complexified differential equations in four variables. The first-order coherences given by the Cauchy-Riemann equations are displayed together with the newly-discovered second-order analytical coherences given by the perturbation derivative. As a result, new physical meanings are obtained for complex analytic functions. It is then shown how these new physical meanings can be applied to space flight mechanics revealing additional intuition and insight.

SESSION 20: EARTH MISSIONS

Session Chair: Aline Zimmer, Jet Propulsion Laboratory

8:00 **AAS 14-407** **Optimization of Lattice Flower Constellations for Intensity Correlation Interferometric Missions**

Sanghyun Lee, Texas A&M University; Daniele Mortari, Texas A&M University

This paper addresses the problem of designing suitable satellite constellation for intensity correlation interferometric missions. The Lattice Flower Constellations theory is here applied to design constellations maximizing coverage with in prescribe time limit. Optimizations are performed using Genetic Algorithms to estimate constellation design parameters. Optimization is constrained by altitude range (drag and Van Allen belt avoidance) and nodal precession is used. Numerical results clearly show the coverage gain of circular and elliptical Lattice Flower Constellations with respect to the classic string-of-pearls formations.

8:20 **AAS 14-408** **A Numerical Simulation-based Design of Operational Orbits for Multiple Sun-synchronous Spacecraft**

Tae Soo No, Chonbuk National University; Okchul Jung, Korea Aerospace Research Institute; Dae-Won Chung; Hwayeong Kim

In this paper, a purely numerical simulation and optimization approach is proposed in designing a sun-synchronous orbit. Specifically, the initial mission orbit is numerically propagated during a specified period, and necessary information are generated such right ascension of ascending node, nodal crossing time and position, geographical longitude of ascending node, longitude difference between two consecutive and contiguous nodal crossing points, etc. These information are used to form a cost function and a set of constraints that are pertinent to a particular design problem under consideration. Finally, the desired mission orbit is iteratively found using the numerical optimization.

8:40 **AAS 14-409** **Architecture Analysis Framework For Space Systems Supported By On-Orbit Refueling**

SeungBum Hong, Korea Advanced Institute of Science and Technology; Jaemyung Ahn, Korea Advanced Institute of Science and Technology

This paper proposes a general framework to compare the cost and benefit of different space system architecture alternatives, including architectures with support of on-orbit refueling function. A decision tree and real option theory are applied to embed the value of flexibility into architecture selection procedure. Multiple simulations with decision point information are performed to provide a guideline for designers to find out the necessity of on-orbit refueling architecture in the early stage of development. Case studies are also carried out to validate the framework.

9:00 **AAS 14-410** **Resonant perturbations with Earth's gravity field for GTO-like orbits.**
Jerome Daquin, IMCCE, Paris Observatory; Florent Deleflie, IMCCE; Pierre Mercier; Jerome Perez

This paper is devoted to the study of long-time evolution of artificial satellites that are in deep (2:1) resonance with the Earth's gravitational field. We present Poincare's sections that we realized in various dynamical configurations, in particular for some eccentric and inclined orbits. We'll be showing some practical results obtained from Lyapunov maps obtained with a specific version of the STELA. These maps will be compared with Lyapunov maps obtained with classical osculating integration. This last point is a first step towards the comparison between the osculator and mean chaos.

9:20 **AAS 14-411** **Revisiting The DSST Standalone Orbit Propagator**
Paul Cefola, University at Buffalo, State University of New York; Zachary Folcik, Arlington, MA; Romain Di-Costanzo, CS Communications & Systems; Nicolas Bernard, CSCommunications $ Systems; Srinivas Setty, DLR/GSOC; Juan Felix San-Juan, University of LA Rioja

The goal of the DSST Standalone Orbit Propagator is to provide the same algorithms as in GTDS DSST, without GTDS's overhead. However, this goal was not achieved. The 1984 DSST Standalone included complete models for the mean element motion but truncated models for the short-periodic motion. The 1997 update included the short-periodic terms due to tesseral linear combinations and lunar-solar point masses, 50 x 50 geopotential, and J2000 coordinates. However, the 1997 version did not demonstrate the expected accuracy improvement. Three projects undertaken by the authors since 2010 have led to the discovery of additional bugs

9:40 **Morning Break**

10:00 **AAS 14-413** **The observation of micron-size debris environment by using multi-satellite network for the IDEA project**
Mitsuhiko Tasaki, Kyushu University; Toshiya Hanada, Kyushu University; Kazuaki Ae, Kyushu University; Koki Fujita, Kyushu University

Space System Dynamics Laboratory in Kyushu University has initiated IDEA, the project for In-situ Debris Environmental Awareness to correctly understand current space debris problem. One method selected by IDEA project is using multi-measurement satellites that have a dust impact detector. Latest mission analysis demonstrated that a constellation of measurement satellites is very fruitful to detect micron-size debris. As future action assignments, we are going to analyze how many micron-size debris collide against a dust impact detector on the IDEA satellites and study how we can identify the orbits of breakup objects by using the collision data.

10:20 **AAS 14-414** **Safe Release of a Picosatellite from a Small Satellite Carrier in Low Earth Orbit**
Martin Wermuth, GSOC/DLR; Simone D'Amico, DLR; Gabriella Gaias

This paper addresses the design of a safe strategy to inject a picosatellite in low Earth orbit from a small satellite carrier. The preliminary design of the maneuvering strategy to establish a safe passively stable relative orbit is carried out in the relative orbital elements framework. Although the problem was initially motivated by the Autonomous Vision Approach Navigation and Target Identification (AVANTI) experiment onboard the Berlin Infrared Optical System (BIROS) spacecraft, the results of this paper allow the extension and generalization of the relative eccentricity/inclination vector separation method to a new class of distributed space systems.

10:40 **AAS 14-415** **Designing Chip-sized Spacecraft for Missions to L4/L5 Lagrangian Points in the Earth-Moon System**

Lorraine Weis, Cornell University; Mason Peck

Chip-scale spacecraft represent a novel, inexpensive way to explore the triangular Lagrangian points of the Earth-Moon system. The dynamics of particles in these regions have intrigued scientists for decades. This paper examines the feasibilty of a mission using a swarm of chip-scale spacecraft rather than a monolithic spacecraft strategy. In aggregate, the swarm will maintain a position near the triangular points, thus establishing distributed sensors through the region. We present simple navigational strategies for this proposed swarm, suited for the lower power and mass requirements of chip-scale spacecraft.

SESSION 21: OPTICAL NAVIGATION

Session Chair: Lincoln Wood, Jet Propulsion Laboratory

13:30 AAS 14-418 Asteroid Characterization via Stellar Occultation: SNR Calculation and Observation Opportunities

David Hyland, Texas A&M University; Haithem Altwaijry, King Abdulaziz City for Science and Technology

This paper develops additional results supporting the novel asteroid characterization technique which uses the theory of the diffraction of shadows and phase retrieval technology to determine the size and shape of hazardous Near-Earth Asteroids (NEAs) via stellar occultation. In particular, we obtain an estimate of the SNR with which the silhouette of NEAs in the 140-to-40 meter diameter class can be determined. Via a Monte Carlo approach we estimate the rate at which a given NEA is occulted by a star of given apparent magnitude. Thanks to the abundance of stars above 10th magnitude, occultation observations will

13:50 AAS 14-419 Fuzzy Logic Approach Strategy Based Feature Point Measurements For Asteroid Exploration Guidance

Hongliang Ma; Shijie Xu

In this paper, a fuzzy logic approach strategy based feature point measurements of asteroid surface is presented for asteroid exploration guidance. According to the feature points of asteroid surface and the established 3D model of asteroid measured via laser imaging detection and ranging sensor, the fuzzy logic approach strategy based on Takagi-Sugeno-Kang fuzzy controller is designed via four processes with different number of feature points. Numerical simulations are undertaken to verify the feasibility of the fuzzy logic approach strategy with all mentioned processes and evaluate its adaptability for the influence of the uncertainty change of asteroid model parameters.

14:10 AAS 14-421 Optical and Infrared Sensor Fusion for Hypervelocity Asteroid Intercept Guidance

Joshua Lyzhoft

This paper presents a new terminal-phase guidance system architecture for a hypervelocity asteroid intercept vehicle (HAIV). All previous terminal-phase guidance system studies for asteroid intercept have considered mainly optical cameras due to their cost-effectiveness and acceptable tracking, demonstrated by Deep Impact mission. However, this paper considers a blended use of optical and infrared (IR) sensors for intercept of asteroids (50-150 m). Preliminary design of a reference 100-kg class IR sensor system for a 1000-kg class HAIV is described. The intercept performance of a closed-loop guidance system employing optical and IR sensors is demonstrated

14:30 **AAS 14-420** **Lidar And Optical-Based Autonomous Navigation For Small Body Proximity Operations**

Matthew Abrahamson, NASA / JPL-CalTech; Shyam Bhaskaran, NASA / JPL-CalTech

Future missions to small bodies will require greater onboard navigation capabilities to execute orbit surveys, landings, impacts, and sample return scenarios. This paper explores the performance of an onboard navigation system using lidar measurements of slant range to the small body surface and optical measurements of surface landmarks during orbiting and landing scenarios. Performance relative to shape model fidelity is explored, with a simple triaxial ellipsoid shape model compared to a highly refined faceted plate model. Variations in measurement frequency, orbit determination (OD) update frequency, measurement weighting, and measurement density are investigated in each scenario.

14:50 **AAS 14-422** **Small Body Optical Navigation Using the Additive Divided Difference Sigma Point Filter**

Corwin Olson, UT Austin; Ryan Russell, The University of Texas at Austin

An Additive Divided difference sigma point Filter (ADF) is employed for optical navigation of a spacecraft near a small body. The ADF is chosen to better address the problem nonlinearities, especially for cases with few available landmarks and uncertain measurements. Performance of the ADF is shown to be favorable to that of traditional filters such as the Extended Kalman Filter, Batch Least Squares, and a two-level nested Batch Least Squares approach from a recent similar study.

15:10 **AAS 14-423** **Autonomous Rendezvous and Proximity Operations Using Flash LIDAR and Optical Measurements**

Steven Gehly, University of Colorado at Boulder; Jay McMahon, University of Colorado; Penina Axelrad

Autonomous rendezvous and docking between satellites offers a cost-effective alternative to manned missions to repair and refuel satellites on orbit. The central problem is estimation of the relative position and attitude (pose) between the two satellites. The use of optical and Light Detection and Ranging (LIDAR) instruments allows features to be extracted from the target spacecraft, which can then be compared to a reference model to solve the relative pose problem. This paper summarizes the development of algorithms necessary to solve the problem and applies them to a simulated spacecraft rendezvous scenario.

15:30 **Afternoon Break**

SESSION 22: SPACE ENVIRONMENT

Session Chair: Marcus Holzinger, Georgia Institute of Technology

13:30 AAS 14-424 **Orbital Evolution Of Dust Particles Originating From Jupiter's Trojan Asteroids**
Aline K. Zimmer, NASA / JPL-CalTech; Keith Grogan, NASA / JPL-CalTech

The objective of this study is to characterize the dust environment encountered on a mission to Jupiter's Trojan asteroids. Dust particles are assumed to separate from parent bodies and the orbital evolution of these particles under the influence of planetary gravitational perturbations, radiation pressure, PR drag, and solar wind drag is studied. The initial distribution of dust particles is derived from the population of Trojan asteroids and propagated for 500,000 years. In this manner, the fate of these particles is determined giving insight into which particle sizes become unbound or remain in the vicinity of Jupiter's orbit.

13:50 AAS 14-425 **Space Weather Influence on Relative Motion Control using the Touchless Electrostatic Tractor**
Erik Hogan, University of Colorado at Boulder; Hanspeter Schaub, University of Colorado

With recent interest in the use of electrostatic forces for contactless tugging and attitude control of noncooperative objects, the need for a method of remote charge control arises. In this paper, the use of a directed electron beam for remote charge control is considered. The relative position feedback control between the tug and the passive debris object is studied subject to electron beam charge control. Two control strategies are considered. In one, the beam current is modified to compensate for changing space weather conditions. In the other, a constant current is maintained throughout the duration of the maneuver.

14:10 AAS 14-426 **Determining Orbits That Can Be Controlled By Natural Forces Effects Of Eccentricity And Inclination**
Thais Oliveira; Arun Misra; Antonio Fernando Prado; Evandro Rocco

This paper aims to map orbits based on the magnitude of the perturbation forces. Particularly, the effects of the inclination and the eccentricity of the orbit in those mappings are studied. The perturbation forces are the solar radiation pressure, the LuniSolar perturbation, the zonal harmonics J2 to J4 and the atmospheric drag. The mappings are based on the integral of those perturbation forces over time. The results of these integrals are the velocity change the perturbation causes on the satellite. Also the necessary conditions to use the solar sail to reduce the other perturbations acting on the satellite are considered.

14:30 **AAS 14-427** **Impact Probability Analysis for Near-Earth Objects in Earth Resonant Orbits**
George Vardaxis, Iowa State University; Bong Wie, Iowa State University

Accurate estimation of the impact probability of near-Earth objects (NEOs) is required for planning a space mission to mitigate their threat. There are several methods that can be used to determine the odds of an asteroid impacting the planet. Methods incorporating analytic encounter geometry analyses, target b-planes, and analytic keyhole and resonant orbit theory are useful in obtaining a quick rough estimation of the impact probability. Taking the advantages of a direct numerical simulation approach, incorporating analytic keyhole theory, this paper presents a new computational approach to accurately estimating the impact probability of NEOs in Earth resonant orbits.

14:50 **AAS 14-428** **Passive Electrostatic Charging Of Near-Geosynchronous Space Debris HAMR Objects And Its Effects On The Coupled Object Dynamics**
Carolin Frueh, Texas A&M University; Moriba Jah, Air Force Research Laboratory; Dale Ferguson , Air Force Research Laboratory; Chin Lin , Air Force Research Laboratory

Anomalies caused by charging of operational satellites is a well investigated topic. But little to no attention has been paid to the charging of non-operational objects. The orbital and attitude dynamics however, are significantly altered by passive electrostatic charging of objects and their motion relative to the Earth magnetic field. This paper investigates the effect of charging in the near geostationary regime of a special class of space debris objects. So-called high area-to-mass ratio (HAMR) objects are very sensitive to perturbations. This paper shows the significant effect charging has on their orbit and attitude evolution.

15:10 **AAS 14-429** **New Model For The Thermal Radiation Of Space Objects And Its Effects On Yorp And Yarkowski Of High-Area-To-Mass Ratio (HAMR) Objects**
Carolin Frueh, Texas A&M University

Commonly used models for the thermal re-radiation of space objects are mathematically very simple but also insufficient. This paper suggests an improved thermal model, which is still computationally inexpensive. The effects of using different models on the attitude and orbit dynamics of objects with high area-to-mass ratios (YORP and YARKOWSKI) is shown. The differences are significant even for only a couple of hours of propagation time.

15:30 **Afternoon Break**

SESSION 23: ORBIT DETERMINATION II

Session Chair: Geoffrey Wawrzyniak, a.i. Solutions

13:30 **AAS 14-430** **Precise Non-Gravitational Forces Modeling for GOCE**
Stefano Casotto, Universita' di Padova; Francesco Gini, CISAS "G.Colombo" - University of Padova; Massimo Bardella, Universita' di Padova

GOCE (ESA) is orbiting at 250 km to recover the Earth's gravity field and is subject to strong non-gravitational perturbations requiring highly precise modeling. A new methodology has been developed based on ray-tracing techniques, which is a significant improvement over the commonly used macro modeling. Models for aerodynamics, solar radiation pressure, Earth radiation, and spacecraft thermal re-radiation are presented. The results of applications to GOCE show a significant decrease of the estimated empirical accelerations and of the post-fit RMS, which confirm the goodness of the approach.

13:50 **AAS 14-431** **Utilization of Uncertainty Information in Angles-Only Initial Orbit Determination**
Christopher Binz, Naval Research Laboratory; Liam Healy, Naval Research Laboratory

In an initial orbit determination (IOD) problem with known sensor uncertainty characteristics, we may derive probabilistic information beyond the typical point solution. In our previous work (AAS 13-822), we demonstrated methods of determining state uncertainty estimates directly from an angles-only IOD process. This paper extends the previous work by applying it to other IOD methods using angles-only observations, as well as simulating different orbits and observation geometries. We also explore performance for using the IOD state and uncertainty estimate as an initial guess when processing additional observations. The sigma point method described previously is also expanded upon.

14:10 **AAS 14-432** **LiAISON Tracking for a Lunar Farside Sample Return Mission**
Ryan McGranaghan, University of Colorado at Boulder; Jason Leonard, University of Colorado at Boulder; George Born, University of Colorado at Boulder; Ann Dietrich, University of Colorado Boulder; Jeffrey Parker, University of Colorado; Siamak Hesar, University of Colorado Boulder

Autonomous orbit determination is conducted between a spacecraft orbiting at the Earth-Moon L2 point and a simulated lander ascending from the farside lunar surface. Navigation of the vehicle from the surface to an L2 libration point orbit rendezvous is explored. Estimation of the lander's trajectory is conducted using satellite-to-satellite tracking via Linked Autonomous Interplanetary Satellite Orbit Navigation (LiAISON). A set of trade studies is explored, varying quantity and type of tracking, ascent trajectory parameters, and whether the LiAISON satellite is robotic or crewed. The navigation solution for the lander's trajectory is dramatically improved using LiAISON.

14:30 AAS 14-433 K-Vector Approach for Extensive Solving of the Kepler Equation

Stoian Borissov, Texas A&M University; Francesco de Dilectis, Texas A&M University; Daniele Mortari, Texas A&M University

This paper provides a method for solving Kepler's Equation using an optimal look-up table. Motivation comes from problems such as Keplerian or J2 analytical performance analysis, conjunction analysis of satellite constellations, or any problem where repeated solving of the Kepler equation for the same elliptical orbit is needed. The proposed method requires buildingan optimal look-up table where linear interpolation provides an estimate solution of the Kepler Equation. The look-up table is then accessed via the k-vector technique, a searchless range searching technique.

14:50 AAS 14-434 Uncertainty Quantification for Angles-Only Initial Orbit Determination

Ryan Weisman, Air Force Research Laboratory; Moriba Jah, Air Force Research Laboratory

This paper addresses appropriately characterizing the state uncertainty distribution within the range and range-rate solution space for the problem of angles-only initial orbit determination of resident space objects. The transformation of variables technique is applied to map the measurement uncertainty of angles-only tracklets into the range and range-rate domain using dynamics as the distribution link as well as angular-velocity and angular-acceleration using Taylor Series. The mapping technique allows for improved characterization of the state uncertainty distribution within the energy and eccentricity constrained admissible region associated with the angles-only initial orbit determination process.

15:10 AAS 14-435 Reconstruction Of Earth Flyby By The Juno Spacecraft

Paul Thompson, NASA / JPL-CalTech; Matthew Abrahamson, NASA / JPL-CalTech; Shadan Ardalan, NASA / JPL-CalTech; John Bordi, NASA / JPL-CalTech

The Juno spacecraft conducted a successful gravity-assist flyby of the Earth on 9 October 2013, helping the spacecraft to reach Jupiter in July 2016. The DSN tracking was supplemented by tracking from two ESA stations, giving us an unprecedented, near continuous level of tracking for an interplanetary spacecraft flyby of Earth. We discuss the process of reconstructing that trajectory, the challenges encountered in that effort, and the results. In particular, no anomalous velocity change was observed at or near perigee as has been observed in previous Earth flybys by other spacecraft.

15:30 Afternoon Break

SESSION 24: AERONOMY SPECIAL SESSION

Session Chair: David Finkleman, SkySentry Stratospace Technologies

13:30 AAS 14-437 The Intersection of Satellite Aerodynamics and Aeronomy

David Finkleman, Center for Space Standards and Innovation; David Vallado, Center for Space Standards and Innovation; Josef Koller, Los Alamos National Laboratory

We will describe the intersections of descriptions of the atmosphere for different purposes. Orbit determination either requires or estimates aerodynamic forces that satellites experience in the tenuous atmosphere. Aeronomy, characterization of the tenuous atmosphere requires objects whose aerodynamic characteristics are well known. The disciplines invoke diverse assumptions about the nature of interactions between the gasdynamic environment and satellites of different geometries and surface characteristics. Estimating either aerodynamic forces or the composition and distriution of properties of the atmosphere pivots on these assumptions. We will expose the issues that these assumptions create for the different disciplines, introducing companion papers addressing them.

13:50 AAS 14-330 Multi-Model Orbital Simulation Development with Python

Sean Brennan, Los Alamos National Laboratory

The Integrated Modeling of Perturbation in Atmospheres for Conjunction Tracking (IMPACT) project integrates drag modeling, orbit propagation, and conjunction analysis to better predict collisions in orbit. This is built on, and propels the further development of, our integration architecture: /SysDevel/. The =sysdevel= Python package generically aids multi-model simulation development through model coupling, data visualization and collaborative software distribution. We describe in detail how /SysDevel/ handles each of these tasks, and the ongoing challenges they present, as a case study of the IMPACT project's integration efforts.

14:10 AAS 14-436 Gas-Surface Interactions for Satellites Orbiting in the Lower Exosphere

Andrew Walker, Los Alamos National Laboratory; Michael Shoemaker, Los Alamos National Laboratory; Josef Koller, Los Alamos National Laboratory; Piyush Mehta, Los Alamos National Laboratory

Sensitivity analyses have revealed that drag coefficients are most sensitive to the gas-surface interaction (GSI). In the lower exosphere, the nature of the GSI remains largely a mystery due to conflicting observations. Recent work has shown that fitted drag coefficients for STELLA cannot be fit by simple adsorption models but are well fit by diffuse reflection with complete accommodation, implying adsorbate coverage or erosion due to energetic particles. The goal of this work is to compute fitted drag coefficients for spherical satellites orbiting in the lower exosphere and investigate temporal variations in the drag coefficients that may indicate erosion.

14:30 **AAS 14-341** **Simultaneous Estimation of Atmospheric Density and Satellite Ballistic Coefficient Using a Genetic Algorithm**

Michael Shoemaker, Los Alamos National Laboratory; Andrew Walker, Los Alamos National Laboratory; Josef Koller, Los Alamos National Laboratory

This research describes a new method to estimate simultaneously the spatially-resolved thermospheric neutral density and drag ballistic coefficient for a number of target satellites. A genetic algorithm is used to find an optimal set of density model parameters and ballistic coefficients that minimizes the position error, compared against ground-based tracking of the satellites. The method has advantages over existing methods, which rely on a priori knowledge of the targets' ballistic coefficients in order to estimate the current state of the density. Simulation results are presented using different satellite configurations and genetic algorithms.

14:50 **AAS 14-200** **The IMPACT Framework for Enabling System Analysis of Satellite Conjunctions**

Josef Koller, Los Alamos National Laboratory; Sean Brennan, Los Alamos National Laboratory; David Higdon; Moriba Jah, Air Force Research Laboratory; Thomas Kelecy, Boeing LTS; Alexei Klimenko, Los Alamos National Laboratory; Brian Larsen, Los Alamos National Laboratory; Earl Lawrence; Richard Linares, University at Buffalo, State University of New York; Craig McLaughlin, University of Kansas; Piyush Mehta, Los Alamos National Laboratory; David Palmer, Los Alamos National Laboratory; Aaron Ridley, University of Michigan; Michael Shoemaker, Los Alamos National Laboratory; Eric Sutton, US Air Force; David Thompson, Los Alamos National Laboratory; Andrew Walker, Los Alamos National Laboratory; Brendt Wohlberg, Los Alamos National Laboratory; Humberto C. Godinez, Los Alamos National Laboratory

The IMPACT project (Integrated Modeling of Perturbations in Atmospheres for Conjunction Tracking) has developed an integrated system of atmospheric drag modeling, orbit propagation, and conjunction analysis with detailed uncertainty quantification to address the space debris and collision avoidance problem. We are combining physics-based density modeling of the upper atmosphere, satellite drag forecasting for quiet and disturbed geomagnetic conditions, and conjunc-tion analysis with non-Gaussian uncertainty quantification. The IMPACT framework is an open research framework enabling the exchange and testing of a variety of models. We will present capabilities and results including a demo of the control interface and

15:10 **AAS 14-441** **Comparison of Satellite Orbit Tomography with Simultaneous Atmospheric Density and Orbit Estimation Methods**

Michael Shoemaker, Los Alamos National Laboratory; Brendt Wohlberg, Los Alamos National Laboratory; Richard Linares, University at Buffalo, State University of New York; David Palmer, Los Alamos National Laboratory; Alexei Klimenko, Los Alamos National Laboratory; David Thompson, Los Alamos National Laboratory; Josef Koller, Los Alamos National Laboratory

Satellite orbit tomography is a newly developed method for addressing the Dynamic Calibration of the Atmosphere (DCA). The focus of this paper is a side-by-side comparison with other DCA methods that use the raw tracking measurements and solve simultaneously for the orbit state and parameterized density. The main contribution of this work is to test the notion that, in general, an estimator benefits from using raw measurements to solve for the state, in contrast with an estimator that uses intermediate estimated quantities in place of the raw measurements. Status updates are also given on a LANL observational campaign.

15:30 **Afternoon Break**

SESSION 26: DYNAMICS AND CONTROL OF LARGE SPACE STRUCTURES & TETHERS

Session Chair: Maruthi Akella, University of Texas at Austin

8:00 AAS 14-442 Dynamics and Controls of a Generalized Frequency Domain Model Flexible Rotating Spacecraft

Tarek Elgohary, Texas A&M University; James Turner, Texas A&M University

A flexible rotating spacecraft is modeled as a hybrid system consisting of a rigid rotating hub, a flexible appendage and a tip mass. Hamilton's extended principle is used to derive the equations of motion and the boundary conditions of the system. A generalized state space model for the frequency domain representation of the system is derived. Analytical closed form solution is derived and used to generate transfer functions for the system response in terms of the input torque. Frequency domain control design techniques are used with the exact transfer functions for controlling the spacecraft and the attached appendages.

8:20 AAS 14-443 Tether Design Considerations for Large Thrust Debris De-orbit Burns

Lee Jasper, University of Colorado; Hanspeter Schaub, University of Colorado

The use of tethers in space has been applied to many concepts, most recently towing in space. Active debris removal, asteroid retrieval, and satellite servicing all may require a towing vehicle that can maneuver a large object. Because a tether is not rigid, post-maneuver collision avoidance is a critical concern. Earlier work with input-shaped towing strategies resulted in the tug and debris aligning with the gravity gradient stable nadir axis. However, the tether property design space (length, damping, elasticity) will be considered because it may also be exploited to create a post-burn, collision free trajectory into the

8:40 AAS 14-444 Gravitational Actions upon a Tether in a Non-Uniform Gravity Field with Arbitrary Number of Zonal Harmonics

Hodei Urrutxua, Technical University of Madrid (UPM); Jesus Pelaez, Technical University of Madrid (UPM); Martin Lara

We develop general closed-form expressions for the mutual gravitational potential, resultant and torque acting upon a rigid tethered system moving in a non-uniform gravity field produced by an attracting body with revolution symmetry, so that an arbitrary number of zonal harmonics is considered. We conclude that for high precision applications it might be necessary to take into account additional perturbing terms, which come from the mutual Two-Body interaction, and become as important as some of the higher degree zonal harmonics.

9:00 **AAS 14-445** **Orbital Dynamics of Large Solar Power Satellites**
Ian McNally, University of Glasgow; Daniel Scheeres, University of Colorado; Gianmarco Radice, University of Glasgow

The solar power satellite (SPS) is an extremely large satellite designed to collect solar energy in space and transmit it to Earth via microwaves. The primary objective of this study is to perform detailed analysis of SPS orbit dynamics. Previous studies have assumed a geostationary (GEO) SPS, and then designed control systems for maintaining it. It is found that an alternative SPS orbital location known as the geosynchronous Laplace plane (GLP) is superior to GEO. A SPS in GLP requires nominal fuel to maintain its orbit, avoids the main orbital debris population originating from GEO satellites, and is extremely robust.

9:20 **AAS 14-446** **Discretized Input Shaping for a Large Thrust Tethered Debris Object**
Lee Jasper, University of Colorado; Hanspeter Schaub, University of Colorado

Towing objects in space has become an increasingly common concept. Asteroid retrieval , satellite servicing, and debris removal concepts often rely on a thrusting vehicle to maneuver a passive object. One effective way to tow the object is through a tether. A discretized tether model, attached to six degree-of-freedom end bodies, is employed. Because the system is not rigid, collision avoidance between the end bodies is accomplished by means of input shaping using continuous, discrete, and impulsive thrust profiles. On-orbit simulations show the tethered system achieves oscillations about a gravity gradient alignment, reducing the post-burn collision likelihood.

9:40 **Morning Break**

10:00 **AAS 14-447** **Generalized Frequency Domain Solution for a Hybrid Rigid Hub Timoshenko Beam Rotating Aerospace Structure**
Tarek Elgohary, Texas A&M University; James Turner, Texas A&M University

A hybrid system consisting of a rotating rigid hub and a flexible appendage following the Timoshenko beam assumptions is introduced. Generalization of Lagrange's equations utilizing Hamilton's extended principle is used to derive the equations of motion and the boundary conditions of the system. A generalized state space model is constructed in the frequency domain for the hybrid system. The beam sub-problem is solved to provide the full system solution. The solution is used to generate transfer functions for both the rigid and the flexible modes of the system in terms of the input torque.

10:20 **AAS 14-448** **Jovian Orbit Capture and Eccentricity Reduction Using Electrodynamic Tether Propulsion**
Maximilian Schadegg, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin; Gregory Lantoine, NASA / JPL-CalTech

Electrodynamic tether propulsion is attractive for outer planet missions, which are traditionally handicapped by scarcity of power available and large propellent requirements. In this paper, the orbital dynamics of an electrodynamic tether spacecraft during capture, apojove pump-down and perijove pump-up phases at Jupiter are investigated. The main result is the mapped design space involving mission duration, tether length and minimum perijove radius. Phase-free flyby sequences and bang-bang control laws are also included, which provide performance upper bounds for a given mission architecture. These design trades are useful for any future planetary missions considering electrodynamic tether propulsion.

10:40 **AAS 14-449** **Long-Term Dynamics of Fast Rotating Tethers Around Planetary Satellites**

Hodei Urrutxua, Technical University of Madrid (UPM); Jesus Pelaez, Technical University of Madrid (UPM); Martin Lara

We derive the coupled equations of motion and rotational dynamics for Fast Rotating Tethers orbiting planetary satellites, and average them in the fastest time scales in the problem, yielding equations that govern the long-term variations of the mean orbital elements, as well as the attitude of the tether plane of rotation. We study the coupled dynamics in the long time scales, with special focus on frozen orbits and how these depend on the orientation of the tether plane of rotation.

11:00 **AAS 14-450** **OKID as a Unified Approach to System Identification**

Francesco Vicario, Columbia University; Raimondo Betti, Columbia University; Richard Longman, Columbia University; Minh Phan, Dartmouth College

The OKID/ERA algorithm (Observer/Kalman filter Identification followed by Eigensystem Realization Algorithm) distributed by NASA has proven to be very effective for the identification of lightly damped structures when the measurements are corrupted by noise. This paper presents a generalization of the OKID method. It takes a new approach based on the estimation of the Kalman residuals and uses them to construct a new noise-free problem that can be solved by any deterministic identification algorithm, establishing OKID as a unifying method in system identification. Several new identification algorithms are derived and compared via both numerical and experimental examples.

11:20 **AAS 14-451** **On-Line Mass Estimation For A Tethered Space Debris During Post-Capture And Retrieval**

Fan Zhang; Inna Sharf, Mcgill University; Arun Misra

This paper presents a new methodology for on-line mass estimation for massive space debris captured by a tethered satellite, which is critical for subsequent tasks, in particular, for debris retrieval and deorbiting. The mass estimation problem is formulated and solved in two phases. First, a coarse estimate of the target mass is obtained during the post-capture phase, while the tethered system is experiencing in-plane and out-of-plane oscillations. Then, with a proper tension control scheme and the coarse estimate used as an initial guess, the debris is retrieved smoothly and a precise mass estimate is achieved.

SESSION 27: ATTITUDE DYNAMICS AND CONTROL

Session Chair: Kyle DeMars, Missouri University of Science and Technology

8:00 **AAS 14-452** **External Torques Affecting the Attitude Motion of a Mercury Orbiter**
Takahiro Kato, German Aerospace Center (DLR); Jozef van der Ha, Consultant; Stephan Theil, DLR German Aerospace Center

This paper investigates the attitude effects on a Mercury orbiter due to the non-gravitational disturbances together with gravity gradient torque of Mercury. The harsh solar flux on Mercury induces a strong constraint on the satellite attitude orientation with respect to the Sun direction. After making relevant assumptions,simplified orbit and attitude orientation models can be established. On top of the analytical descriptions provided in the previous study based on MESSENGER, torque calculation methods are implemented including the gravity gradient effects. The detailed attitude effects under different attitude control modes and several Mercury orbit conditions are presented.

8:20 **AAS 14-453** **Analytical Solution for Flat-Spin Recovery of Spinning Satellites**
Frank Janssens, Retired; Jozef van der Ha, Consultant

The paper presents new results in self-excited rigid-body motion with application to spinning satellites under a continuous constant body-fixed torque. A straightforward analytical solution for a flat-spin recovery maneuver is presented. The concept uses a torque about the axis of minimum inertia. The motion is similar to a pendulum which is either oscillating (no recovery) or revolving (recovery) with increasing angular velocity. The transition between these two cases corresponds to the minimum required torque level. The results are of significant interest for the design of spacecraft that spin about the minimum inertia axis.

8:40 **AAS 14-454** **Globalstar Second Generation Hybrid Attitude Control On-Orbit Experience**
Johannes Hacker Thales, Globalstar Inc.; Laurent Houis, Thales Alenia Space; Jim Goddard, Globalstar Inc.; Peter Lai, Globalstar Inc.

GB2 is Globalstar's second generation communication satellite fleet manufactured by Thales Alenia Space and launched in four batches starting in October 2010. It currently consists of 24 satellites in the constellation to provide worldwide satellite phone and data services. The reaction wheel is one of the most reliable attitude control components in the spacecrafts. However, due to increasing demand in mission life and reaction wheel design change, reaction wheel anomalies have been increasing recently industry-wide. To extend the lifetime of the GB2 fleet, a two-wheel hybrid control was developed and successfully implemented in the satellites on orbit.

9:00 **AAS 14-455** **Design Procedure of Chattering Attenuation Sliding Mode Attitude Control of a Satellite System**

Hamidreza Nemati, Kyushu University; Shinji Hokamoto, Kyushu University

This study presents a design procedure for a new robust nonlinear control algorithm based on the theory of non-singular terminal sliding mode (NTSM) to control the attitude of a satellite. Since conventional NTSM controllers include a discontinuous function, a significant problem called chattering can occur. In this paper, a methodology for designing a new switching function is discussed to alleviate this drawback over time. Besides, to highlight the robustness of the proposed method against model parameter uncertainties, a satellite with three pairs of thrusters subject to parameter variation is simulated.

9:20 **AAS 14-457** **Architectures for Vibrating Mass Attitude Control Actuators**

Burak Akbulut, METU Aerospace Engineering Dept.; Ozan Tekinalp, METU Aerospace Engineering Dept.

Reaction wheels, magnetic torque rods, momentum wheels and CMGs are the most common actuators used in attitude control. However, they use rotor and/or gimbal mechanisms susceptible to failure. An alternative solution may be vibrating mass actuators. Previous research by Reiter et al and Chang et al showed the possibility of obtaining a net output torque from vibrating actuators. To build upon this, current research aims to expand the vibratory actuators to different and more complex architectures such as double axis CMGs. Additionally simulation models will be built to investigate their functioning in satellite attitude pointing scenarios.

9:40 **Morning Break**

10:00 **AAS 14-458** **Takagi-Sugeno Fuzzy Model-Based Attitude Control Of Spacecraft With Partially-Filled Fuel Tank**

Lilit Mazmanyan, Santa Clara University; Mohammad Ayoubi, Santa Clara University

This paper presents a Takagi-Sugeno fuzzy model-based controller to stabilize the attitude of spinning spacecraft with a partially-filled fuel tank during a transfer orbit maneuver. First, the nonlinear equations of motion of spacecraft containing a liquid fuel store and momentum wheels are presented briefly. Then, the fuzzy modeling and the parallel distributed compensation control technique are applied. The proposed fuzzy controller utilizes full-state feedback with bounded control input. Using the Lyapunov stability theorem, the fuzzy control design problem is formulated in terms of linear matrix inequalities. We evaluate the presented control system performance via numerical simulation

10:20 **AAS 14-459** **Attitude Passive Stability Criteria Of Axisymmetric Solar Sail Under A General SRP Model**

Xiaosai Hu; Gong Shengping

Attitude passive stability criteria of a solar sail whose membrane surface is axisymmetric are studied in this paper under a general SRP model. This paper proved that arbitrary attitude equilibrium position can be designed through adjusting the deviation between the center of the pressure and the center of the mass of the system. Two different linearization methods are adopted to analyze the stability of the attitude equilibrium. The results show that the attitude stability depends on the membrane surface shape and area. Several numerical examples are presented to validate the criteria.

10:40 **AAS 14-460** **Path Planning for Flexible Satellite Slewing Maneuvers: A Spectrum-Analysis-Based Approach**

Tingxuan Huang; Shijie Xu, Beihang University

A new path planning approach based on spectrum analysis is proposed for flexible spacecraft slewing maneuvers. First, the characteristics of traditional Bang-Coast-Bang Path and Sinusoidal angular acceleration path are analyzed by deriving and plotting the amplitude spectrums of the acceleration trajectories. Then, to reduce structural excitations. a modified path planning method is proposed from a frequency-domain point of view. This approach transforms the vibration reduction problem into constraints on maneuver time, the maximum angular acceleration and maximum angular velocity. Finally, a path planning example and a numerical simulation are presented to validate the new method.

11:00 **AAS 14-461** **CMG Momentum Management For Spacecraft In Inertial Frame**

Mengping Zhu, China Academy of Space Technology; Xinlong Chen, China Academy of Space Technology CAST; Shijie Xu; Yue Wang, Beihang University

The concept of momentum management was proposed to slow down the momentum accumulation of CMGs. In this paper, emphasis is on the momentum management for the long-life spacecraft which are normally inertia oriented. Stable operating attitudes for momentum management and comparisons of CMG momentum accumulations with and without momentum management are illustrated. Constraints on the moment of inertia properties and the CMG capacities for successful momentum management are analyzed. An optimal momentum management controller is developed. Both the theoretical analysis and the effectiveness of the controller are tested and verified through simulations.

11:20 **AAS 14-462** **Chatter Avoidance In Delayed Feedback Attitude Control With MRP Shadow Set Switching**

Eric Butcher, New Mexico State University; Ehsan Samiei, New Mexico State University

The chattering response at the MRP shadow set switching point for the controlled attitude dynamics of a rigid tumbling spacecraft using delayed state feedback control with MRPs is investigated, where the time delay is assumed to be in the measurement of the state. In addition, a strategy to reduce or completely avoid the chattering phenomena using a hysteretic boundary layer switching rule is employed. Simulations are performed to demonstrate the chattering phenomenon and the advantages of the modified MRP shadow set switching rule.

SESSION 28: LUNAR MISSION DESIGN

Session Chair: Jeffrey Parker, University of Colorado

8:00 **AAS 14-464** **Orbit Design Considerations for Precision Lunar Landing for a Sample Return Mission**
Zhong-Sheng Wang, China Academy of Space Technology ; Adly Espinoza

A lunar probe for a sample return mission achieves a circular orbit after the lunar orbit insertion maneuvers, and then enters an elliptical orbit before the descent. It is demonstrated in this paper that a plane change maneuver and a two-by-two targeting maneuver can be used to help achieve the precision landing on the lunar surface. It is essential to use a descent dynamic model with high fidelity and have accurate information of the guidance law used during the powered descent. Also demonstrated is an orbit design technique that uses the tracking condition as a natural time reference.

8:20 **AAS 14-465** **Some Options for Lunar Exploration Utilizing the Earth-Moon L2 Libration Point**
David Dunham, KinetX, Inc.; Robert Farquhar, KinetX, Inc.; Natan Eismont, Space Research Institute; Evgeny Chumachenko, Moscow Institute of Electronics and Mathematics/HSE; Sergey Aksenov, Moscow Institute of Electronics and Mathematics/HSE; Yulia Fedorenko, Moscow Institute of Electronics and Mathematics/HSE; Iulia Nickolaeva, Moscow Institute of Electronics and Mathematics/HSE; Katrina Efrimova, Moscow Institute of Electronics and Mathematics/HSE; Pavel Krasnopolski, Moscow Institute of Electronics and Mathematics/HSE; Roberto Furfaro, The University of Arizona; John Kidd, University of Arizona

The Moon is a logical next step for human exploration beyond low-Earth orbit. The lunar far side remains unexplored by landed spacecraft. From Earth-Moon L2 libration-point orbits, astronauts could operate robotic spacecraft on the lunar farside. Such orbits can also be used as transportation nodes for reaching more distant destinations. We investigate low deltaV trajectories that simply loop around L2, spending nearly two weeks over the lunar back side. Also investigated are the occultation times for Earth ground stations for Lissajous orbits of different sizes, and the deltaV costs to reach and return from such orbits.

8:40 **AAS 14-466** **Study Of Gravitational Lunar Capture In The Bi-Circular Problem**
Yi Qi; Shijie Xu, Beihang University; Rui Qi; Yue Wang, Beihang University

In this paper, gravitational lunar capture in the bi-circular problem is studied. Corrected ratio of the radial force is presented to derive capture eccentricity in the bi-circular model. Considering time-of-flight restriction and corrected ratio, we study the minimum capture eccentricity in the bi-circular model and discover in two special regions the capture point on direct orbit possesses the global minimum eccentricity, which means the optimal quality of capture. Numeric methodology reveals the relationship between capture points and the enter points on the sphere of influence. At last, we apply our results to the trajectory designing.

9:00 **AAS 14-467** **Various Transfer Options from Earth into Distant Retrograde Orbits in the Vicinity of the Moon**

Lucia Capdevila, Purdue University; Kathleen Howell

Future applications within the Earth-Moon neighborhood under a variety of mission scenarios, such as NASA's Asteroid Redirect Mission (ARM), may exploit lunar Distant Retrograde Orbits (DROs). Thus, further investigation of transfers to and from these orbits is useful. The current study is focused on transfer trajectory options that employ impulsive maneuvers to deliver a vehicle from Low Earth Orbit (LEO) into various lunar DROs. The stability region surrounding specific DROs, as modeled in the Earth-Moon Circular Restricted Three-Body (CR3B) problem, may also serve to facilitate the transfer design process and is explored within that context.

9:20 **AAS 14-468** **Low-energy Escape from the Sun-Earth L2 Utilizing Unstable Manifolds and Lunar Gravity Assist**

Hongru Chen, Kyushu University; Yasuhiro Kawakatsu, JAXA / ISAS; Toshiya Hanada, Kyushu University

The paper analyses escape trajectories utilizing lunar gravity assist and unstable manifolds of the Sun-Earth L2 point. There are 4 cases of crossing resulting from the intersection of the manifold tubes associated with the halo orbits and the orbit of the Moon. The 4 crossings have different V-infinity with respect to the Moon. The corresponding lunar gravity assists can result in a range of excess velocities with respect to the Earth. The results can be applied to the design of low-energy escape trajectories as well as the orbit control to bind spacecraft into the Earth system.

9:40 **Morning Break**

10:00 **AAS 14-469** **Design Of Lunar Free-Return Trajectories Based On UKF Parameter Estimation**

Hongli Zhang, Beihang University; Qinqin Luo; Jianfeng Yin, China Academy of Space Technology; Chao Han, Beihang University

A new algorithm based on unscented Kalman filter (UKF) parameter estimation for the fast and efficient design of lunar free-return trajectories is proposed. The initial estimate of the free-return trajectory is generated under the two-body model. Then the original design is converted to a parameter estimation problem. Through solving the problem using UKF, the converged exact solution is found. Compared with the traditional differential-correction method, the derivation of the gradient matrix is not required and a much larger convergence domain is obtained. Numeric examples are implemented to examine the reliability and efficiency of the algorithm.

10:20 **AAS 14-470** **Trade-Off Between Cost And Time In Lunar Transfers: A Quantitative Analysis**

Francesco Topputo, Politecnico di Milano

In this paper, two-impulse Earth--Moon transfers are studied in a four-body model. For given departure, arrival orbits, the focus is on reconstructing the total set of possible solutions below a specified maximum transfer time. This is done by formulating the transfer as a nonlinear programming problem, through direct transcription and multiple shooting. The outcome is analyzed in a cost vs transfer time plane, where orbits showing their best balance are studied. With this approach, Hohmann, interior, and exterior transfers, as well as already existing literature, can be viewed as special points of a more general picture.

10:40 **AAS 14-471** **Families Of Solar-Perturbed Moon-To-Moon Transfers**

Gregory Lantoine, NASA / JPL-CalTech; Tim McElrath, NASA / JPL-CalTech

In the modern space era, the Moon is now considered as a gateway to deep space, and the ability to design multiple lunar flybys is therefore becoming increasingly important. In this paper, to provide quick estimates of lunar flyby trajectories, we compute, characterize and classify families of solar-perturbed Moon-to-Moon transfers in the Sun-Earth three-body problem. These families are obtained by continuation on the initial lunar relative velocity and the angle between the first lunar flyby location and the solar direction. Practical use of the families to design double and triple lunar flybys is also demonstrated.

11:00 **AAS 14-472** **Establishing a Network of Lunar Landers via Low-Energy Transfers**

Jeffrey Parker, University of Colorado

Low-energy trajectories have been found to offer an incredibly flexible architecture for placing multiple landers on the surface of the Moon using a single launch. The low-energy architecture makes it possible to place each lander anywhere on the surface -- the near side or the far side -- such that it lands in the local morning. Each lander requires only small course adjustments before landing: the landing itself is the only large maneuver. This feature permits the landers to be designed using simplified propulsion systems, such as solid rocket motors and monopropellant systems, which improves the value of each lander.

AUTHOR INDEX

CONFERENCE PLANNER

Monday January 27, 2014 - Morning

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8:00				
01	North Ballroom	AAS 14-201	Kohei Fujimoto	A Boundary Value Problem Approach to Too-Short
02	South Ballroom	AAS 14-211	David Geller	Relative Orbital Motion and Angles-Only Relative
03	Stiha Room	AAS 14-222	Jaemyung Ahn	Framework for Performance Comparison of
04	Santa Fe Room	AAS 14-233	Rodney Anderson	A Quick Search Method for Low-Energy Trajectory
8:20				
01	North Ballroom	AAS 14-202	Camilla Colombo	Distant Periodic Orbits for space-based Near Earth
02	South Ballroom	AAS 14-212	David Geller	Initial Relative Orbit Determination Performance
03	Stiha Room	AAS 14-224	Alexander Wittig	Long-term orbital propagation through transfer maps
04	Santa Fe Room	AAS 14-234	Kenta Oshima	Applications of Gravity Assists in the Bicircular and
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01	North Ballroom	AAS 14-203	Earl Lawrence	Estimation for Satellite Collision Probabilities using
02	South Ballroom	AAS 14-213	Stefano Casotto	A Non-Singular Keplerian Differential State
03	Stiha Room	AAS 14-225	Jesus Pelaez	An asymptotic solution for the main problem
04	Santa Fe Room	AAS 14-235	Cody Short	Flow Control Segment and Lagrangian Coherent
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02	South Ballroom	AAS 14-214	Fabio Ferrari	Formation Flying and Relative Dynamics Under the
03	Stiha Room	AAS 14-226	Juan Luis Gonzalo	Asymptotic solution for the two body problem with
04	Santa Fe Room	AAS 14-236	Jeffrey Parker	Improved Transfers to Earth-Moon L3 Halo Orbits
9:20				
01	North Ballroom	AAS 14-205	Laura Henderson	"Inverse Crime" and Model Integrity in Unresolved
02	South Ballroom	AAS 14-215	Giorgio Mingotti	Relative Dynamics and Control of High Area-to-
03	Stiha Room	AAS 14-227	Giulio Ba˘	EDromo: an accurate propagator for elliptical orbits
04	Santa Fe Room	AAS 14-237	Etienne Pellegrini	F And G Taylor Series Solutions To The Circular
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01	North Ballroom	AAS 14-206	Brad Sease	Enabling the use of rotating platforms for orbit
02	South Ballroom	AAS 14-216	Jianfeng Yin	Inverse Transformation of Relative State Transition
03	Stiha Room	AAS 14-228	Daniel Oltrogge	Efficient Kepler's Solution Via Blended Laguerre
04	Santa Fe Room	AAS 14-238	Joseph Dinius	Near Optimal Feedback Guidance Design and the
10:20				
01	North Ballroom	AAS 14-207	Carolin Frueh	Probability Of Correct And Wrong Detection Of
02	South Ballroom	AAS 14-217	Mohammad Mehdi	Relative Position Control Of A Two-Satellite
03	Stiha Room	AAS 14-229	Keith LeGrand	Solutions of Multivariate Polynomial Systems Using
04	Santa Fe Room	AAS 14-239	Jeannette Heiligers	Novel Solar Sail Mission Concepts for Space
10:40				
01	North Ballroom	AAS 14-208	Jianfeng Yin	Collision Avoidance in Elliptical Formation Flying
02	South Ballroom	AAS 14-218	Andrew Sinclair	Use of Cartesian-Coordinate Calibration for Satellite
03	Stiha Room	AAS 14-230	Noble Hatten	Application of the Stark Problem to Space
04	Santa Fe Room	AAS 14-240	Nathan Mogk	A Mission Profile Utilizing Sun-Earth Libration
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01	North Ballroom	AAS 14-209	Islam Hussein	Stochastic Optimization for Sensor Allocation Using
02	South Ballroom	AAS 14-219	Ashley Biria	Periodic Orbits in the Elliptical Relative Motion
03	Stiha Room	AAS 14-231	Donghoon Kim	Applications of Implicit Functions to Orbital
04	Santa Fe Room	AAS 14-241	John Kidd	Using Lunar Swingbys And Libration-Point Orbits
11:20				
01	North Ballroom	AAS 14-210	Richard Linares	Particle Filtering Light Curve Based Attitude
02	South Ballroom	AAS 14-220	William Anthony	Future Exploration of Lamberts' Problem Using
03	Stiha Room	AAS 14-232	Donghoon Kim	Multi-Segment Adaptive Modified Chebyshev
04	Santa Fe Room	AAS 14-242	Jennfer Dowling	Investigating the Optimization of Midcourse
11:40				
02	South Ballroom	AAS 14-221	Daero Lee	Finite-Time Control For Body-Fixed Hovering Of
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Monday January 27, 2014 - Afternoon

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06	South Ballroom	AAS 14-254	Todd Ely	Expected Performance of the Deep Space Atomic
07	Stiha Room	AAS 14-265	Jing Cao	Forced Precession Orbit Departing from Keplerian
08	Santa Fe Room	AAS 14-275	Reza Raymond Karimi	Interplanetary Superhighways: Cheaper Roards To
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05	North Ballroom	AAS 14-245	Roberto Furfaro	Orbit Control and Hovering In Asteroid Dynamical
06	South Ballroom	AAS 14-255	Lincoln Wood	The Evolution Of Deep Space Navigation: 1999-
07	Stiha Room	AAS 14-266	Wenbo Zhang	Optimal Impulsive Rendezvous with Terminal
08	Santa Fe Room	AAS 14-276	Hodei Urrutxua	What Does it Take to Capture an Asteroid? A Case
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05	North Ballroom	AAS 14-246	Abran Alaniz	Fault Detection and Isolation Strategy for
06	South Ballroom	AAS 14-256	Peter Lai	Navigation Filter Simulator Development For Small
07	Stiha Room	AAS 14-267	Jeffrey Stuart	Design of End-to-End Trojan Asteroid Rendezvous
08	Santa Fe Room	AAS 14-277	Jacob Englander	Asteroid Retrieval via Direct Launch and Solar
14:30				
05	North Ballroom	AAS 14-247	Stoian Borissov	Optimal Autonomous Pose and Trajectory
06	South Ballroom	AAS 14-257	Jacob Darling	Extended and Unscented Kalman Filters for
07	Stiha Room	AAS 14-269	Zhang Zhiguo	Explore Europa by the Jovian Magnetic Lorentz
08	Santa Fe Room	AAS 14-278	Daniel Scheeres	Comprehensive Modeling of the Effects of
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05	North Ballroom	AAS 14-248	Jules Simo	Performance Evaluation of Artificial Neural
06	South Ballroom	AAS 14-259	Kai Wang	Performance Evaluation of the Target-star Angles
07	Stiha Room	AAS 14-270	Eric Trumbauer	Autonomous Trajectory Redesign for Phobos
08	Santa Fe Room	AAS 14-279	Mai Bando	Robust Deflection Strategies of Near Earth
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05	North Ballroom	AAS 14-249	Christopher Petersen	Model Predictive Control And Extended Command
06	South Ballroom	AAS 14-260	Daero Lee	Finite-Time Observer For Rigid Spacecraft Motion
07	Stiha Room	AAS 14-271	Benjamin Villac	A Framework For Exporting Ballistic Orbits Across
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15:50				
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06	South Ballroom	AAS 14-262	Baichun Gong	A Novel Angles-only Relative Navigation
07	Stiha Room	AAS 14-272	Galen Harden	Automated Patch Point Placement for Spacecraft
08	Santa Fe Room	AAS 14-281	Ryan Hupp	Suborbital Intercept and Fragmentation of Asteroids
16:10				
05	North Ballroom	AAS 14-251	Paolo Lunghi	Semi-Analytical Guidance Algorithm for
06	South Ballroom	AAS 14-263	Renato Zanetti	Navigation Design and Analysis for the Orion
07	Stiha Room	AAS 14-273	Nicholas Bradley	A Continuation Method to Transition Simplified
08	Santa Fe Room	AAS 14-283	Sam Wagner	Low-Thrust Trajectory Optimization for Asteroid
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05	North Ballroom	AAS 14-252	Anil Chinnan	Feedback And Iterative Learning Control With
06	South Ballroom	AAS 14-244	Jozef van der Ha	Solar and Thermal Radiation Pressure Models &
07	Stiha Room	AAS 14-274	Alan Zorn	Three Problems in Space Flight Mechanics Solved
08	Santa Fe Room	AAS 14-284	Damon Landau	Capture and Storage Orbit Options for an Asteroid
16:50				
05	North Ballroom	AAS 14-253	Richard Longman	Idiosyncrasies In The Inverse Models Of Digital
08	Santa Fe Room	AAS 14-285	Pavithra Premaratne	Nuclear Explosion Energy Coupling Models for

Tuesday January 28, 2014 - Morning

Session	Room	Paper No.	Presenter	Title
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10	South Ballroom	AAS 14-297	Daniele Mortari	Mapping to Compensate Radial Geometrical
11	Stiha Room	AAS 14-308	Shengping Gong	Design resonant transfer orbit using Low-thrust v-
12	Santa Fe Room	AAS 14-319	Srinivas Setty	Prediction Accuracies of Draper Semi-analytical
8:20				
09	North Ballroom	AAS 14-287	David Vallado	Sequential Orbit Determination Using Satellite
10	South Ballroom	AAS 14-298	Sharan Asundi	Adverse Effects of Satellite Magnetic Field on
11	Stiha Room	AAS 14-309	Jacob Englander	Global Optimization of Low-Thrust, Multiple-Flyby
12	Santa Fe Room	AAS 14-320	Melissa Zemoura	Near-Earth orbit debris identification to secure
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09	North Ballroom	AAS 14-288	Roger L. Mansfield	Preliminary Determination of the Geocentric Earth
10	South Ballroom	AAS 14-299	Robert Melton	Approximate Constrained Time-Optimal
11	Stiha Room	AAS 14-310	Donald Ellison	Analytical Partial Derivative Calculation Of The
12	Santa Fe Room	AAS 14-321	Paul Anderson	Longitude-Dependent Effects of Fragmentation
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09	North Ballroom	AAS 14-289	James Thorne	Convergence Behavior of Series Solutions of the
10	South Ballroom	AAS 14-300	Divya Thakur	Gyro-Free Rigid Body Attitude Stabilization using
11	Stiha Room	AAS 14-311	Jose Manuel Sanchez	Automation of Multi-Revolution Low-Thrust Orbit
12	Santa Fe Room	AAS 14-322	Paul Anderson	Characterizing Localized Debris Congestion in the
9:20				
09	North Ballroom	AAS 14-294	F. de Dilectis	Bezier Description of Space Trajectories
10	South Ballroom	AAS 14-301	Roberto Furfaro	RSO Attitude Estimation via LIDAR Altimetry and
11	Stiha Room	AAS 14-312	Thierry Dargent	Averaging Technic In T_3d An Integrated Tool For
12	Santa Fe Room	AAS 14-323	Pierluigi Di Lizia	Disposal Strategies for Spacecraft in Lagrangian
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09	North Ballroom	AAS 14-290	Stefano Casotto	A new approach to Gaussian Initial Orbit
10	South Ballroom	AAS 14-302	Daniele Mortari	Memory Adaptive k-vector
11	Stiha Room	AAS 14-314	Xingshan Cai	Low-thrust Trajectory Optimization in a Full
12	Santa Fe Room	AAS 14-324	Francesca Letizia	Analytical model for the propagation of small debris
10:20				
09	North Ballroom	AAS 14-291	Yinrui Rao	Space-Time Coordinate Systems In The High-
10	South Ballroom	AAS 14-303	Charles Wetterer	Shape, Surface Parameter, and Attitude Profile
11	Stiha Room	AAS 14-315	Andrew Abraham	Preliminary Optimization Of Low-Thrust,
12	Santa Fe Room	AAS 14-325	Camilla Colombo	End-of-life Earth re-entry for highly elliptical orbits:
10:40				
09	North Ballroom	AAS 14-292	Keith LeGrand	Initial Relative Orbit Determination Using Multiple
10	South Ballroom	AAS 14-304	F. de Dilectis	Assessment of the Adaptive Angular Velocity
11	Stiha Room	AAS 14-317	Paola Libraro	Application of a Quaternion-Based Formulation to
12	Santa Fe Room	AAS 14-326	Masahiko Uetsuhara	Orbital anomaly analysis to detect breakups in GEO
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09	North Ballroom	AAS 14-293	Ethan Pratt	A Second Order Method for Initial Relative Orbit
10	South Ballroom	AAS 14-305	Brad Sease	Catalog-free angular rate estimation and on-line
11	Stiha Room	AAS 14-318	Jesse Campbell	Classification of Time-Optimal Low to Medium-
12	Santa Fe Room	AAS 14-329	Felix Hoots	Satellite Breakup Debris Cloud Characterization
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09	North Ballroom	AAS 14-295	Tsutomu Ichikawa	Orbit Determination for the Low-thrust spacecraft
10	South Ballroom	AAS 14-306	William Silva	Application Of The Extended H Infinity Filter For
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10	South Ballroom	AAS 14-307	Francesco Vicario	Bilinear Observer/Kalman Filter Identification
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Tuesday January 28, 2014 - Afternoon

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14	South Ballroom	AAS 14-342	Ahmad Bani Younes	application of High-OrDer stts Uncertainity
15	Stiha Room	AAS 14-352	Yue Wang	Body-fixed orbit-attitude hovering at equilibria near
16	Santa Fe Room	AAS 14-363	Fernando Abilleira	2016 Mars Insight Mission Design And Navigation
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13	North Ballroom	AAS 14-332	Renato Zanetti	High Order State Updates For Estimation Of
14	South Ballroom	AAS 14-343	James McCabe	Coordinatization Effects On Non-Gaussian
15	Stiha Room	AAS 14-353	Xingshan Cai	Solar Sailing Apophis Rendezvous Mission with
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13	North Ballroom	AAS 14-334	Carolin Frueh	Phylogenetic Taxonomy For Artificial Space
14	South Ballroom	AAS 14-344	Pierluigi Di Lizia	An automatic domain splitting technique to
15	Stiha Room	AAS 14-354	Jay McMahon	Asteroid Proximity Navigation using Direct
16	Santa Fe Room	AAS 14-365	Zachary Bailey	Round-Trip Solar Electric Propulsion Missions For
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13	North Ballroom	AAS 14-335	C. Bombardelli	Collision Avoidance Maneuver Optimization
14	South Ballroom	AAS 14-345	Renato Zanetti	Adaptable Iterative and Recursve Kalman Filter
15	Stiha Room	AAS 14-355	Simon Tardivel	High-altitude deployment of landers to asteroid
16	Santa Fe Room	AAS 14-366	Stijn Smet	Preliminary Mission Design For A Crewed Earth-
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13	North Ballroom	AAS 14-336	Abel Brown	GPU Accelerated Conjunction Assessment: Parallel
14	South Ballroom	AAS 14-346	Jeffrey Aristoff	Error Estimation and Control for Efficient and
15	Stiha Room	AAS 14-356	Fabio Ferrari	Trajectory Design About Binary Asteroids Through
16	Santa Fe Room	AAS 14-367	Fu-Yuen Hsiao	Spacecraft Trajectory Design with Photonic Laser
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14	South Ballroom	AAS 14-347	Liam Healy	Orbital density determination from unassociated
15	Stiha Room	AAS 14-357	Eric Jurado	Rosetta Lander Philae Mission: Flight Dynamics
16	Santa Fe Room	AAS 14-368	Tim McElrath	There And Back Again: Using Planet-Based Sep
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14	South Ballroom	AAS 14-349	David Spencer	Drag Coefficient Estimation Using Satellite Attitude
15	Stiha Room	AAS 14-359	Daniel Wibben	ZEM/ZEV Sliding Guidance for Asteroid Close-
16	Santa Fe Room	AAS 14-369	James McAdams	Orbit Design And Navigation Though The End Of
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14	South Ballroom	AAS 14-351	Humberto Godinez	Estimation And Prediction For An Orbital
15	Stiha Room	AAS 14-360	Pedro J. Llanos	Orbital Evolution and Environmental Analysis
16	Santa Fe Room	AAS 14-370	Arnaud Boutonnet	Mission Analysis Update for the JUpiter ICy moon
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15	Stiha Room	AAS 14-361	Demyan Lantukh	Frozen orbits at small bodies subject to solar
16	Santa Fe Room	AAS 14-371	Wen Changxuan	Precise Determination of the Reachable Domain for
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16	Santa Fe Room	AAS 14-372	Lorenzo Ferrario	Europa lander mission analysis: non-Keplerian
17:10				
16	Santa Fe Room	AAS 14-373	A. Petropoulos	Techniques for Designing Many-Revolution,
Brower Award Ceremony and Lecture 18:00-19:00 in Lumpkins Ballroom				
Dinner Buffet 19:00-23:00 in La Terraza Room				

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18	South Ballroom	AAS 14-385	Brad Atkins	Internal Moving Mass Actuator Based Angle of
19	Stiha Room	AAS 14-396	Keric Hill	Comparing a High-Fidelity Radiation Pressure
20	Santa Fe Room	AAS 14-407	Sanghyun Lee	Optimization of Lattice Flower Constellations for
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18	South Ballroom	AAS 14-386	Hongli Zhang	Optimal low-thrust transfer and guidance scheme for
19	Stiha Room	AAS 14-397	Jozef van der Ha	Comparison of Solar and Thermal Radiation
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18	South Ballroom	AAS 14-387	Martin Ozimek	Near-Optimal Guidance For Precision Lunar
19	Stiha Room	AAS 14-398	Tingxuan Huang	Saturated Attitude Control with Almost Global
20	Santa Fe Room	AAS 14-409	SeungBum Hong	Architecture Analysis Framework For Space
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17	North Ballroom	AAS 14-377	Yinrui Rao	Hovering Formation Design and Control Based on
18	South Ballroom	AAS 14-388	Pradipto Ghosh	Near-Optimal Feedback Guidance For Aeroassisted
19	Stiha Room	AAS 14-399	Liang Zhou	An Energy-Matching Optimal Control Method for
20	Santa Fe Room	AAS 14-410	Jerome Daquin	Resonant perturbations with Earth's gravity field for
9:20				
17	North Ballroom	AAS 14-378	Trevor Bennett	Touchless Electrostatic Three-Dimensional
18	South Ballroom	AAS 14-390	Sean Wagner	Maneuver Performance Assessment of the Cassini
19	Stiha Room	AAS 14-400	Hsien-Lu Huang	A Unique Maiden Device For Propulsion And A
20	Santa Fe Room	AAS 14-411	Paul Cefola	Revisiting The Dsst Standalone Orbit Propagator
Morning Break 9:40-10:00				
10:00				
17	North Ballroom	AAS 14-379	Hui Yan	State Transition Matrix for Relative Motion
18	South Ballroom	AAS 14-391	Go Ono	Optimal Spin Rate Control of a Spinning Solar Sail
19	Stiha Room	AAS 14-401	Sasi Prabhakaran	A General Dynamics Model For Spacecraft With
20	Santa Fe Room	AAS 14-413	Mitsuhiko Tasaki	The observation of micron-size debris environment
10:20				
17	North Ballroom	AAS 14-380	Divya Thakur	Spacecraft Swarm Finite-Thrust Cooperative
18	South Ballroom	AAS 14-392	Morad Nazari	Continuous Thrust Stationkeeping In Earth-Moon
19	Stiha Room	AAS 14-402	Zhibin Li	Analysis on dynamic characteristics and control
20	Santa Fe Room	AAS 14-414	Martin Wermuth	Safe Release of a Picosatellite from a Small Satellite
10:40				
17	North Ballroom	AAS 14-381	Shu Leizheng	Relative Orbit Determination For Formation Flying
18	South Ballroom	AAS 14-393	Valdemir Carrara	A Gas Bearing Platform Attitude Control For
19	Stiha Room	AAS 14-403	Richard Longman	Incorporating Physical Considerations In The
20	Santa Fe Room	AAS 14-415	Lorraine Weis	Designing Chip-sized Spacecraft for Missions to
11:00				
17	North Ballroom	AAS 14-382	Javier Roa	The elliptic rendezvous problem in DROMO
18	South Ballroom	AAS 14-394	William Anthony	Statistical Fuel Budgets For Impulsive Guidance To
19	Stiha Room	AAS 14-406	Alan Zorn	Elevating Ordinary Differential Equations to the
11:20				
17	North Ballroom	AAS 14-383	Xu Zengwen	Optimal Control of Two-Craft Electromagnetic
18	South Ballroom	AAS 14-395	Deepti Kannapan	Design of the Attitude Control Subsystem of
AAS Technical Committee Lunch 12:00-13:30 in New Mexico Room				

Wednesday January 29, 2014 - Afternoon

Session	Room	Paper No.	Presenter	Title
		13:30		
21	North Ballroom	AAS 14-418	David Hyland	Asteroid Characterization via Stellar Occultation:
22	South Ballroom	AAS 14-424	Aline K. Zimmer	Orbital Evolution Of Dust Particles Originating
23	Stiha Room	AAS 14-430	Stefano Casotto	Precise non-gravitational forces modeling for GOCE
24	Santa Fe Room	AAS 14-437	David Finkleman	The Intersection of Satellite Aerodynamics and
		13:50		
21	North Ballroom	AAS 14-419	Hongliang Ma	Fuzzy logic approach strategy based feature point
22	South Ballroom	AAS 14-425	Erik Hogan	Space Weather Influence on Relative Motion
23	Stiha Room	AAS 14-431	Christopher Binz	Utilization of Uncertainty Information in Angles-
24	Santa Fe Room	AAS 14-330	Sean Brennan	Multi-Model Orbital Simulation Development with
		14:10		
21	North Ballroom	AAS 14-421	Joshua Lyzhoft	Optical and Infrared Sensor Fusion for
22	South Ballroom	AAS 14-426	Thais Oliveira	Determining Orbits That Can Be Controlled By
23	Stiha Room	AAS 14-432	Ryan McGranaghan	LiAISON Tracking for a Lunar Farside Sample
24	Santa Fe Room	AAS 14-436	Andrew Walker	Gas-surface Interactions for Satellites Orbiting in
		14:30		
21	North Ballroom	AAS 14-420	M. Abrahamson	Lidar And Optical-Based Autonomous Navigation
22	South Ballroom	AAS 14-427	George Vardaxis	Impact Probability Analysis for Near-Earth Objects
23	Stiha Room	AAS 14-433	Stoian Borissov	K-Vector Approach for Extensive Solving of the
24	Santa Fe Room	AAS 14-341	Michael Shoemaker	Simultaneous Estimation of Atmospheric Density
		14:50		
21	North Ballroom	AAS 14-422	Corwin Olson	Small Body Optical Navigation Using the Additive
22	South Ballroom	AAS 14-428	Carolin Frueh	Passive Electrostatic Charging Of Near-
23	Stiha Room	AAS 14-434	Ryan Weisman	Uncertainty Quantification for Angles-Only Initial
24	Santa Fe Room	AAS 14-200	Josef Koller	The IMPACT Framework for Enabling System
		15:10		
21	North Ballroom	AAS 14-423	Steven Gehly	Autonomous Rendezvous and Proximity Operations
22	South Ballroom	AAS 14-429	Carolin Frueh	New Model For The Thermal Radiation Of Space
23	Stiha Room	AAS 14-435	Paul Thompson	Reconstruction Of Earth Flyby By The Juno
24	Santa Fe Room	AAS 14-441	Michael Shoemaker	Comparison of Satellite Orbit Tomography with
		Afternoon Break 15:30-15:50		
		ASTRIA Special Session 16:00-17:30 in Lumpkins Ballroom		
		AAS CAS Sub-Committee Meeting 17:30-18:30 in Santa Fe Room		
		AAS TAS Sub-Committee Meeting 17:30-18:30 in Exchange Room		
		AAS WAS Sub-Committee Meeting 17:30-18:30 in Stiha Room		

Thursday January 30, 2014 - Morning

Session	Room	Paper No.	Presenter	Title
Thursday Speakers' Breakfast 6:45am in La Terraza Room				
8:00				
26	North Ballroom	AAS 14-442	Tarek Elgohary	Dynamics and Controls of a Generalized Frequency
27	South Ballroom	AAS 14-452	Takahiro Kato	External Torques Affecting the Attitude Motion of a
28	Stiha Room	AAS 14-464	Zhong-Sheng Wang	Orbit Design Considerations for Precision Lunar
8:20				
26	North Ballroom	AAS 14-443	Lee Jasper	Tether Design Considerations for Large Thrust
27	South Ballroom	AAS 14-453	Jozef van der Ha	Analytical Solution for Flat-Spin Recovery of
28	Stiha Room	AAS 14-465	David Dunham	Some Options for Lunar Exploration Utilizing the
8:40				
26	North Ballroom	AAS 14-444	Hodei Urrutxua	Gravitational Actions upon a Tether in a Non-
27	South Ballroom	AAS 14-454	Johannes Hacker	Globalstar Second Generation Hybrid Attitude
28	Stiha Room	AAS 14-466	Yue Wang	Study of gravitational lunar capture in the bi-circular
9:00				
26	North Ballroom	AAS 14-445	Ian McNally	Orbital Dynamics of Large Solar Power Satellites
27	South Ballroom	AAS 14-455	Hamidreza Nemati	Design Procedure of Chattering Attenuation Sliding
28	Stiha Room	AAS 14-467	Lucia Capdevila	Various Transfer Options from Earth into Distant
9:20				
26	North Ballroom	AAS 14-446	Lee Jasper	Discretized Input Shaping for a Large Thrust
27	South Ballroom	AAS 14-457	Burak Akbulut	Architectures for Vibrating Mass Attitude Control
28	Stiha Room	AAS 14-468	Hongru Chen	Low-energy Escape from the Sun-Earth L2 Utilizing
Morning Break 9:40-10:00				
10:00				
26	North Ballroom	AAS 14-447	Tarek Elgohary	Generalized Frequency Domain Solution for a
27	South Ballroom	AAS 14-458	Lilit Mazmanyan	Takagi-Sugeno Fuzzy Model-Based Attitude
28	Stiha Room	AAS 14-469	Hongli Zhang	Design Of Lunar Free-Return Trajectories Based On
10:20				
26	North Ballroom	AAS 14-448	M. Schadegg	Jovian Orbit Capture and Eccentricity Reduction
27	South Ballroom	AAS 14-459	Xiaosai Hu	Attitude Passive Stability Criteria Of Axisymmetric
28	Stiha Room	AAS 14-470	Francesco Topputo	Trade-Off Between Cost And Time In Lunar
10:40				
26	North Ballroom	AAS 14-449	Hodei Urrutxua	Long-Term Dynamics of Fast Rotating Tethers
27	South Ballroom	AAS 14-460	Tingxuan Huang	Path Planning for Flexible Satellite Slewing
28	Stiha Room	AAS 14-471	Gregory Lantoine	Families of solar-perturbed Moon-to-Moon transfers
11:00				
26	North Ballroom	AAS 14-450	Francesco Vicario	OKID as a Unified Approach to System
27	South Ballroom	AAS 14-461	Yue Wang	CMG momentum management for spacecraft in
28	Stiha Room	AAS 14-472	Jeffrey Parker	Establishing a Network of Lunar Landers via Low-
11:20				
26	North Ballroom	AAS 14-451	Fan Zhang	On-Line Mass Estimation For A Tethered Space
27	South Ballroom	AAS 14-462	Ehsan Samiei	Chatter Avoidance In Delayed Feedback Attitude

RECORD OF MEETING EXPENSES

24th AAS/AIAA Space Flight Mechanics Meeting
La Fonda Hotel, Santa Fe, New Mexico
26 - 30 January 2014

Name:_______________________________ Organization: _______________________________

Category	Early Registration (through 5 Jan 2014)	Regular Registration
Full - AAS or AIAA Member	$530	$630
Full - Non-member	$630	$730
Retired*	$165	$190
Student*	$165	$190

Registration Fee: ____________________

Conference Proceedings (Hard Cover)[1]

___ @ $290 (domestic) ____________________

___ @ $380 (international) ____________________

Extra CD Conference Proceedings[1] ___ @ $10 ____________________

Special Event Guest Ticket ___@ $48 ____________________

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

- Online Conference App