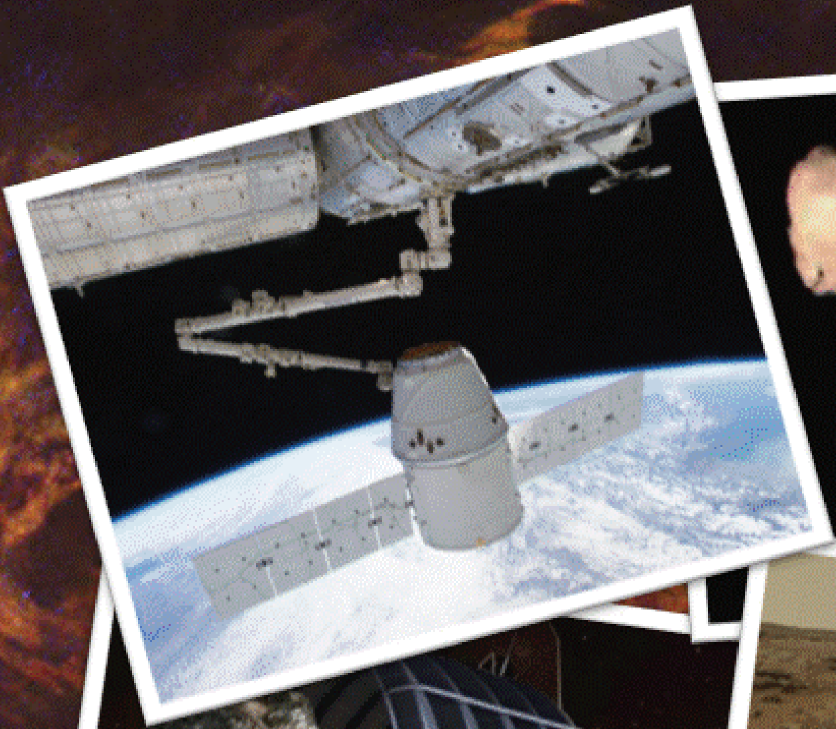
Conference Program

2013 AAS/AIAA Astrodynamics Specialist Conference

August 11-15, 2013 Hilton Head, South Carolina




American Astronautical Society

AIAA
The World's Forum for Aerospace Leadership

AAS General Chair
Prof. Kathleen Howell
Purdue University

AAS Technical Chair
Dr. Stephen Broschart
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AIAA General Chair
Dr. Felix Hoots
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Front Cover Images:

Background: Part of Herschel's view of the Horsehead Nebula.

Credit: ESA/Herschel/PACS, SPIRE/N. Schneider, Ph. André, V. Könyves (CEA Saclay, France) for the "Gould Belt survey" Key Programme

Upper Left: SpaceX Dragon being captured by the Canadian "Canadarm 2" robotic arm as part of International Space Station Expedition 34 on Mar. 3, 2013.

Credit: NASA

Upper Right: Asteroid Toutatis as seen by the Chinese Chang'e 2 during a close flyby on Dec. 13, 2012.

Credit: Chinese Academy of Sciences / Daniel Macháček (for creating the composite image)

Bottom Left: Artist's conception of the proposed Asteroid Redirect Mission approaching a small asteroid.

Credit: NASA/Advanced Concepts Lab.

Bottom Right: Mars Science Laboratory "self-portrait", taken using the rover's MAHLI instrument on Feb. 3 and May 10, 2013.

Credit: NASA/JPL-Caltech/MSSS

Cover design by Steve Broschart and Ted Sweetser

Program printing sponsored by:

AEROSPACE
Assuring Space Mission Success

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AAS/AIAA ASTRODYNAMICS SPECIALIST CONFERENCE
CONFERENCE INFORMATION

GENERAL INFORMATION

Welcome to the Astrodynamics Specialist Conference, hosted by the American Astronautical Society (AAS) and co-hosted by the American Institute of Aeronautics and Astronautics (AIAA), August 11 – 15, 2013. This meeting is organized by the AAS Space Flight Mechanics Committee and the AIAA Astrodynamics Technical Committee, and held at the Hilton Head Marriott Resort & Spa, 1 Hotel Circle, Hilton Head, South Carolina 29928. Phone: 843-686-8400.

REGISTRATION

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

In order to encourage early registration, we have implemented the following conference registration rate structure: **Register by July 21, 2013 and save $50!**

Category	Early Registration (through July 21, 2013)	Registration (after July 21, 2103)
Full - AAS or AIAA Member	$530	$580
Full - Non-member	$630	$680
Retired*	$165	$165
Student*	$165	$165

**does not include proceedings CD or buffet dinner*

The “Flavors of the Low Country” dinner on Tuesday evening is included with all registrations. Guest tickets for the dinner may be purchased for $75. Tickets for children ages 5 to 11 are $35 and children under 5 eat free. More information about the “Flavors of the Low Country” dinner is included below.

A conference registration and check-in table will be located on the Lobby Level of the Hilton Head Marriott Resort & Spa and will be staffed according to the following schedule:

- Sunday Aug. 11 3:00 PM - 6:00 PM
- Monday Aug. 12 7:30 AM - 2:00 PM
- Tuesday Aug. 13 8:00 AM - 2:00 PM
- Wednesday Aug. 14 8:00 AM – 2:00 PM
- Thursday Aug. 15 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 11 August	3pm	6pm	Registration	East registration
	6pm	9pm	Early Bird Reception	Sabal Palm Room

Day	Start	End	Function	Room
Monday 12 August	7am	8am	Speakers Breakfast	Sabal Palm Room
	7:30am	2pm	Registration	East registration
	8am	11:25am	Session 1: SSA I: Detection and Estimation	Ballroom A
	8am	11:45am	Session 2: Mission Operations	Ballroom B
	8am	11:25am	Session 3: Nonlinear Modeling and Analysis Methods	Ballroom C
	8am	11:45am	Session 4: Spacecraft Autonomy and Rendezvous	Ballroom D
	9:40am	10:05am	Morning Break	East registration
	12:00	1:30pm	Joint Technical Committee Lunch	Conroy's
	1:30pm	3:10pm	Session 5: Solar Sails, Tethers, and Large Space Structures I	Ballroom A
	1:30pm	3:10pm	Session 6: Earth Orbiters	Ballroom B
	1:30pm	3:10pm	Session 7: Maneuver Design	Ballroom C
	1:30pm	3:10pm	Session 8: Attitude Determination and Dynamics I	Ballroom D
	3:10pm	3:35pm	Afternoon Break	Prefunction
	4:00pm	5:30pm	Plenary Session	Ballroom A & B
	5:30pm	7:00 pm	CAS/TAS/WAS committee meetings	Ballroom A, B, C

Day	Start	End	Function	Room
Tuesday 13 August	7am	8am	Speakers Breakfast	Sabal Palm Room
	8am	2pm	Registration	East registration
	8am	11:45am	Session 9: SSA II: Prediction and Uncertainty	Ballroom A
	8am	11:05am	Session 10: Orbit Determination and Estimation I	Ballroom B
	8am	11:45am	Session 11: Dynamical Systems Theory	Ballroom C
	8am	11:25am	Session 12: Formation Flying and Relative Motion I	Ballroom D
	9:40am	10:05am	Morning Break	East registration
	Noon	1:30pm	AIAA Astrodynamics Technical Committee Lunch	Conroy's
	1:30pm	5:15pm	Session 13: Interplanetary Mission Design and Concepts	Ballroom A
	1:30pm	4:55pm	Session 14: Close-proximity Operations near Primitive Bodies	Ballroom B
	1:30pm	4:55pm	Session 15: Orbit Determination and Estimation II	Ballroom C
	1:30pm	5:15pm	Session 16: Attitude Guidance and Control	Ballroom D
	3:10pm	3:35pm	Afternoon Break	East registration
	5:30pm	6:30pm	Social hour	Basshead Deck
	6:30pm	9:00pm	"Flavors of the Low Country" buffet dinner	Basshead Deck

Day	Start	End	Function	Room
Wednesday 14 August	7am	8am	Speakers Breakfast	Sabal Palm Room
	8am	2pm	Registration	East registration
	8am	11:45am	Session 17: SSA III: Orbit Debris Modeling and Mitigation	Ballroom A
	8am	11:25am	Session 18: Spacecraft Guidance, Navigation, and Control	Ballroom B
	8am	11:45am	Session 19: Orbit Dynamics	Ballroom C
	8am	11:45am	Session 20: Atmospheric Flight and Entry, Descent, and Landing	Ballroom D
	9:40am	10:05am	Morning Break	East registration
	Noon	1:30pm	AAS Space Flight Mechanics Committee Lunch	Conroy's
	1:30pm	3:10pm	Session 21: Lunar Mission Design and Concepts	Ballroom A
	1:30pm	3:30pm	Session 22: Attitude Determination and Dynamics II	Ballroom B
	1:30pm	3:10pm	Session 23: Solar Sails, Tethers, and Large Space Structures II	Ballroom C
	1:30pm	3:30pm	Session 24: Special Session: High-performance and On-board Computing Architectures	Ballroom D
	3:30pm	3:55pm	Afternoon Break	East registration
	4:00pm	5:30pm	Asteroid Redirection Mission Concept	Ballroom A

Day	Start	End	Function	Room
Thursday 15 August	7am	8am	Speakers Breakfast	Sabal Palm Room
	8am	10am	Registration	East registration
	8am	11:05am	Session 25: SSA IV: Collisions and Conjunctions	Ballroom A
	8am	11:05am	Session 26: Formation Flying and Relative Motion II	Ballroom B
	8am	11:05am	Session 27: Low-thrust Trajectory Design	Ballroom C
	8am	11:25am	Session 28: Primitive-body Mission Design and Concepts	Ballroom D
	9:40am	10:05am	Morning Break	East registration

HILTON HEAD MARRIOTT RESORT & SPA LAYOUT

Lobby Level

SPECIAL EVENTS

EARLY BIRD RECEPTION

Sunday, 11 August 6:00 – 9:00 pm
Location: Sabal Palm Room

PLENARY SESSION – DAVID BARNHART (DARPA)

Monday, 12 August 4:00 – 5:30 pm
Location: Ballroom A & B

"Mambo dogfish to the banana patch":
Bridging the gap between technology and policy to unleash a dramatic surge in space capabilities

Democratization in technology is enabling surges in areas that benefit individual lives, society and the world in general. This same trend is beginning to occur in one medium that has eluded all but the very few well-funded organizations, that of space. Space may hold the greatest potential for expansion of markets and capabilities into the future, yet it is adjudicated by a set of policies and regulations that are typically decades old. Technology democratization in space is occurring at such a rapid pace, there may well be a clash between those policies and the true capabilities that technology may enable. The presentation will focus on understanding the natural struggle between technology advances versus possible risks they engender in the unique environment of space, and postulate ways technologists could incorporate this into every day developments to truly unleash the same surge in space currently enjoyed on Earth.

** Note that the Breakwell Travel Award will be presented prior to the speaker.

FLAVORS OF THE LOW COUNTRY – BASSHEAD DECK

Tuesday,13 August 5:30 – 6:30 pm Social Hour (cash bar)
6:30 – 9:00 pm Buffet dinner
Location Basshead Deck

Starters
Cornbread, Biscuits and Hush Puppies
Charleston She Crab Soup

Salads
Tossed Mixed Green Salad
Red Pear Tomatoes, Homemade Croutons and Shredded Parmesan Cheese
Ranch, Blue Cheese, Lemon Balsamic Vinaigrette and Low-Fat Honey Dijon Dressing

Jalapeño Coleslaw
Cucumber Salad
New Red Potato Salad with Bacon

Shrimp Boil
Peel and Eat Shrimp Simmered in Cajun Spices
with Sausage, Corn and Potatoes

Entrées
The Best Fried Chicken Anywhere
Carolina Barbecue
Chopped BBQ Pork Seasoned with Cider Vinegar

Fried Potato Wedges
Fried Green Tomatoes and Tomato Chutney

Desserts
Sour Cream Pound Cake with Strawberry Sauce
Georgia Peach Crisp with Whipped Cream
Chocolate Peanut Butter Pie with Chocolate Sauce

Guests with any dietary restrictions should contact Felix.Hoots@aero.org by August 6 so the caterer can be informed.

All conference registrations will receive an event ticket. Adult guest tickets will be available for $75 each. Tickets for children from 5-11 are available for $35. Children under 5 are free. Please contact the conference chairs if interested in guest tickets prior to August 6, 2013.

SPECIAL INTEREST SESSION – NATHAN STRANGE (JET PROPULSION LABORATORY)

Wednesday, 14 August 4:00 – 5:30 pm
Location: Ballroom A

Overview of Mission Design for NASA Asteroid Redirection Mission Concept

Part of NASA's new asteroid initiative is a robotic mission to capture a roughly six to eight meter asteroid and redirect its orbit to place it in trans-lunar space. Once in a stable storage orbit at the Moon, astronauts will then visit the asteroid for science investigations, to test in space resource extraction, and to develop experience with human deep space missions. This talk will discuss the mission design techniques that enable the redirection of a 100-1000 metric ton asteroid into lunar orbit with a 40-50 kW Solar Electric Propulsion (SEP) system. The mission design is still in the early stages, and we welcome any comments from the astrodynamics community on our methodology or suggestions of alternate approaches.

Conference Location

Hilton Head Marriott Resort & Spa

1 Hotel Circle
Hilton Head, South Carolina 29928 USA
Phone: 1-843-686-8400
Fax: 1-843-686-8450

Toll-free: 1-888-511-5086

http://www.marriott.com/hhhgr

Ranked by CONDE NAST as one of the top 10 best islands and family beaches in the country, Hilton Head Island http://www.hiltonheadisland.org will provide a superb family vacation opportunity to accompany your conference experience. Kids and teens will especially enjoy the myriad of activities tailored especially for them www.wheretogohiltonhead.com/teens.htm.

The Hilton Head Marriott Resort & Spa, situated on the historic Palmetto Dunes Plantation, provides a central base for exploration of all the island has to offer. ***Recreation*** opportunities abound with an 11 mile canoe and kayak lagoon network interlaced across the island, the Palmetto Bay Marina (sailing, fishing, parasailing, ocean kayaking), 20 golf courses on the island and surrounding low country, plus loads of kids activities including crafts, pool games, scavenger hunts, boat excursions to watch for dolphins, crabbing and kayaking. Interested in the local ***History and Culture***? The Coastal Discovery Museum showcases the history, culture and ecology of Hilton Head Island area, while the Parris Island Museum addresses the Spanish colonization, Tarawa WWII Exhibit, Iron Mike (acclaimed statue of WWI marine), and the Beaufort Historic District ("Forrest Gump" filming) offers carriage rides, walking tours, and biking. How about ***Shopping***? The Mall at Shelter Cove houses every conceivable outdoor recreation, shopping, and restaurant choice including the world's largest sundial. Waterfront evening entertainment is especially oriented for the children. Harbour Town with its iconic lighthouse, shops, galleries, and cafés provides a picturesque setting for activities. If you prefer more choices, visit the Tanger Outlets (1 and 2) or the Coligny Plaza with 60 stores. And you should not miss an opportunity to enjoy the unique ***Nature*** experiences on Hilton Head Island. Pinckney Island National Wildlife Refuge is a 4,000 acre preserve with bird watching of shore birds, wading birds, waterfowl, and migratory flocks. 10 miles of trails for hiking and cycling offer glimpses of white ibis, herons, ospreys, egrets, bald eagles and a visit to the butterfly garden.

HILTON HEAD MARRIOTT RESORT & SPA POOL AND DECK LAYOUT

The Conference rate for the conference hotel is $123 (current government per diem) plus applicable taxes. Currently, the tax rate is 11% plus a $1.00 per room, per night destination fee. Please request the AAS/AIAA Space Flight Mechanics Meeting rate. The deadline for securing the conference rate at the hotel is July 21, 2013. The conference rate is valid for 3 nights before and after the conference dates, subject to availability.

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

TRANSPORTATION INFO

The Savannah/Hilton Head International Airport, www.savannahairport.com, is 47 miles from the Hilton Head Marriott Resort & Spa. The airport is served by multiple major carriers, and has direct flights from 17 locations.

K-Shuttle is the official provider of scheduled shuttle service from Savannah/Hilton Head International to the resorts of Hilton Head Island. Shuttles run throughout the day from the Airport to the Island beginning at 10:00 a.m. Service from the Island to the Airport can be scheduled as early as 3:45 a.m. with advance reservations. Cost is $45 one way or $80 round trip. For more information and shuttle schedules call (877) 243-2050. A private taxi costs approximately $85 to the hotel.

DRIVING DIRECTIONS

From the Savannah/Hilton Head Intl Airport:

- Turn onto Interstate 95 N. Take Exit 8 in SC to Hwy 278 East. Follow 278E (approximately 18 miles to the bridge) to Hilton Head. Stay right on 278 Business for another 8 miles to Palmetto Dunes. Turn left at Queens Folly Rd. (Palmetto Dunes traffic light). The Hilton Head Marriott Resort and Spa is one mile into Palmetto Dunes; turn left before the guard gate

From the Hilton Head Airport:

- Turn left onto Beach City Road. At the traffic light, turn left onto Hwy 278E. Follow 278E to Queens Folly Rd. at the Palmetto Dunes. The Hilton Head Marriott Resort and Spa is located one mile into Palmetto Dunes, turn left before the guard gate.

From the North:

- I-95 South to Exit 8, Hwy 278 East
- Follow Driving directions from Savannah/Hilton Head Intl Airport

From the South:

- I-95 North to Exit 8, Hwy 278 East
- Follow Driving directions from Savannah/Hilton Head Intl Airport

ARRIVAL INFORMATION

Check-In and Checkout

- Check-in: 4:00 PM
- Check-out: 11:00 AM

Departure dates of each guest will be verified upon check-in. At that time, the guest may make adjustments to the actual departure date.

Parking

Valet parking is available at a rate of $18.00 plus tax per night, automatically billed to your room. Self-parking is complimentary.

HOTEL RESTAURANTS AND LOUNGES

- **The Cafe.** Modern American cuisine. Unique sunlit dining open for breakfast and lunch.

- **Conroy's Fine Dining.** Take in views of the Atlantic Ocean while enjoying fresh seafood or classic American cuisine. Large wine selection, kid's menu and early bird dining.

- **The Lounge.** Open for early smack or late night meal. Enjoy ocean views as large screen televisions.

- **The Ocean Blu Café and Liquid Bar.** Ultimate ocean front dining experience. Open for lunch and dinner as well as liquid refreshments.

HOTEL RECREATION AND LEISURE

- Palmetto Dunes Golf Club: Three championship golf courses, including our true oceanfront Robert Trent Jones course, multiple pro-shops, eateries, and clubhouses.
- Fitness Center
- Atlantic Ocean
- Indoor Pool
- Outdoor Pool
- Whirlpool
- Spa Soliel (appointment required)
- Tennis Complex
- State-of-the-art Game Room
- Sport Court
- Volleyball
- Sea Pines Golf Club (3 miles)
- Palmetto Hall Golf Club (5 miles)
- Biking trail
- Horseback riding (5 miles)
- Jet-skiing (1 mile)
- Jogging / fitness trail
- Kayaking
- Minature golf (1 mile)
- Nature preserve, trail
- Sailing (1 mile)
- Water skiing (1 mile)

AREA ATTRACTIONS

The suggestions below are a partial list of the many things to do and see on Hilton Head Island. For more information and suggestions visit the concierge desk. The Hilton Head Island visitor's bureau also has a very informative website: www.hiltonheadchamber.org.

Bluffton Historical Preservation Society/ Heyward House. (843)757-6293.
Step back in time and experience Historic Bluffton, developed as a retreat for the rice and cotton plantation owners in the early 19th century, the town provided relief from the heat and mosquitoes on the bluff high above the May River. The winds of secession began to blow here in 1844 with the birth of the "Bluffton Movement". Burned after the war, Heyward House, 14 homes and 2 churches survived. Begin your tour at the restored Hayward House and discover the laid-back "Bluffton state of mind". www.heywardhouse.org

Coastal Discovery Museum at Honey Horn. (843)689-6767.
The mission of this outdoor museum is to "Teach the public about the cultural heritage and natural history of the Lowcountry". Take in 300 years of history while enjoying the 68 acres of live oaks, salt marshes, and historic buildings on the Honey Horn property. www.coastaldiscovery.org.

Gullah Museum of Hilton Head Island. (843) 681-3254.
Take a cultural tour and experience the history, stories, songs and customs of the Gullah culture. Consider a visit to the "Little House" and learn about the efforts to preserve the history of this important cultural group and its influence on Hilton Head Island. www.gullahmuseumhhi.org.

The Sandbox: An Interactive Children's Museum. (843) 842-7645.
Ready for a break from the sun and fun with the little ones? The Sandbox is the perfect place for the kids....and you! Interactive exhibits include the Builders of Tomorrow, the Rhythm and Hues Room, the Loggerhead Sandcastle, the No Swim Aquarium, and Track the T-Rex. All of the exhibits are designed to stimulate various types of experiential learning with an island flavor. www.thesandbox.org.

Shopping

Beach Market Located on the South end of the island, the market has offered "premier shopping, dining and entertainment for the last 20 years". Traditionally open 9am-5pm daily, this shopping area has a good variety of Gift Shops, Souvenir Shops, Eateries, and Bars.

Coligny Circle / Plaza. This quaint shopping area on the beach offers over 60 Upscale Boutique Shops and Restaurants along with local entertainment. For more information visit www.colgnyplaza.com.

Main Street Village. Visit this unique shopping area complete with popular Chain Stores, Small Boutiques, and Local Eateries. Centrally located at 1500 Main Street just outside the gates of Hilton Head Plantation this area is easily assessable. www.mainstreetvillagehhi.com

Shelter Cove Harbour Shops & Restaurants at Palmetto Dunes. This authentic harbor venue offers "year-round waterfront dining, shopping and entertainment, plus spectacular views of Broad Creek. This laid-back Mediterranean-style village combines the Island's best shops, restaurants and waterfront activities." Visit http://www.palmettodunes.com/shelter-cove-harbour-shops.php for more information.

NOTE: Families and Adults alike, DO NOT miss the experience of Shannon Tanner performing live at Shelter Cove. Daily show schedule and Pirate Tours are posted on www.shannontanner.com. This is a memory that will last for a lifetime! Just ask our grown kids!

Tanger Outlet Center Hilton Head. The Tanger Outlets bring you a selection of your favorite brands at outlet prices. Visit the outdoor shopping area at 1414 Fording Island Road in Bluffton. Regular hours Monday through Saturday are 10 am to 9 pm. Sunday hours are 11 am to 6 pm. www.tangeroutlet.com

Village at Wexford. This island destination offers elegant shopping, relaxation and pampering, and evenings filled with exceptional dining, the sounds of jazz, and dancing. Located near the pristine beaches on William Hilton Parkway, this is an island experience that should not be missed. www.villageatwexford.com

Golf

Barony Golf Course. (843)681-1750, www.hiltonheadgolf.net.

Crescent Pointe Golf Club. (843)706-2600, www.crescentpointegolf.com.

Eagle's Pointe Golf Club. (843) 757-5500, www.eaglespointegolf.com.

Harbour Town Golf Links. (843) 886-2164, www.seapines.com.

Heron Point by Pete Dye. (843) 886-2164, www.seapines.com.

Hilton Head National Golf Club. (843) 886-2164, www.golfhiltonheadnational.com.

Ocean Course. (843) 886-2164, www.seapines.com.

Old South Golf Links. (843) 886-2164, www.oldsouthgolf.com.

Oyster Reef. (843) 886-2164, www.hiltonheadgolf.net.

Palmetto Hall Golf Club. (843) 886-2164, www.palmettohallgolfcom.

Planter's Row Golf Course. (843) 886-2164, www.hiltonheadgolf.net.

Port Royal Golf Club. (843) 886-2164, www.heritagegolfgroup.com.

Robber's Row Golf Course. (843) 886-2164, www.hiltonheadgolf.net .

Rose Hill Golf Club. (843) 886-2164, www.golfrosehill.com.

Shipyard Golf Club. (843) 886-2164, www.hiltonheadgolf.net.

Area Map

Additional maps are located at http://www.sciway.net/maps/hilton-head-island-sc-maps.html

Additional Information

Speaker Orientation

On the day of their sessions, authors making presentations meet with their session chairs at 7:00 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://aas.pxi.com/registration/reg/ 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 $50 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 **$600** (approx.)
- Authors (post-conference) **$300** (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 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

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/

SATISFACTION SURVEY

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

COMMITTEE MEETINGS

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

Session 1: SSA I: Detection and Estimation

Chair: Moriba Jah, Air Force Research Laboratory

8:00 AAS 13-701 Detection Probability of Earth Orbiting Objects Using Optical Sensors
Carolin Früh, Air Force Research Laboratory

The reflected light received by the telescope depends on the observation geometry, object size, reflection properties as well as attitude motion of the object. Whether an object is detected, when it is in the field of view (FOV), as well as its position accuracy and accuracy of extracted magnitudes in case of detection crucially depends on the signal to noise ratio (SNR) of the point source on the telescope frames. In this paper the detection probability in different object and observation scenarios in investigated.

8:20 AAS 13-702 An Optimal Control-Based Estimator for Maneuver Detection and Reconstruction
Daniel Lubey, University of Colorado at Boulder; Daniel Scheeres, University of Colorado

A new type of estimator that incorporates optimal control and outputs a control policy is developed and analyzed in this study. The estimator is developed in a similar manner to a Kalman Algorithm with an almost identical form, but with additional properties for more accurate tracking. Unlike the Kalman Algorithm, this estimator frees up the initial state, which results in an algorithm that decouples a priori state uncertainty and dynamics uncertainty. The dynamic uncertainty inflates the state covariance in an automatic fashion that prevents filter saturation. The algorithm also outputs control estimates that may be used to both identify the

8:40 AAS 13-704 Probabilistic Initial Orbit Determination using Radar Returns
Kyle DeMars, Missouri University of Science and Technology; Moriba Jah, Air Force Research Laboratory

The most complete description of the state of a system at any time is given by knowledge of the probability density function, which describes the locus of possible states conditioned on any available measurement information. When employing radar returns, an admissible region approach provides a physics-based region of the right-ascension rate/declination rate space which provides Earth-bound orbit solutions. This work develops a method that employs a probabilistic interpretation of the admissible region and approximates the admissible region by a Gaussian mixture to formulate an initial orbit determination solution.

9:00 **AAS 13-705** **Multiple Hypothesis Tracking (MHT) for Space Surveillance: New Capabilities in LEO**

Jeffrey Aristoff, Numerica Corporation; Joshua Horwood, Numerica Corporation; Navraj Singh, Numerica Corporation; Aubrey Poore, Numerica Corporation

The need to accurately track breakups or clusters with closely-spaced objects requires new, robust, and autonomous methods for space surveillance to enable the development and maintenance of the space catalog and to support the overall SSA mission. This paper presents a newly-developed, statistically-robust, system-level, multiple hypothesis tracking (MHT) capability for joint catalog maintenance, uncorrelated track (UCT) resolution, and initial orbit determination. The MHT system provides improved tracking performance at a lower computational cost in realistic multi-radar tracking scenarios consisting of thousands of UCTs emanating from hundreds of closely-spaced objects in LEO.

9:20 **<No talk scheduled>**

9:40 **Session Break**

10:05 **AAS 13-706** **Guaranteed Approach for Orbit Determination with Limited Error Measurements**

Zakhary Khutorovsky, Vympel Corp; Alexander Samotokhin, Keldysh Institute of Applied Mathematics; Kyle T. Alfriend, Texas A&M University

A non-statistical statement of the orbit determination of a near-Earth space object in Earth orbit with certain limitations on the measurement errors is considered. The optimization criterion and the algorithms satisfying the limited error criterion are given. As distinguished from the traditionally used least squares (LS) method, the interpolated algorithms are adapted to the measurement errors and always provide a guaranteed error range of the estimated parameters. Simulation of a typical object in low Earth orbit show that the orbit determination errors using this non-statistical approach may be less than the LS method errors.

10:25 **AAS 13-707** **Optical Sensor Constraints on Space Object Detection and Admissible Regions**

Johnny Worthy; Marcus Holzinger, Georgia Institute of Technology

This paper presents work on an model used to simulate the space debris environment. Current monitoring capabilities of the Space Surveillance Network (SSN) use predictive techniques to track known objects. The model presented visualizes high density regions of space objects in angular space. An approximate analytical relationship between the locations of objects in angular space and the predicted probability of detection or the estimated object density is presented. The analytical relationship found can then be used to approximate optimal pointing trajectories for the detection and tracking of new space debris objects.

10:45 AAS 13-708 Towards an Artificial Space Object Taxonomy

Matthew Wilkins, Applied Defense Solutions; Avi Pfeffer, Charles River Analytics; Paul Schumacher, Air Force Research Laboratory; Moriba Jah, Air Force Research Laboratory

Provided we have appropriately defined a satellite taxonomy that allows us to place a given RSO into a particular class of object without any ambiguity, one can assess the probability of assignment to a particular class by determining how well the object satisfies the unique criteria of belonging to that class. Tree-based taxonomies delineate unique signatures by defining the minimum amount of information required to positively identify an RSO. This work describes a new RSO taxonomy, provides stressing examples, and uses Figaro, a probabilistic programming language, to demonstrate results.

11:05 AAS 13-709 On-orbit Trajectory Analysis of Local Area LEO Objects

Paul McCall, Air Force Research Labratory/Florida International University; Madeleine Naudeau; Malek Adjouadi, Florida International University

Many satellite operators rely in some part, on the capabilities of the U.S. SSN for the operational safety of their spacecraft. Further validation of a FPA pixel-speed based classifier for rapid orbit characterization and trajectory analysis of LEO objects may prove to be a vital resource for the situational safety of satellites. The current work, reported here, assesses the feasibility of performing this analysis for objects in various LEO orbits from observations made from LEO. This analysis would increase a satellite's Local Area Awareness via an intimate understanding of the trajectory of objects passing through the environment

11:25 <No talk scheduled>

Session 2: Mission Operations

Chair: Zhiqiang Zhou, NASA Langley Research Center

8:00 **AAS 13-711** **Navigation of the Grail Spacecraft Pair Through the Extended Mission at the Moon**

Troy Goodson, NASA / Caltech JPL; Peter Antreasian, NASA / Caltech JPL; Ramachandra Bhat; Min-Kun Chung, Jet Propulsion Laboratory; Kevin Criddle, NASA / Caltech JPL; Sara Hatch; David Jefferson, NASA / Caltech JPL; Eunice Lau, NASA / Caltech JPL; Ralph Roncoli; Mark Ryne, NASA / Caltech JPL; Theodore H Sweetser, Jet Propulsion Laboratory; Tung-Han You, NASA / Caltech JPL; Brian Young, Jet Propulsion Laboratory, California Institute of Technology.; Mau C. Wong, JPL; Julie Kangas, JPL; Hui Ying Wen, NASA / Caltech JPL

The GRAIL Extended Mission flew the pair of spacecraft at the lowest orbit the flight team could safely support. From the perspective of the Navigation team, the low orbit altitude introduces new challenges. This paper reports on the strategy and performance of the Navigation system for GRAIL's Extended Mission. The Navigation team, on a weekly basis, provided reference trajectory updates, designed three maneuvers, and reconstructed the execution of those maneuvers. In all, the XM involved approximately 44 maneuvers. The results of those maneuvers, in terms of maintaining the reference-trajectory targets and desired separation distance, are assessed.

8:20 **AAS 13-712** **GRAIL TCM-5 Go/No-Go: Developing Lunar Orbit Insertion Criteria**

Min-Kun Chung, Jet Propulsion Laboratory

Two Gravity Recovery and Interior Laboratory (GRAIL) spacecraft were launched on 10-Sep-2011 to study the lunar gravity. Achieving a correct Lunar Orbit Insertion (LOI) condition during the Trans-Lunar Cruse (TLC) Phase was critical to the rest of the mission. This paper describes the development of LOI criteria in terms of LOI targets such that the future phases can meet all the Sci-ence requirements before entering the Science Phase. The developed LOI crite-ria, in turn, established the boundaries for the last statistical Trajectory Correc-tion Maneuver (TCM-5) before LOI.

8:40 **AAS 13-713** **Conjunction Assessment Concept of Operations for the Magnetospheric Multi-Scale (MMS) Mission**

Geoffrey Wawrzyniak, a.i. solutions, Inc.; Russell Carpenter, NASA/Goddard Space Flight Center; Daniel Mattern, a.i. solutions, Inc.; Trevor Williams, NASA/Goddard Space Flight Center; Neil Ottenstein, a.i. solutions, Inc.; Brandon Jones, University of Colorado, Boulder

While collisions between the four MMS observatories are unlikely, the consequence of a collision between two observatories is mission failure. The MMS mission-design requirements state that missed detections of unsafe conjunctions shall not exceed 1 in 1000 conjunctions. However, mission operators and the science team require that collision risk mitigation maneuvers are not excessive and that false alarms (unnecessary maneuvers) are limited to no more than 1 in 20 collision avoidance maneuvers. These competing requirements—collision avoidance conservatism vs. unnecessary interruption of science activities and inconvenience to the ground system—necessitate a conjunction assessment ConOps for the MMS mission.

9:00 **AAS 13-719** **Cloudsat's A-Train Return: Solving the Orbital Dynamics Problem**
Barbara Braun, The Aerospace Corporation; Donald Keenan, The Aerospace Corporation

Launched in 2006, NASA's CloudSat mission flew in formation with other earth-observing satellites in NASA's Afternoon Constellation until April 2011, when a serious battery anomaly forced CloudSat to lower its orbit and leave the formation. Following a heroic recovery effort, CloudSat returned to the constellation in a new position behind the CALIPSO satellite in early 2012. The return to the formation posed several complex astrodynamical problems involving maneuver timing and frozen orbits; this paper and presentation will describe the mathematical tools and models developed to simplify the planning process, and discuss the evolution and execution of CloudSat'

9:20 **<No talk scheduled>**

9:40 **Session Break**

10:05 **AAS 13-715** **Telemetry Parameter Period-Based Anomaly Detection**
WeiZheng Li, Southeast University

We find a rule that the value of an onboard unit's telemetry parameter at a time of each cycle is same or very close when the unit is in good condition. If the regularity is broken it means something wrong. This paper presents a novel method which takes advantage of the dynamic and periodic characteristic of telemetry parameters to detect anomalies for on-orbit satellites. It has been successfully applied to a China satellite. It is more sensitive to find any subtle anomaly and can be used as a complement to Limit-Check algorithm to guarantee satellite's health

10:25 **AAS 13-716** **Multipoint Extension of Pontryagin's Maximum Principle Applied to the Optimal Attitude Scheduling of an Imaging Satellite**
Alan Zorn, Stanford University; Matt West, University of Illinois

A new result in nonlinear optimal control is applied to the scheduling of high-resolution imaging of successive ground targets from an orbiting satellite. The new result is a rigorous statement and proof of Pontryagin's Maximum Principle extended to the multipoint case. The paper focuses on explaining the new result, outlines its proof with intuition in mind, demonstrates its wide applicability, and solves the attitude scheduling problem for a low-budget satellite application.

10:45 **AAS 13-717** **Cassini Solstice Mission Maneuver Experience: Year Three**
Sean Wagner, NASA / Caltech JPL; Juan Arrieta, NASA / Caltech JPL; Yungsun Hahn, Jet Propulsion Laboratory; Paul Stumpf, NASA / Caltech JPL; Powtawche Valerino, NASA / Caltech JPL; Mau C. Wong, JPL

The Solstice Mission is the final extension of the Cassini spacecraft's tour of Saturn and its moons. To accommodate an end-of-mission in 2017, the maneuver decision process has been refined. For example, the Cassini Project now prioritizes saving propellant over minimizing maneuver cycles. This paper highlights 30 maneuvers planned from June 2012 through July 2013, targeted to nine Titan flybys and the final Rhea encounter. Of these maneuvers, 90% were performed to maintain the prescribed trajectory and preserve downstream delta-V. Recent operational changes to maneuver executions based on execution-error modeling and analysis are also discussed.

11:05 AAS 13-720 Post-Maneuver Collision Probability Estimation Using Polynomial Chaos

Brandon Jones, University of Colorado, Boulder; Michael S. Werner, Colorado School of Mines; Alireza Doostan, University of Colorado Boulder

This paper describes the use of polynomial chaos for approximating the probability of a collision between two satellites after at least one performs an orbit maintenance maneuver. Polynomial chaos provides an approximate solution of a stochastic differential equation, requires no inherent Gaussian assumptions, and allows for improved uncertainty propagation with both maneuver execution and navigation errors. This paper first demonstrates the use of these techniques for the Magnetospheric Multiscale mission, which must regularly perform conjunction assessment between the spacecraft in the formation. The techniques are then applied to the more general problem for more typical Earth-orbiting missions.

11:25 AAS 13-854 A Homotopy Method for Optimal Actuator Failure Control

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

Most spacecraft are designed to be maneuvered to achieve pointing goals. This is most generally accomplished by designing a three-axis control system, where the goal is to repoint the spacecraft and match a desired attitude and angular velocity at the end of the maneuver. New control laws are required, however, if one of the three-axis control actuators fails. The existing state-of-the-art strategies do not permit efficient solutions of this under-actuated nonlinear control problem. This paper develops a homotopy algorithm to achieve optimal nonlinear maneuver strategies for large-angle three-axis spacecraft reorientation maneuvers.

Session 3: Nonlinear Modeling and Analysis Methods

Chair: James Turner, Texas A&M University

8:00 AAS 13-721 A Simple Perturbation Algorithm for Inverting the Cartesian to Geodetic Transformation

James Turner, Texas A&M University

A singularity-free perturbation solution is presented for inverting the Cartesian to Geodetic transformation. Geocentric anomaly is used to model the satellite ground-track position vector. A natural geometric perturbation variable is identified as the ratio of the major and minor Earth ellipse radii minus one. A rapidly converging perturbation solution is developed by expanding the satellite height above the Earth and the geocentric anomaly as a perturbation power series in the geometric perturbation variable. Simulation results are presented that compare the solution accuracy and algorithm performance for applications spanning the LEO-to-GEO range of missions.

8:20 AAS 13-722 Proper Averaging via Parallax Elimination

Martin Lara; Juan F. San-Juan , Universidad de La Rioja; Luis M. López-Ochoa, Universidad de La Rioja

The elimination of the parallax simplification may deprive the simplified Hamil- tonian of the geopotential from some long-period terms of the second order of J2, consequently making the achievement of a centered orbit in mean elements unsuc- cessful. We show that the exact separation of short- and long-period variations is achieved by choosing wisely the generating function of the elimination of the parallax transformation, thus producing the long-term closed-form Hamiltonian of an averaged orbit in which the long-period effects in the mean motion are exactly the same as in the osculating orbit.

8:40 AAS 13-723 An Analytical Approach to Computing Step Sizes for Finite-Difference Derivatives

Ravishankar Mathur, Emergent Space Technologies

An algorithm that computes optimal step sizes for a multidimensional finite-difference derivative is presented. The algorithm's mathematical foundations are derived and numerical examples are given. The computed step size minimizes the combined roundoff and truncation errors in the finite-difference derivative, and the algorithm provides information on the validity of the step size with respect to changes in the independent variables. It is shown that the computed step size is correlated to the true optimal step size by a closed-form equation. The algorithm is also able to compute the function's condition error without additional user input.

9:00 **AAS 13-724** **Conic Sections by Rational Bezier Functions**

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

Conic sections can be considered a subset of rational quadratic B\'ezier curves. These curves are defined based on three control points and three weights. First and third control points belong to the curve while the second point is provided at the intersection of the tangents passing through the endpoints. This paper shows that the weights associated with the endpoints can always be arbitrary selected while closed-form solution is provided for the weight associated with the second control points to obtain specific conic section. The expressions for the control point weights are provided for all three different conic sections.

9:20 **AAS 13-725** **F and G Taylor Series Solutions to the Stark Problem**

Etienne Pellegrini, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin; Vivek Vittaldev, The University of Texas at Austin

The classic F and G Taylor series of the Kepler initial value problem are extended to include 1) a perturbing acceleration term, and 2) a Sundman transformation in the independent variable. Exact recursion formulas are presented, and the method is implemented to high order via symbolic manipulation software. The result is a fast propagation model with an efficient geometrical discretization. The new series solutions are shown to compare favorably to the traditional Runge-Kutta and the Modern Taylor Series integration methods. Further gains are realized when computing the often needed state transition matrices.

9:40 **Session Break**

10:05 **AAS 13-726** **Solving Kepler's Equation using Implicit Functions**

Daniele Mortari, Texas A&M University; Antonio Elipe, Centro Universitario de la Defensa

A new approach to solve Kepler's equation based on implicit functions is presented. First, new upper and lower bounds are derived for two ranges of mean anomaly. These upper and lower bounds initialize a two-step procedure involving the solution of two implicit functions. These two implicit functions, which are non-rational (polynomial) Bezier functions, can be linear or quadratic, depending on the initial bound values. The procedure reaches machine error accuracy with no more that one quadratic and one linear iterations in the tough range of almost parabolic orbits and small values of Mean anomaly.

10:25 **AAS 13-727** **Reflection Decomposition of Rotation Matrices**

Daniele Mortari, Texas A&M University; Martin Avendano, University of Zaragoza

Orthogonal matrices are important mathematical objects in astrodynamics because they represent transformation matrices among reference frames arbitrarily oriented. The fact that the product of two reflections gives an orthogonal matrix is a well known property. Conversely, the decomposition of an orthogonal matrix into the product of two reflection is not known. This decomposition is not unique, and this paper provides the whole set of reflection products providing the same orthogonal matrix. This is initially done for the for the most important 3-D space and it is then extended to any dimensional space.

10:45 AAS 13-728 A Fast and Robust Multiple Revolution Lambert Algorithm Using a Cosine Transformation

Nitin Arora, Georgia Institute of Technology; Ryan Russell, The University of Texas at Austin

A new universal variable is introduced to improve solution performance for the multiple revolution Lambert problem. The formulation is based on the cosine of the change in eccentric anomaly and uses a geometry parameter to simplify the the universal time of flight equation and the associated partial derivatives. Judicious initial guesses and a second order correction step lead to rapid root-solving and drastic reduction in the number of minimization calls typically required to bound the multiple revolution case. The proposed method is demonstrated to be statistically as accurate as the Gooding method, while achieving 40-60% reductions in runtime.

11:05 AAS 13-729 Improved Uniform Points On A Sphere with Application to Any Geographical Data Distribution

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

This paper describes improved algorithms with equal-areas spherical subdivision to solve the problem of distribution of points uniformly on a 2-sphere, known as Smale's seventh problem. The algorithms provide quasi-uniform points by splitting Platonic solids into subsequent spherical triangles. The main feature of improved algorithm is that adjacent triangles share common vertices by splitting Platonic solid into p identical smaller triangles once, where p is number of edges in a face of Platonic solid. It can provide discrete values which is asymptotically uniform. Suggested algorithm is appropriate for various applications that require lots of uniform data.

11:25 <No talk scheduled>

Session 4: Spacecraft Autonomy and Rendezvous

Chair: Yanping Guo, Johns Hopkins University Applied Physics Laboratory

8:00 **AAS 13-731** **Autonomous Relative Navigation for Spacecraft Rendezvous Based on Celestial Observations and Relative Range Measurements**

Kai Wang, Beihang University; Xinghong Huang, Beihang University; Shijie Xu, Beihang University

This paper presents a novel autonomous relative navigation method for far or medium range rendezvous via the angles between the line of sight to the target and the reference stars as well as the relative distance to the target. The target-star angles are calculated on the focal plane and more accurate than the ordinary measurements, such as azimuth and elevation angles. An extended Kalman filter is developed to estimate relative states from the target-star angles and the relative distance. Monte Carlo simulations are undertaken to evaluate the filter's performance. The observability is also analyzed by numerical calculations.

8:20 **AAS 13-732** **A Robust Control Method of Lunar Orbit Spacecraft Autonomous Rendezvous**

Yunyi Hou, Harbin Institute of Technology; Guangfu Ma, Harbin Institute of Technology; Hou Jianwen

The lunar orbital rendezvous is a key technique of lunar return mission. In this paper, the C-W relative dynamic model is established. The virtual target trajectory was segmented designed, allowing the chaser remain at the docking corridor. The H? sub-optimal theory was applied in controller design, restraining the interference and overmuch energy consumption. The mathematical simulation showed that the proposed control method have advantages of high-accuracy, low power consumption, strong robustness and fast. Finally, the real-time visualization platform was established to demonstrate the whole process of lunar orbit spacecraft autonomous rendezvous mission.

8:40 **AAS 13-733** **MPCV ESA Demo-Spacecraft: Mission Design for a Non-Cooperative Rendezvous Demonstration in Elliptic Orbit Around the Moon**

Eric Joffre, ASTRIUM ST; Adrien Chapelle; Philippe Augros; Siegfried Chavy; Stéphane Reynaud; Massimiliano Bottacini; Olivier Mongrard

Contracted by ESA, Astrium conducted a preliminary study on the design of a rendezvous demonstration mission during the unmanned MPCV EM-1 mission to the Moon. Once inserted on a lunar elliptic orbit, a small spacecraft ESA-DS is jettisoned from MPCV before completing a series of maneuvers, using MPCV as the target. This paper presents the main features of the ESA-DS vehicle and mission design with a focus on the mission scenario: elliptic relative orbital dynamics, proximity maneuvers computation (hold-points, forced translations, flyarounds), contingency analysis, eclipse issues, and their impacts on the overall system will be addressed.

9:00 **AAS 13-734** **Recursive Update Filter Applied to Spacecraft Rendezvous**
Renato Zanetti, Draper Laboratory

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). In a typical spacecraft rendezvous very accurate lidar measurements are available to navigate the chaser vehicle with respect to the target. Incorporating these highly accurate nonlinear measurements can cause filter divergence in the presence of highly uncertain initial conditions. This work proposes to use a nonlinear estimator to accurately navigate the chaser vehicle to the target without the need of any \textit{ad. hoc} algorithm to keep the

9:20 **AAS 13-735** **A Closed-Loop Solution for Spacecraft Rendezvous Using the KS Transformation**
Sonia Hernandez, The University of Texas at Austin; Maruthi Akella, The University of Texas at Austin

A finite-thrust closed-loop solution is presented for spacecraft rendezvous using Lyapunov stability theory. The model used is the Kustaanheimo-Stiefel transformation of the two-body problem, where the unperturbed equations of motion are equivalent to a simple harmonic oscillator. The guidance scheme is performed in two maneuver phases: first, a matching of the target's semi-major axis, and second, a matching of position and velocity of the target. The algorithm is robust, computationally fast, and there are no restrictions on the thrust magnitude or the chaser's initial separation from the target.

9:40 **Session Break**

10:05 **AAS 13-736** **Autonomous Aerobraking Development Software: Phase 2 Summary**
Alicia Dwyer Cianciolo, NASA

NASA has used aerobraking at Mars and Venus to reduce the fuel required to deliver a spacecraft into a desired orbit. Although aerobraking reduces the propellant required to reach a final low period orbit, it does so at the expense of mission duration, staff, and DSN coverage. By automating ground-based tasks and moving them onboard the spacecraft, a flight project could save millions of dollars. This paper summarizes the Phase 2 effort to improve the NESC sponsored Phase 1 Autonomous Aerobraking Development Software (AADS). Improvements include updating all the AADS models and rigorous testing the improved AADS.

10:25 **AAS 13-737** **Adaptive Envisioning of Reachable Mission Outcomes for Autonomous Motion Planning at Small Bodies**
David Surovik, University of Colorado at Boulder; Daniel Scheeres, University of Colorado

An algorithm for efficient, automatic mapping between a spacecraft's set of available maneuvers and their corresponding mission outcomes is sought to aid motion planning in strongly perturbed orbital environments. An existing method, which charts Boolean safety criteria, is extended to provide flexible functionality for tracking fulfillment of complex science goals. Runtime efficiency is improved to facilitate the mapping of outcomes on 3D maneuver sets, which are generated for an orbiter of a uniformly rotating triaxial ellipsoid. Visualization tools are developed to ease access of the high-dimensional results, whose complex structure motivates the use of adaptive envisioning.

10:45 AAS 13-738 Application of LiAISON Orbit Determination Architecture in Navigating a Rover on the Lunar Surface

Siamak Hesar, University of Colorado Boulder; Jeffrey Parker, University of Colorado; Ryan McGranaghan, University of Colorado at Boulder; Jason Leonard, University of Colorado at Boulder; George Born, University of Colorado at Boulder

This paper examines the use of Linked Autonomous Interplanetary Satellite Orbit Navigation (LiAISON) architecture to perform tracking of a rover on the lunar surface. LiAISON architecture has been demonstrated to achieve precise orbit determination solutions by processing satellite-to-satellite tracking observations alone. In a novel approach, LiAISON architecture is applied to perform autonomous navigation of a lunar rover and a satellite in a halo orbit about Earth-Moon L1 or L2 points. High fidelity simulations results show that LiAISON is able to successfully estimate the absolute states of lunar rover and halo orbiting satellite simultaneously.

11:05 AAS 13-739 Force Modeling and State Propagation for Navigation and Maneuver Planning for CubeSat Rendezvous, Proximity Operations, and Docking

Christopher Roscoe, Applied Defense Solutions; Jacob Griesbach, Applied Defense Solutions; Jason Westphal, Applied Defense Solutions; Dean Hawes, Applied Defense Solutions; John Carrico, Applied Defense Solutions

State propagation accuracy resulting from different choices of gravitational force models and orbital perturbations is investigated for a pair of CubeSats flying in formation in low Earth orbit. In particular, the relative effect of drag depends on differences in ballistic coefficient between the two spacecraft, differences which can be large since they are non-symmetric. Accurate propagation is necessary to autonomously plan maneuvers and perform docking. Propagation accuracy is investigated both in terms of absolute and relative state. Model parameters are quantified and related to mission factors such as maneuver accuracy, fuel use (mission lifetime), and collision prediction/avoidance (safety).

11:25 AAS 13-740 Optimal One and Two-Impulse Maneuvers for Relative Satellite Interception and Reconfiguration

Ashish Jagat, Auburn University; Andrew Sinclair, Auburn University; Ryan Sherrill, Auburn University; Thomas Lovell, Air Force Research Laboratory

This paper investigates impulsive maneuver planning for relative satellite motion about either elliptical or circular reference orbits. Problems to intercept an arbitrary final position or reconfigure to an arbitrary final position and velocity, while minimizing the magnitude of the velocity changes, are considered. By specifying the maneuvers to use one or two impulses, respectively, the problem can be reduced to an unconstrained optimization problem for the maneuver times, without requiring solution for the primer vector. Results show the significance of the phasing of the maneuver times relative to the final time.

Session 5: Solar Sails, Tethers, and Large Space Structures I

Chair: Brent Barbee, NASA Goddard Space Flight Center

13:30 AAS 13-741 Multibody Modeling of the Attitude Dynamics of Large Square Solar Sails
Evan Sperber; Fidelis Eke

A multibody model is constructed for the purposes of studying the attitude dynamics of a flexible solar sail. The model's rigid body components consist of a payload and sail support spars while the membrane itself is discretized using nodal coordinates and a linear stiffness to account for membrane tension. The model is implemented using Kane's method via a combination of Autolev and custom C code. Numerical simulation of the nonlinear equations of motion is performed with particular attention paid to passive nutation damping of a spin-stabilized square sailcraft.

13:50 AAS 13-742 A Reorientation Scheme for Large Solar Sails
Bo Fu; Fidelis Eke

This paper develops a control scheme that can be used to change the orientation of a large solar sail that has a surface area in excess of one square kilometer. The scheme exploits the fact that any orientation change of a body can be accomplished through three rotations about body-fixed axes. The torque vector needed for each rotation is generated by appropriately modifying the shape of portions of the sail material, and feedback control logic is used to implement each prescribed axial rotation. Detailed algorithmic steps for an orientation change are given and a case study is presented.

14:10 AAS 13-743 Earth Escape Capabilities of the Heliogyro Solar Sail
Daniel Guerrant, University of Colorado; Dale Lawrence, University of Colorado; Andrew Heaton, NASA Marshall Space Flight Center

The heliogyro is a high performance solar sail architecture that divides the sail membrane into "blades" spun about a central hub. It can pitch these blades to generate attitude control moments, similar to a helicopter. The heliogyro is found to nearly double or more the solar acceleration of other sail concepts. Earth escape is exceptionally difficult for solar sails, yet most near-term missions will begin here. The heliogyro's performance for Earth escape trajectories is evaluated, accounting for reasonable slew rates and thrust variation during attitude maneuvers. Such work is vital to near-term heliogyro mission planning.

14:30 AAS 13-744 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 following the Euler-Bernoulli beam assumptions and/or a tip mass. A generalized state space model for the frequency domain is derived and fully solved in closed form. Transfer functions for both the rigid and the flexible modes of the system in terms of the input torque are derived and numerically validated. The exact transfer functions are then utilized for the controls of the spacecraft and the attached appendage(s).

14:50 AAS 13-745 Free Floating Space Robot Kinematic Modeling and Analysis

Xinghong Huang, Beihang University; Shijie Xu, Beihang University

A space robot, composed of a satellite base and an arm, is important for on-orbital servicing. It usually works with orbital and attitude control systems down. The dynamic coupling between the base and the arm makes the system kinematic model very complicated. Former researches on modeling are not elaborate enough. In this paper, we derived the model by starting from the basic momentum conservation laws, proceeds in an obvious way, and gets a more simple and clear result at last. After this, a series of comprehensive analysis and proof of model properties are presented, composed of 4 aspects.

Session 6: Earth Orbiters

Chair: Robert Melton, Pennsylvania State University

13:30 AAS 13-746 The Effect of Different Adsorption Models on Satellite Drag Coefficients
Andrew Walker, Los Alamos National Laboratory; Piyush Mehta, Los Alamos National Laboratory; Josef Koller, Los Alamos National Laboratory

Langmuir, Freundlich, and several other adsorption models (such as the Temkin, Dubinin, and Halsey isotherms) will be investigated for their ability to match fitted drag coefficients and also the physics that drive them. At high altitudes (> 500 km), fitted drag coefficients are sparse and have a great deal of noise due to atmospheric model biases and unmodeled dynamics. Several adsorption models will be explored at higher altitudes to determine whether a single model can describe the variation of drag coefficients from 200 to 1000 km altitude.

13:50 AAS 13-747 Uncertainty Quantification of the Orbital Lifetime of a LEO Spacecraft
Lamberto Dell'Elce, University of Liège; Gaetan Kerschen, University of Liège

Orbital lifetime estimation is a crucial problem in astrodynamics. Several uncertainty sources make any deterministic estimation of the lifetime questionable. The stochastic nature of the thermosphere and the complexity of the mechanisms involved in the drag modeling emphasize this problematic in Low-Earth Orbit. In this paper, we dig up into the nature of the drag model and of the other uncertainty sources affecting lifetime. A detailed characterization of the most relevant and sensitive variables as stochastic parameters is the main outcome of this paper. Such characterization is at the basis of a probabilistic description of the orbital lifetime.

14:10 AAS 13-748 Precise Determination of Mean Orbital Elements for LEO Monitoring and Maintenance
Sofya Spiridonova, DLR / GSOC

In this research, an analytical algorithm for conversion of osculating orbital elements into mean orbital elements was developed for operational use at GSOC: monitoring the long-term behaviour of LEO satellites and manoeuvre planning. The algorithm fuses two previously developed theories, and can be used to account for gravity perturbations due to spherical harmonics of arbitrary degree and order. The algorithm was evaluated on several missions (TOPEX/Poseidon, GRACE, TerraSAR-X) and showed encouraging results. In all the tests, the mean semi-major axis could be estimated to the accuracy of 2-3 meters.

14:30 AAS 13-749 Semi Analytical Implementation of Tesseral Harmonics Perturbations for High Eccentricity Orbits
Vincent Morand, CNES

In the frame of the French Space Operations Act, CNES addresses the compliance of disposal orbit with the law technical requirement: long term orbit propagation techniques are required. To ensure reasonable computation times, a semi-analytical method has been adopted and implemented in the STELA tool (Semi-Analytical Tool for End of Life Analy-sis). The paper details the semi analytical implementation of tesseral harmonics perturbations in STELA, which is valid for high eccentricity orbits. The algorithm is discussed, validation results are given and the impacts of tesseral perturbation on the statistical lifetime distribution of geostationary transfer orbits are presented.

14:50 AAS 13-750 An Optimization Method for Nano-satellite and Pico-satellite Separation through a Two Mass-One Spring System

Shu Ting Goh, Nanyang Tecnological University; Zi Rui Lau, Nanyang Technological University; Kay Soon Low, Nanyang Technological University

This paper studies the picosatellite ejection system from a nanosatellite, using one spring two mass ejection model. It is desired that both satellites maintain a long communication time after separation though they do not carry propulsion system. Moreover, picosatellite is required to return to nanosatellite communication range in a given time period. The dynamic motion of the ejection system has been derived. The impact of ejection location, force and direction on the communication and separation time is studied. Results show that a continuous satellite communication could be maintained if the picosatellite is ejected in perpendicular to the flight path direction.

Session 7: Maneuver Design

Chair: Ahmad Bani Younes, Texas A&M University

13:30 AAS 13-751 Geometry of Transformed Variables in the Impulsive Transfer Problem

Thomas Carter, Eastern Connecticut State University,; Mayer Humi, WPI

Recently a transformation of variables has been used for an object in a Newtonian gravitational field that linearizes the equations of motion. This transformation has been found useful for unconstrained orbital rendezvous and transfer problems.
This paper examines the geometry of these transformed variables for planar orbital transfer problems. The transformed initial, final, and transfer orbits are either points or circles with centers on a horizontal axis. Applied velocity impulses cause horizontal jumps between these points or centers and vertical jumps between points on the circular arcs.

13:50 AAS 13-752 Optimal Open Two-Impulse Transfers in a Plane

Thomas Carter, Eastern Connecticut State University,; Mayer Humi, WPI

The problem of finding a planar open optimal impulsive two-impulse transfer orbit between two known Keplerian orbits is found in terms of a set of necessary conditions for minimizing the total characteristic velocity of the transfer arcs and a test to pick the minimizing orbit from the extremals. The problem is open in the sense that the difference between the final and initials true anomaly is unbounded
Using a transformation of the variables presented in previous work, necessary conditions for an optimal transfer are determined, followed by a proof that an optimal transfer exists, conclduing with some sufficiency argument

14:10 AAS 13-753 Impulsive Guidance for Optimal Manifold-Based Transfers to Earth-Moon L1 Halo Orbits

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

An impulsive guidance scheme is proposed which maintains a spacecraft on the stable manifold of an Earth-Moon L1 halo orbit in the presence of thrust errors for a 2-impulse ballistic transfer from LEO. A Monte Carlo analysis is shown using Gaussian input dispersions in burn magnitude and direction to evaluate the effectiveness of the impulsive guidance. Both cases of using single burns that only re-target the manifold and employing full burn pairs that include a velocity correction are compared, and the locations of the maneuvers are optimized. Finally, a statistical fuel budget is obtained from the analysis.

14:30 AAS 13-754 Precise Determination of the Reachable Domain for a Spacecraft with a Single Impulse

Wen Changxuan, Beijing University of Aeronautics and Astronautics; Zhao Yushan, Beijing University of Aeronautics and Astronautics; Wenlong Li; 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.

14:50 AAS 13-755 Optimal Earth-Mars Trajectory Control Strategy Design Using Adaptive Genetic Algorithm and Monte Carlo Method

Hou Jianwen; Zhou Jie; Yunyi Hou, Harbin Institute of Technology; Liu Fucheng; He Liang

Trajectory control strategy design is an important work for the future Mars explore mission of China. B-plane differential correction targeting technique is analyzed. In order to optimize the integration index of propellant cost of trajectory control maneuver (TCM) and position precision, the trajectory control strategy is studied by Adaptive Genetic Algorithm (AGA). With comparing the traditional numerical method, it can raise the efficiency obviously. At last, delivery statistics for all TCMs is achieved by Monte Carlo (MC) analysis. Results of this work show the ability to design trajectory control strategy for future Mars exploration mission of China.

Session 8: Attitude Determination and Dynamics I

Chair: Renato Zanetti, The Charles Stark Draper Laboratory

13:30 **AAS 13-756** **Attitude Motion of a Spinning Spacecraft With Fuel Sloshing In High-G Maneuvers**
Lilit Mazmanyan, Santa Clara University

We present the equations of motion of spinning spacecraft with partially-filled, multiple-tanks, nutation damper, and momentum wheels in the high-g environment. We adopt a two-spherical-pendulum with torsional dampers in hinge points-as a mechanical equivalent model-to model the fuel sloshing in each tank. Using Kane's method, the nonlinear equations of motion of a spacecraft containing liquid fuel stores are derived. The proposed model is an extension of the existing models in the literature. Derived equations of motion of spacecraft are numerically solved and the effects of the slosh-model parameters are investigated.

13:50 **AAS 13-757** **Fast, Simple and Efficient Asteroid Attitude Propagation by Perturbations**
Martin Lara

The attitude dynamics of a free rigid body is analytically described by a perturbation solution that hinges on a dynamical, rather than a physical, small parameter. This choice of the small parameter releases the restriction to small inertia triaxiality coefficients typical of classical perturbation theories. Therefore, the new approach results useful for attitude propagation of asteroids, although limited to the cases of short- and long-axis mode rotation. The perturbation theory remains within the algebra of trigonometric functions, thus allowing for the straightforward computation of higher orders.

14:10 **AAS 13-758** **Star Tracker Anomalies: Root Causes and Mitigation Strategies**
Austin Lee, The Aerospace Corporation

In this paper, results from a recent survey of star tracker anomalies are presented. The objective of the survey was to better understand the nature of star tracker anomalies and assist in preventing anomalies to minimize future risks. The collected anomaly data includes over 100 cases including many recent and some as far back as 30 years. The data analysis was done using three classification methods: by development phase, by subsystem, and by severity of the anomaly. Among the identified anomalies, the majority were design issues related with software and electronic subsystems.

14:30 **AAS 13-759** **Solar Sail Attitude Dynamics Considering Sail Deformation**
Toshihiro Chujo, The University of Tokyo; Yuichi Tsuda, Japan Aerospace Exploration Agency; Jun'ichiro Kawaguchi, Japan Aerospace Exploration Agency

The attitude motion of spinning solar sail IKAROS caused by solar radiation pressure was unique. Its behavior has much to do with the sail shape, which is flexible and easily changed by the spin motion. It is important, therefore, to understand the relation between the sail deformation and the attitude motion. In this study, we consider how the sail deformation changes according to the spin motion and how it influences the attitude motion from the view point of the structure. We evaluate the theory by using the flight-data of IKAROS and estimate its sail shape.

14:50 AAS 13-760 Stability of the Relative Equilibria of a Rigid Body in a J2 Gravity Field

Yue Wang, Beihang University; Haichao Gui, Beihang University; Shijie Xu, Beihang University

Linear stability of the relative equilibria of a rigid body in a J2 gravity field is studied with geometric mechanics. Linear stability are obtained with energy-Casimir method, and then investigated in wide ranges of system parameters. We find that both the harmonic J2 and dimension of the rigid body have significant effects on the stability. Similar to the attitude stability in a gravity field, linear stability region is consisted of two regions that are analogues of Lagrange and DeBra-Delp regions.

Session 9: SSA II: Prediction and Uncertainty

Chair: Marcus Holzinger, Georgia Tech University

8:00 **AAS 13-761** **Improved Empirical Covariance Estimation**
W. Todd Cerven, The Aerospace Corporation

Covariance estimation through a measurement space method can be made more robust by incorporating weights into the least squares solution process. When the measurements are of full rank, it can be shown that the calculation replicates that of a normalized sample covariance calculation. Furthermore, distribution sampling theory can then be used to estimate errors in these covariance estimates. Lastly, this estimator is applied successfully to realistic scenarios where the error distribution is non-Gaussian in Cartesian space.

8:20 **AAS 13-762** **Efficient Covariance Interpolation Using Blending of Approximate State Error Transitions**
Sergei Tanygin, Analytical Graphics, Inc.

Efficient storage and quick access to covariance data are important aspects of orbit catalog maintenance and conjunction analysis (CA). The catalog and CA access and storage requirements cannot accommodate running a complete estimation process whenever orbit state and covariance are requested at some time. Instead, ephemeris and reduced covariance data are recorded at discrete times. Covariance interpolation from tabulated data must preserve positive definiteness and evolve covariance similar to the estimation process. This paper describes a new covariance interpolation method which blends approximate state error transitions anchored at end points of interpolation interval to produce accurate physically meaningful covariance.

8:40 **AAS 13-763** **High-fidelity Solar Radiation Pressure Effects for High Area-to-mass Ratio Debris with Changing Shapes**
Jay McMahon, University of Colorado; Daniel Scheeres, University of Colorado

In this paper, we focus on answering two main questions about the 6 degree-of-freedom evolution of HAMR debris with high-fidelity SRP force and torque models. First, for a given shape and set of SRP coefficients, are there any preferred equilibrium-like end states for the attitude motion? Second, how will the orbit and attitude evolution of a HAMR object be changed if the object changes shape? These question are answered through high-fidelity numerical simulation with a variety of initial conditions in near geosynchronous orbit and various shape-changing models.

9:00 **AAS 13-764** **The Effect of Dynamical Accuracy for Uncertainty Propagation**
Inkwan Park, University of Colorado at Boulder; Daniel Scheeres, University of Colorado; Kohei Fujimoto, University of Colorado at Boulder

A major topic in the field of space situational awareness is to accurately map the uncertainty of an observed object, accounting for nonlinear relative dynamics using either analytic or numerical approaches. For analytic approaches, an open question exists regarding what the importance of the short-period terms in the analytic theory is relative to the secular dynamics terms. This paper will explore this question using the classical Brouwer theory (CBT). Especially, we discuss how well uncertainty propagation under the secular Brouwer theory (without short-period terms) compares to the CBT, and how the CBT compares to a fully numerical propagation.

9:20 **AAS 13-765** **Comparison of Multitarget Filtering Methods As Applied to Space Situational Awareness**
Steven Gehly, University of Colorado at Boulder; Brandon Jones, University of Colorado, Boulder; Penina Axelrad

A fundamental problem in space situational awareness (SSA) is the computational complexity that arises from tracking a large number of objects. Conventional approaches to the multitarget problem leverage off familiar single target estimators, and as a result are reliant on computationally expensive data association algorithms. Newer multitarget filters, derived using finite set statistics (FISST), process a set of measurements to update a set of object states, independent of data association algorithms. Previous research has examined the application of FISST-based filters to SSA. This paper provides a quantitative comparison between the FISST-based methods and conventional multitarget filters.

9:40 **Session Break**

10:05 **AAS 13-766** **Adaptive Split and Merge Algorithm for Gaussian Mixture Models**
Kumar Vishwajeet, University at Buffalo; Puneet Singla, University at Buffalo; Moriba Jah, Air Force Research Laboratory

Number of components in a Gaussian mixture model plays an important role in its accuracy and computational complexity. New adaptive split and merge technique is introduced in this paper based on the minimization of error in the solution of Fokker Planck Kolmogorov Equation. A single Gaussian component at initial time is split and merged to account for the change in the probability density function of the states of the system. Measurement update is finally introduced to show the effectiveness of Adaptive Gaussian Mixture model against classical filtering techniques

10:25 **AAS 13-767** **Parallel Track Initiation for Optical Space Surveillance Using Range and Range-Rate Bounds**
Christopher Roscoe, Applied Defense Solutions; Paul Schumacher, Air Force Research Laboratory; Matthew Wilkins, Applied Defense Solutions

The track initiation problem is addressed for optical observation of space objects. Angles are the primary quantities available from line-of-sight measurements, but angle rates may also be derived if the data are of sufficient quality. For a specified rectangular partition in orbital element space, explicit bounds on range and range rate are derived based on angles and angle rates. Discretizing the resulting range-range rate hypothesis region allows candidate orbits to be generated in an embarrassingly parallel fashion. The number of hypotheses for track initiation is further constrained by imposing conditions from special solutions of Lambert's problem.

10:45 AAS 13-768 Refined Orbit Prediction for Catalog Objects

Dolan Highsmith, The Aerospace Corporation; W. Todd Cerven, The Aerospace Corporation; Lael Woods, The Aerospace Corporation

Approximately 95% of objects in orbit are inactive. Because of limited tracking resources and a low level of interest, these objects are infrequently tracked and have poor quality predictions with large uncertainties. Thus, satellite owner-operators are faced with numerous close approaches involving low confidence in the location of the inactive object. Consequently, owner-operators either must perform collision avoidance maneuvers more often (reducing mission life and operations) or accept a higher operational risk. This paper describes an algorithm to leverage historical orbital data to increase accuracy in orbit knowledge of inactive objects, and, in turn, provide for more accurate

11:05 AAS 13-769 Investigating the Suitability of Analytical and Semi-analytical Satellite Theories for Space Object Catalogue Maintenance in Geosynchronous Regime

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

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 well-known flavors of Simplified General perturbation theories for deep space(SDP4/SDP8), Kamel's theory – a dedicated geosynchronous satellite perturbation theory formulated in equinoctial elements, and draper semi-analytical satellite theory – which makes use of generalized method for averaging are examined for their best possible fit with numerically generated orbits. Along with this, their computational efficiencies are marked and presented.

11:25 AAS 13-770 Comparisons of PHD Filter and CPHD Filter for Space Object Tracking

Yang Cheng, Mississippi State University

The Probability Hypothesis Density (PHD) filter and the Cardinalized PHD (CPHD) filter are two computationally tractable approximate Bayesian multi-object filters. Both filters are based Finite Set Statistics. The PHD filter propagates the PHD. The CPHD filter propagates the PHD and the conditional distribution of the number of objects. The two filters are compared in the context of multiple space object tracking in terms of tracking accuracy and time complexity.

Session 10: Orbit Determination and Estimation I

Chair: Puneet Singla, University of Buffalo

8:00 **AAS 13-771** **A Linear-Time-Varying Approach for Exact Identification of Bilinear Discrete-Time Systems by Interaction Matrices**

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

Bilinear systems offer a promising approach for nonlinear control because a nonlinear problem such as the satellite attitude control can be reformulated in bilinear form. Recent bilinear model identification methods rely on Input-Output-to-State Relationships. These IOSRs are exact only for a certain class of bilinear systems. They are also limited by high dimensionality of the state and explicit bounds on the input magnitude. This paper offers new IOSRs where the bilinear system is treated as a linear time-varying system through the use of specialized input signals. All the mentioned limitations are overcome by the new approach.

8:20 **AAS 13-772** **Orbit Determination Using Nonlinear Particle Filter and GPS Measurements**

Paula C P M Pardal, ICT-UNIFESP; Rodolpho Moraes, UNIFESP; Helio Kuga, INPE

It is proposed to determine an artificial satellite orbit using signals from GPS constellation, suitable modeling of the perturbations that affect the orbit, and modern estimation techniques. The purpose is to improve orbits determination procedures performance, and, at the same time, to analyze the computational procedure cost. It shall be developed a nonlinear particle filter, based on the Sequential Importance Sampling algorithm, to estimate the state vector that characterizes the orbit of the satellite, using a set of real satellite data, e.g. that ones from Topex/Poseidon and JASON, which are available at Internet.

8:40 **AAS 13-776** **LiAISON-Supplemented Navigation of a Crewed Vehicle in a Lunar Halo Orbit**

Jeffrey Parker, University of Colorado; Jason Leonard, University of Colorado at Boulder; Rodney Anderson, NASA / Caltech JPL; George Born, University of Colorado at Boulder

This paper offers an early examination of the challenges of navigating a crewed vehicle, with all of the associated unmodeled accelerations that arise from the crew's activities, in an orbit about the Earth-Moon L2 point. The combination of the unstable nature of libration orbits with lack of acceleration knowledge makes station keeping challenging. It is found that a combination of ground tracking and satellite-to-satellite tracking produces favorable navigation accuracy. This paper examines the costs and benefits of applying LiAISON (Linked Autonomous Interplanetary Satellite Orbit Navigation) to a crewed mission in an unstable L2 orbit.

9:00 **AAS 13-778** **Trajectory Determination with Unknown Perturbations**
Francesco de Dilectis, Texas A&M University; Daniele Mortari, Texas A&M University; Christopher D'Souza, NASA - Johnson Space Center

In this paper the Initial Trajectory Determination for a restricted 3-Body problem (Earth - Moon - spacecraft) is discussed. Motivation comes from the possibility of using image processing data from visible camera in Earth/Moon trajectories to estimate the trajectory. This will add useful autonomy in the case of communication lost. The method is proposed to provide the Kalman-Filter based estimator (or similar) with an accurate good estimation of a set of initial positions. The estimation algorithm has at its core a Maximum-Likelihood cost function, and uses a Jacobian to evaluate the corrections to the state vector.

9:20 **<No talk scheduled>**

9:40 **Session Break**

10:05 **AAS 13-774** **Improving Orbit Determination with Low-order Fourier Solar Radiation Pressure Models**
Jay McMahon, University of Colorado; Daniel Scheeres, University of Colorado

Precise orbit determination and subsequent accurate prediction of orbiting objects requires accurate force models. In this paper, we show that using a low-order Fourier model for solar radiation pressure can improve orbit determination performance when an object is uniformly spinning about a fixed spin vector. In particular, we investigate two cases that fit this assumption. First, we look at the orbit of an empty upper stage in a geosynchronous transfer orbit that is spinning about an inertially fixed spin vector. Second, we analyze a simple box-and-wing spacecraft in a nadir pointing science orbit about an asteroid.

10:25 **AAS 13-779** **A Novel Set of Broadcast Ephemeris for Compass**
Zhang Zhongkai

Compassconstellation includes variable orbit satellites different from GPS constellation. A set of Broadcast Ephemeris like GPS is used in Compass, but a new Broadcast Ephemeris set quite suitable for the hybrid constellation is necessary. Dynamic models of variable orbits in Compass and difficulties with current Broadcast Ephemeris are analyzed. We introduce a novel set of Broadcast Ephemeris for Compass. Advantages of the novel set in Compass are stated and numerical verifications are given. The novel set of broadcast ephemeris turns out to be more suitable for Compass.

10:45 **AAS 13-780** **Space-based Autonomous Navigation Utilizing Asymmetry of Perturbations**
Zhang Zhongkai

SST between two spacecrafts in two-body model or with some perturbations provides information on the size, shape, and relative orientation of two orbits. Shortage of absolute orientation leads to the insufficiency only with SST. However, some special perturbations can indirectly provide information about the direction to some reference bodies and the absolute orientation with it. We analyze the dynamics of perturbations in SST, and state the strategies of space-based autonomous navigation utilizing asymmetry of perturbations. Finally, the feasibility is proved in formulation forms.

11:05 **<No talk scheduled>**

11:25 **<No talk scheduled>**

Session 11: Dynamical Systems Theory

Chair: John Junkins, Texas A&M University

8:00 **AAS 13-781** **Automating Initial Guess Generation for High Fidelity Trajectory Optimization Tools**

Benjamin Villac, University of California, Irvine; Gregory Lantoine, NASA / Caltech JPL; Jon Sims, Jet Propulsion Laboratory; Gregory Whiffen, NASA / Caltech JPL

Many academic studies in spaceflight dynamics rely on simplified dynamical models, such as three-body models. In practice, the end result of these preliminary orbit studies needs to be transformed into more realistic models, in particular to generate good initial guesses for high-fidelity trajectory optimization tools like Mystic. This paper reviews and extends some of the approaches used in the literature to perform such a task, and explores the inherent trade-offs of such a transformation with a view toward automating it for the case of ballistic arcs. Sample test cases around libration points and small body are presented.

8:20 **AAS 13-782** **Trajectory Selection Strategy for Tours in the Earth-Moon System**

Amanda Haapala, Purdue University; Mar Vaquero, Purdue University; Thomas Pavlak, Purdue University; Kathleen Howell; David Folta, NASA Goddard Space Flight Center

As mission requirements become increasingly complex, improved flexibility in mission design tools is vital. Strategies that offer interactive access to a variety of solutions provide an enhanced perspective of the design space. In this study, interactive and automated trajectory design tools are examined for applications in the Earth-Moon system. Operating within a graphical user interface, these tools offer a composite view of multi-body orbits possessing a variety of characteristics, and facilitate the assembly of end-to-end mission designs via interactive selection of trajectory arcs with desirable characteristics. Final designs are imported into NASA's General Mission Analysis.

8:40 **AAS 13-784** **State Transition Tensor Models for the UncertaintyP of the Two-body Problem**

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

The two-body equations of motion are analytically integrated by an analytical Taylor series, where exact arbitrary order time derivatives of the acceleration equations are computed. The recursive nature of the two-body problem is utilized and scalar Lagrange-Like invariants are defined for the power series solution. State transition tensors are computed utilizing the scalar invariants at each time step. The series solution of the state transition tensor is inverted to examine uncertainty in the initial conditions and handle the stochastic Liouville equation for the probability density of the solution along the motion trajectory.

9:00 **AAS 13-831** **Coverage from Satellites in Earth-Moon Libration Point Orbits**
Kathryn Davis, University of Colorado; Nathan Parrish, University of Colorado at Boulder; Eric Butcher, New Mexico State University

Visibility of the Earth's surface by spacecraft in Earth-Moon libration point orbits at L1 and L3 is examined. Coverage is computed for single satellites and constellations of spacecraft. Initially coverage is analyzed in the model formulated by the Circular Restricted Three-Body Problem. Coverage is also computed in the full ephemeris. A constellation consisting of one spacecraft in an L1 orbit and two spacecraft in L3 orbits can provide nearly continuous global coverage of the Earth's surface.

9:20 **AAS 13-785** **Limits of Linear Approximations for Near-Field Approach in EML-2 Libration Orbits**
Juliana Feldhacker, University of Colorado at Boulder; Kevin Ferrant, University of Colorado at Boulder; Jeffrey Parker, University of Colorado; George Born, University of Colorado at Boulder

The Earth-Moon L2 point is becoming of increasing interest for a wide variety of future space missions. However, the unique dynamics and longer timespans of libration orbits in the Earth-Moon system lead to different behavior during rendezvous and approach than what has been experienced in low Earth and low lunar orbits. This study identifies limits within which a linear approximation can be applied to the rendezvous trajectory between two vehicles in a variety of EML-2 orbits, in both the circular restricted three body problem and the full dynamics model.

9:40 **Session Break**

10:05 **AAS 13-786** **Heteroclinic, Homoclinic Connections Between the Sun-Earth Triangular Points and Quasi-Satellite Orbits for Solar Observations**
Pedro Llanos, GMV; Gerald Hintz, University of Southern California; Martin W. Lo; James Miller, Consultant

Investigation of new orbit geometries exhibit a very attractive behavior for a spacecraft to monitor space weather coming from the Sun. Several orbit transfer mechanisms are analyzed as potential alternatives to monitor solar activity such as a sub-solar orbit or quasi-satellite orbit, short and long heteroclinic and homoclinic connections between the triangular points L4 and L5 and the collinear point L3 of the Circular Restricted Three-Body Problem (CRTBP) in the Sun-Earth system.

10:25 **AAS 13-787** **Broad Search for Unstable Resonant Orbits in the Planar Circular Restricted Three-Body Problem**
Rodney Anderson, NASA / Caltech JPL; Stefano Campagnola, JAXA / ISAS; Gregory Lantoine, NASA / Caltech JPL

Unstable resonant orbits in the circular restricted three-body problem have increasingly been used for trajectory design using optimization and invariant manifold techniques. In this study, several methods for computing these unstable resonant orbits are explored including flyby maps, continuation from two-body models, and grid searches. Families are computed for different mass ratios, and their characteristics are explored. Different parameters such as period and stability are given for each set of resonant orbits. Finally, potential applications for different orbit types are discussed.

10:45 AAS 13-788 Structure of the Web of Resonance within the MEO and GTO Regions

Florent Deleflie, IMCCE; Jerome Daquin; Alain Vienne; Alain Vienne; Marc Fouchard

We detect the structure of the web of resonances in the MEO and GTO regions. We study to what extent the change of initial parameters of storage orbits (namely and mainly the semi--major axis), can affect the long term stability of these orbits over very long time scales (typically, one century). The study is based on the numerical integration of mean equations of motion, in a model that has been approved to be the reference one for the French Space Operations Act (the software STELA). In this paper, we present maps of stability in different dynamical dynamical configurations.

11:05 AAS 13-789 Connecting Halo Orbits with Low Altitude Science Orbits at Europa

Kevin Bokelmann, University of Texas at Austin; Ryan Russell, The University of Texas at Austin

Increasing interest in planetary moons such as Europa calls for capturing into low-altitude science orbits. In this study, the maneuver costs for this final phase are investigated. Loosely-captured, third-body perturbed, gateway orbits are utilized to 1) reduce maneuver size compared to patched conics, and 2) decouple capture phase from inter-moon transfers. The latter leads to a well-defined boundary value problem. Multiple families of gateway orbits are generated to allow comparisons of utility based on stability and energy. Capture transfers are created using two tangential burns. Analytical equations are developed to estimate minimum propulsion for comparison

11:25 AAS 13-790 Analytic High-Order Reversion of Series Solution Algorithm for Solving Lambert's Problem

Ahmad Bani Younes, Texas A&M University

A classic celestial mechanics challenge is concerned with solving two-point boundary-value problems for two-body problems. The goal is to find an orbit that connects two points in space with a given flight time. The main contribution of the paper is the development of three algorithmic advances for improving the robustness of the solution process. First, recursive trajectory (analytic continuation) propagation algorithms. Second, algorithmic differentiation algorithms are introduced for automatically generating nth order state-transition tensor models, for developing non-linear tensor series expansions. Third, both generalized linear algebra routines and tensor perturbation methods.

Session 12: Formation Flying and Relative Motion I

Chair: Craig McLaughlin, University of Kansas

8:00 AAS 13-791 Orbital Maneuver for Spacecraft Using Generalized Canonical Transformations

Yuki Ohtsuka, Nihon University; Kenji Uchiyama, Nihon University

This paper proposes a method of orbital generation and control for a spacecraft using generalized canonical transformations. Spacecraft's orbit in an orbital maneuver depends on initial condition. It is difficult to take potential energy, perturbation of J2 , and nonlinearity into account for an analysis. For solving the problem in various missions, we describe the method of orbital stabilization using generalized canonical transformation that has properties of shaping the field of energy. The method can treat the problem of generation of a periodic orbit and a rendezvous orbit systematically. The efficiency of the proposed method is verified through numerical simulation.

8:20 AAS 13-793 State Transition Matrix for Relative Motion with Higher Order Gravity Perturbations

Hui Yan, Texas A&M University; Srinivas R. Vadali, Texas A&M University; Kyle T. Alfriend, Texas A&M University

Accurate propagation of satellite relative motion for formation flying applications can be achieved by numerically integrating the perturbed nonlinear differential equations for multiple satellites and differencing the results. This process is computationally intensive. The most accurate model for perturbed linear relative motion is the Gim-Alfriend state transition matrix (STM), which is valid for any eccentricity and includes 1st order absolute and differential J2 effects. In this paper we extend the Gim-Alfriend STM to include higher order gravity perturbations.The results are compared with those from GMAT.

8:40 AAS 13-794 Formation Control Problems for Decentralized Spacecraft Systems

Eric Douglass; Marcus Holzinger, Georgia Institute of Technology; Jay McMahon, University of Colorado

Optimal formation control problems for decentralized spacecraft formations using differential mean orbit elements are formulated. The problems are defined in a general manner so that they can be applied to arbitrary formations of N_f spacecraft. Formation system dynamics are defined, performance measures, constraints, and boundary conditions are explored, and example problems showing applications are presented. A simulation showing the feasibility of the proposed approach is shown.

9:00 **AAS 13-795** **Semi-Analytical Global Search Algorithm for Fuel-Optimal Satellite Formation Reconfiguration: Impulsive-Thrust Approach**

Youngkwang Kim; Sang-Young Park, Yonsei University; Chandeok Park, Yonsei University

This paper addresses the coplanar formation reconfiguration problem in a near-circular orbit using impulsive-thrust. Based on linear equations of motion, (semi-)analytical solutions of optimal primer vector histories are found. Boundary conditions determine unknown transfer parameters for each type of optimal primer vector history. A global search algorithm can be constructed by searching solutions for all types of optimal primer vector histories. This approach increases the efficiency of the global search algorithm with a significant reduction in the number of unknown transfer parameters.

9:20 **AAS 13-796** **Calibration of Hill-Clohessy-Wiltshire Initial Conditions for Elliptic Relative Motion**

Ryan Sherrill, Auburn University; Andrew Sinclair, Auburn University; S. C. Sinha, Auburn University; Thomas Lovell, Air Force Research Laboratory

The relative motion between chief and deputy satellites in close proximity with orbits of arbitrary eccentricity can be described by linearized time-varying equations of motion. The linear time-invariant Hill-Clohessy-Wiltshire equations are typically derived from these equations by assuming the chief satellite is in a circular orbit. Two transformations derived from Lyapunov-Floquet Theory and an integral-preserving transformation have previously been determined which relate the time-varying equations of motion to the HCW equations. These transformations are used as a method for selecting initial conditions to approximate elliptic relative motion using the HCW equations with far

9:40 **Session Break**

10:05 **AAS 13-797** **Techniques for LEO Constellation Deployment and Phasing Utilizing Differential Aerodynamic Drag**

Tiffany Finley, Southwest Research Institute; Jillian Redfern, Southwest Research Institute

The Cyclone Global Navigation Satellite System (CYGNSS) mission is a recently selected NASA Earth Venture investigation seeking to improve tropical cyclone (TC) modeling and prediction through remote sensing observation of the ocean surface winds in the TC inner core with a LEO constellation of 8 micro-satellites. This study investigates trades and techniques for the deployment, initial phasing, maintenance, and collision avoidance of the satellite constellation, using an attitude control system without propulsion, to reach an evenly spaced coplanar configuration for the 8 satellites in a circular orbit. This paper reviews these trades and outlines the current CYGNSS mission design.

10:25 **AAS 13-798** **On Control of Spacecraft Relative Motion in the Case of an Elliptic Keplerian Chief**

Morad Nazari, New Mexico State University; Eric Butcher, New Mexico State University; Afshin Mesbahi, Sharif University of Technology

Three alternative control strategies are implemented for control of spacecraft relative motion using the linearized time-periodic equations when the reference orbit is elliptic based on time-varying LQR, constant gain feedback control, and the Lyapunov-Floquet transformation with time-invariant LQR. Both natural and non-natural leader-follower two-spacecraft formations are studied for formation establishment and maintenance. The closed-loop response and the control effort required are investigated and compared, and the region of attraction of the closed-loop system is estimated analytically when the controllers are implemented in the full nonlinear equations of relative motion.

10:45 **AAS 13-799** **Formation Flying Along an Elliptic Orbit by Pulse Control**

Mai Bando, Kyushu University; Akira Ichikawa, Nanzan University

The relative motion of a follower satellite with respect to the leader in a given elliptic orbit is described by Tschauner-Hempel (TH) equations. Periodic solutions of the TH equations are used for formation flying because no control efforts are needed to maintain them. However the shape of periodic solutions is irregular compared to that of the HCW equations, which would be undesirable for some missions. In this paper, active formation flying for the TH system with impulse and pulse input are considered. The output regulation theory for linear periodic systems and the linear quadratic regulator (LQR) theory is employed.

11:05 **AAS 13-800** **Continuous-Thrust Control of Satellite Relative Motion in Elliptic Orbits using a Lyapunov-Floquet Generalization of the HCW Equations**

Ryan Sherrill, Auburn University; Andrew Sinclair, Auburn University; S. C. Sinha, Auburn University; Thomas Lovell, Air Force Research Laboratory

This paper proposes a method for continuous-thrust control for satellite formation flying in elliptic orbits. A previously calculated Lyapunov-Floquet transformation relates the linearized equations of relative motion for arbitrary chief eccentricity to the HCW equations. Using a control law based on Lyapunov-Floquet theory, a time-varying feedback gain is computed that drives a deputy satellite toward rendezvous with an eccentric chief. The control law stabilizes the relative motion across a wide range of chief eccentricities. By contrast, a constant-gain control law may be unstable for high eccentricities and use more control effort for near-circular orbits.

11:25 **<No talk scheduled>**

Session 13: Interplanetary Mission Design and Concepts

Chair: Jeffrey Parker, University of Colorado - Boulder

13:30 AAS 13-801 Design of Initial Inclination Reduction Sequence for Uranian Gravity-Assist Tours

Nathan Strange, NASA / Caltech JPL; Damon Landau, NASA / JPL; James Longuski, Purdue University

Since Uranus has a very high obliquity (97.77º) and its next equinox is in 2049, any mission launched in the next two decades would arrive at Uranus with an approach orbit that is highly inclined (60º-80º). This high inclination causes tours to begin with a very high energy relative to the satellites, and this energy must be "burned-off" before the satellites can provide useful gravity-assists. This paper presents a method for combining a large maneuver on the initial capture orbit with gravity-assists to find the minimum delta-V for a given flight time constraint.

13:50 AAS 13-802 Mission Opportunities to trans-Neptunian Objects – Part III, Orbital Capture, Low Thrust Trajectories and Vehicle Radiation Environment during Jovian Flyby

James Evans Lyne, Univ of Tennessee; Jake Brisby; Charles Stewart; Jordan Kreitzman; Ethan Cansler; Matthew Green

Our group has previously described high-thrust mission trajectories to a number of trans-Neptunian Objects, including Sedna, Eris, Makemake, Quaoar and others. In the current study, we extend that work to examine the possibility of orbital capture, and compare the merits of high-thrust and low-thrust primary propulsion systems in terms of the overall mission performance and potential orbital capture mass. In all cases, the outbound trajectory includes a Jovian flyby, and radiation exposure during that flyby will influence the viability of candidate mission designs. Therefore, we examine the Jovian flyby segments in some detail and present radiation

14:10 AAS 13-803 Broad-search Algorithms for the Spacecraft Trajectory Design of Callisto-Ganymede-Io Triple Flyby Sequences from 2024-2040, Part I: Heuristic Pruning of the Search Space

Alfred Lynam, West Virginia University

Triple flybys of the Galilean moons of Jupiter can capture a spacecraft into orbit about Jupiter or quickly adjust the Jupiter-centered orbit of an already captured spacecraft. In this paper, we focus on Callisto-Ganymede-Io triple flybys. An exhaustive search of these triple-flyby trajectories over a 16-year period from 2024-2040 using ``blind'' searching would require 8,415,358 Lambert function calls to find only 127,289 possible triple flyby trajectories. The novel ``Phase Angle Pruning Heuristic'' is derived and used to reduce this search space by 99%.

14:30 **AAS 13-804** **Broad-search Algorithms for the Spacecraft Trajectory Design of Callisto-Ganymede-Io Triple Flyby Sequences from 2024-2040, Part II: Lambert Pathfinding and Trajectory Solutions**

Alfred Lynam, West Virginia University

Triple-satellite-aided capture employs gravity-assist flybys of three of the Galilean moons of Jupiter in order to decrease the amount of delta-v required to capture a spacecraft into Jupiter orbit. In order to provide a nearly comprehensive search of the solution space from 2024 to 2040, we solve Lambert's problem and the v-infinity matching problem for more than 100,000 Callisto-Ganymede-Io triple flybys. The vast amount of solution data is searched to find the best triple-satellite-aided capture window between 2024 and 2040.

14:50 **AAS 13-805** **Preliminary Analysis of Ballistic Trajectories to Neptune via Gravity Assists from Venus, Earth, Jupiter, Saturn, and Uranus**

Kyle Hughes, Purdue University; James Longuski, Purdue University; James W. Moore

Ballistic gravity-assist trajectories to Neptune are investigated for Earth launch dates ranging from the years 2020 to 2070. Trajectories are identified using patched-conic techniques with an analytic ephemeris. Classical flyby sequences (e.g. Venus-Earth-Earth-Jupiter), as well as less conventional sequences (that may include flybys of Saturn or Uranus), are considered and compared. Trajectories are constrained to flight times of 15 years or less, and desirable trajectories with regard to parameters such as time of flight, launch date, launch V-infinity, arrival V-infinity, and delta-V cost are selected and discussed.

15:10 **Session Break**

15:35 **AAS 13-807** **Preliminary Analysis of Establishing Cycler Trajectories Between Earth and Mars via Low Thrust**

Blake Rogers, Purdue University; James Longuski, Purdue University

While advantages of cycler trajectories are discussed by researchers in the literature, little attention has focused on the problem of placing cycler vehicles into well-known cycler trajectories. Previously analysis employing V-infinity leveraging was addressed. The current paper completes the picture by considering the use of low thrust. The most significant result of the present analysis is that the establishment of the Aldrin cycler, the VISIT cycler, and the two-synodic-period cyclers each require surprisingly low amounts of propellant, ranging from 5 to 8 mt, after Earth escape.

15:55 **AAS 13-808** **Optimal Round-Trip Trajectories for Short Duration Mars Missions**

David Folta, NASA Goddard Space Flight Center; Brent Barbee, NASA Goddard Space Flight Center; Jacob Englander, NASA Goddard Space Flight Center; Frank Vaughn, NASA Goddard Space Flight Center; Tzu Yu Lin, University of Florida

With a Mars human mission as a goal, we conducted a thorough analysis of optimal round-trip Mars trajectories with total durations less than one year. Developed using two state-of-the-art astrodynamics algorithms; embedded trajectory grids and genetic algorithms, round-trip trajectory solutions for direct transfers to and from Mars along with Venus gravity assist improvements were calculated. Reference architectures provide vehicle mass and thruster performance information while the trajectory optimization minimizes the total Initial Mass in Low Earth Orbit. We describe the structure and implementation of the grid search, genetic algorithm, and On-Orbit Staging calculations with

16:15 AAS 13-809 A High Power Solar Electric Propulsion - Chemical Mission for Human Exploration of Mars

Laura Burke, NASA Glenn Research Center; Michael Martini, NASA Glenn Research Center; Steven Oleson, NASA Glenn Research Center

By combining an SEP system with a chemical propulsion system a roundtrip Mars mission is able to utilize the high-efficiency SEP for sustained vehicle acceleration and deceleration in heliocentric space and the chemical system for orbit insertion maneuvers and trans-earth injection, eliminating the need for long duration spirals. By capturing chemically instead of with low-thrust SEP, Mars stay time increases by nearly 200 days. Additionally, the size the of chemical propulsion system can be significantly reduced from that of a standard Mars mission because the SEP system greatly decreases the Mars arrival and departure hyperbolic excess velocities.

16:35 AAS 13-810 A High Earth, Lunar Resonant Orbit for Lower Cost Space Science Missions

Joseph Gangestad, The Aerospace Corporation; Gregory Henning, The Aerospace Corporation; Randy Persinger, The Aerospace Corporation

Many science missions require an unobstructed view of space and stable thermal environment but lack the technical or programmatic resources to reach orbits that satisfy these needs. We present a high Earth orbit in 2:1 resonance with the Moon that provides these conditions, reached via lunar gravity assist. Analytical and numerical investigations yielded insight into this unconventional orbit's behavior, making it possible to select a robust mission design. Solutions are available for a broad range of missions, from smaller missions such as the Transiting Exoplanet Survey Satellite to larger missions such as the Wide-Field Infrared Survey Telescope.

16:55 AAS 13-811 A Proposed Mission to Detect Solar Influences on Nuclear Decay Rates

Blake Rogers, Purdue University; James Longuski, Purdue University; Ephraim Fischbach, Purdue University

Recent evidence suggests a possible solar influence on nuclear decay rates, in which the half-life of isotopes (thought to be physical constants) change with distance from the Sun. To test this idea, spacecraft with relatively large changes in solar distances may be needed. This paper is the first to propose a mission specifically to test various isotopes for a solar influence on their nuclear decay rates. It also forms a baseline for what may be needed if such an experiment is added to the scientific payload of an upcoming mission, such as the Solar Probe Plus.

Session 14: Close-proximity Operations near Primitive Bodies

Chair: Al Cangahuala, Jet Propulsion Laboratory

13:30 **AAS 13-812** **Optical Navigation for Rosetta Operations Near Comet Churyumov-Gerasimenko**
Francesco Castellini; David Wokes; Ramon Pardo; Sabine Kielbassa

This paper presents an overview of the optical navigation methods developed for the near comet operations of the European Space Agency's Rosetta mission. The innovative aspect of this work lays in the challenge of estimating spacecraft position and comet parameters in absence of a-priori knowledge of the comet, in an active environment possibly leading to varying surface features. Navigation results are presented for synthetic images of a simulated body, showing that landmark observation residuals consistent with 1-pixel accuracy can be obtained, starting only from an approximate rotational period estimate and on the basis of purely optical data.

13:50 **AAS 13-813** **Exploration of a Graph-based Method to Orbit Transfers near Vesta**
Eric Arnal Fort, UCI; Benjamin Villac, University of California, Irvine; Josep Maria Mondelo, Universitat Autònoma de Barcelona

A continuation and bifurcation analysis is used to create a database of resonant periodic orbits on a 6th order and degree gravity field, using 4 Vesta as a case of study. A database of approximated minimal cost transfers between such periodic orbits is generated by solving Lambert's problem and differentially correcting. A weighted-edge graph is created and a combinatorial optimization algorithm is applied to find a minimum total Delta-V mission.

14:10 **AAS 13-815** **Design of Quasi-terminator Orbits near Primitive Bodies**
Gregory Lantoine, NASA / Caltech JPL; Stephen Broschart, NASA / Caltech JPL; Daniel Grebow, NASA / Caltech JPL

"Quasi-terminator" orbits are a class of quasi-periodic orbits around a primitive body that exist in the vicinity of the well-known terminator orbits. The inherent stability of quasi-terminator trajectories and their wide variety of viewing geometries make them a very compelling option for primitive body mapping missions. In this paper, we discuss orbit design methodologies for selection of an appropriate quasi-terminator orbit that would meet the needs of a specific mission. Design of these orbits in a full ephemeris is also discussed with some example cases.

14:30 **AAS 13-816** **Circular-orbit Maintenance Strategy for Primitive Body Orbiters**
Mark Wallace, Jet Propulsion Laboratory, California Institute of Technology; Stephen Broschart, NASA / Caltech JPL

For missions to smaller primitive bodies, solar radiation pressure (SRP) is a significant perturbation to Keplerian dynamics. For most orbits, SRP drives large oscillations in orbit eccentricity, which leads to large perturbations from the irregular gravity field at periapsis. Ultimately, chaotic motion results that often escapes or impacts that body. This paper presents an orbit maintenance strategy to keep the orbit eccentricity small, thus avoiding the destabilizing secondary interaction with the gravity field. An estimate of the frequency and magnitude of the required maneuvers as a function of the orbit and body parameters is derived from the analytic perturbation equations.

14:50 **AAS 13-817** **On an Idea about the Method of Absorbing Spin Motion of an Asteroid for Capture**

Shinichiro Narita, Japan Aerospace Exploration Agency; Jun'ichiro Kawaguchi, Japan Aerospace Exploration Agency

This paper presents how to remove the spin of the target asteroid for capture mission. The idea uses a small robotic spacecraft launched separately or carried on the big mother spacecraft. That spacecraft first winds up a tether around the target asteroid and the spacecraft itself plays a role of a tip mass in Yo-Yo mechanism. The operation may rely on sophisticated robotic technology, and may include the surface mobile agent jettisoned from the spacecraft.

15:10 **Session Break**

15:35 **AAS 13-818** **Non-Linear Pulsed Guidance for Asteroid Close-Proximity Operations**

John Kidd, University of Arizona; Roberto Furfaro, The University of Arizona; Daniel Wibben, The University of Arizona

Autonomous close proximity operations (hovering, landing, Touch-And-Go) in the low-gravity environment exhibited by asteroids is particularly challenging. A non-linear, pulsed landing guidance scheme has been developed for spacecrafts that are required to execute autonomous closed-loop guidance to a designated point on the asteroid surface. A guidance law is presented which uses a particular Lyapunov function to maintain global asymptotic stability. The theory behind this Lyapunov function is presented as well as evidence of stability and robustness in an environment of unmodeled yet bounded perturbations.

15:55 **AAS 13-819** **Real-Time State Estimation for Asteroid Close-Proximity Operations via Lidar Altimetry and a Particle Filter**

Brian Gaudet, University of Arizona; Roberto Furfaro, The University of Arizona

Current practice for asteroid close proximity operations uses open loop maneuvers. Due to uncorrected error propagation, navigation accuracy can rapidly degrade to the order of tens of meters after leaving safe orbit, making precision touch and go (TAG) maneuvers impossible. This paper presents a novel real-time state estimation algorithm that uses a Rao-Blackwellized particle filter, a laser altimeter, and an asteroid shape model to provide one-meter navigation accuracy. The state estimation algorithm is coupled with a guidance law, and precision TAG maneuvers on Itokawa and RQ36 are demonstrated via Monte Carlo simulations in a high fidelity simulation.

16:15 **AAS 13-820** **Observer-Based Body-Frame Hovering Control over a Tumbling Asteroid**

Morad Nazari, New Mexico State University; Robert Wauson, New Mexico State University; Thomas Critz, New Mexico State University; Eric Butcher, New Mexico State University; Daniel Scheeres, University of Colorado

Observer-based hovering control over a tumbling asteroid in the body-fixed frame is studied. An EKF is used to process range measurements from a small collection of ground stations, yielding estimates of the spacecraft state vector and the asteroid's gravitational parameters assuming a second degree and order gravity field model. The estimated states are used in the optimal feedback control algorithm which consists of two alternatives: time-varying LQR or the Lyapunov-Floquet transformation and time-invariant LQR. The closed-loop response of the system and the control effort required are investigated and compared for both control strategies.

16:35 AAS 13-821 Spacecraft Hovering Control for Body-Fixed Hovering over a Uniformly Rotating Asteroid Using Geometric Mechanics

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

This paper proposes spacecraft hovering control for body-fixed hovering over a uniformly rotating asteroid using geometric mechanics. The configuration space for a spacecraft is the Lie group of positions and orientations of the rigid spacecraft in three-dimensional Euclidean space. The dynamic equations of motion for the asteroid and spacecraft are described in their body fixed frames with respect to the heliocentric inertial coordinates. An almost globally asymptotic continuous-time feedback control is used to ensure spacecraft tracking. Numerical simulation results demonstrate the successful spacecraft hovering in the asteroid body-fixed frame for a selected uniformly rotating asteroid.

16:55 <No talk scheduled>

Session 15: Orbit Determination and Estimation II

Chair: Ryan Russell, University of Texas - Austin

13:30 **AAS 13-822** **Uncertainty Characterization for Angles-Only Initial Orbit Determination**
Christopher Binz, Naval Research Laboratory; Liam Healy, Naval Research Laboratory

When no information is known about a satellite's orbit, using an initial orbit determination method must suffice. Traditionally, this yields only a point solution, with no uncertainty information. This paper proposes that probabilistic information may be derived directly from the initial orbit solution. This information may be especially useful when observations of the object are very sparse, and any additional information is valuable. In this paper, we examine angles-only initial orbit determination. Assuming the angle measurements are known to within some finite range, we compute the probability density function yielded by combining the required three measurement pairs.

13:50 **AAS 13-823** **A Performance Based Comparison of Angle-only Initial Orbit Determination Methods**
Reza Raymond Karimi, Texas A&M University; Daniele Mortari, Texas A&M University

A comprehensive, performance based comparison of classical and recent methods of angles-only initial orbit determination (IOD) is presented. Several algorithms including techniques developed by the authors will be tested against a variety of ground-based and space-based tracking scenarios. The comparisons are focused on how well the IOD method is capable of estimating the shape and orientation of the or- bit. Specific single scenarios along with Monte Carlo analysis are per- formed. The number of observations vary from three to multiple depending upon the capability of the algorithm.

14:10 **AAS 13-824** **Application of Optical Tracking and Orbit Estimation to Satellite Orbit Tomography**
Michael Shoemaker, Los Alamos National Laboratory; Brendt Wohlberg, Los Alamos National Laboratory; Richard Linares, University at Buffalo, State University of New York; Josef Koller, Los Alamos National Laboratory

A new method, inspired by computed tomography used in medical imaging, was recently developed for atmospheric density estimation using satellite orbits. Previous simulations used several simplifying assumptions for the purposes of that preliminary feasibility study. The goal of the present work is to show the applicability of this tomography-based method to a realistic ground-based sensor network, set of target satellites, and orbit estimation system. The significance of this research is that an end-to-end solution is demonstrated for converting satellite tracking measurements into density corrections based on data from a limited sensor network.

14:30 AAS 13-825 Effect of Coordinate Selection on Orbit Determination

James Woodburn, AGI; Vincent Coppola, Analytical Graphics, Inc.

The application of linear methods to the inherently non-linear problem of orbit determination requires that a linearization be performed. This linearization process can be performed in any number of different coordinates. The effect of coordinate selection on the resulting orbit state and orbit state error covariance in batch and sequential estimators is investigated through examination of the mathematics of the estimators and numerical example. In the numerical comparisons, estimation results based on different coordinates are compared via non-linear transforms on the coordinates and linear transformations of the covariance to expose differences in information content.

14:50 AAS 13-826 Principle of Maximum Entropy for Probability Density Reconstruction: An Application to the Two Body Problem

Nagavenkat Adurthi; Puneet Singla, University at Buffalo

This paper describes the quantification of uncertainty in a simple Two Body Problem where the only source of uncertainty is in the knowledge of the initial condition. When the unknown initial conditions are modeled by a Gaussian pdf, the moments of the state pdf can be propagated and the pdf is estimated via the principle of maximum entropy. The recently developed Conjugated Unscented Transform provide an efficient way to to evaluate the moments compared to the Gauss-Hermite Product rule. The principle of Maximum entropy provides the methodology by which one can reconstruct the state pdf given the moments.

15:10 Session Break

15:35 AAS 13-827 Effects of Orbit Ephemeris Error and Limited Data on Density Estimation

Craig McLaughlin, University of Kansas; Dhaval Mysore Krishna , University of Kansas; Travis Locke, University of Kansas

Precision orbit derived densities have been estimated along the CHAMP and GRACE orbits and been shown to match the low frequency variations in accelerometer derived densities. The precision orbits used previously have accuracies of 5-10 cm compared to satellite laser ranging residuals. This paper examines the effects of different accuracies of orbit data and non-continuous data on density estimation. Random noise of varying levels is added to ephemeris data and/or continuous data is systematically decimated. Density is then estimated and compared to the case with continuous data and no noise added.

15:55 AAS 13-828 Bayesian Inference on Multimodal Distributions from n Interferometer

Liam Healy, Naval Research Laboratory; Christopher Binz, Naval Research Laboratory

In a radio-frequency interferometer, modeling only phase difference (timing) uncertainty with a normal distribution, the posterior probability density function of the direction is multimodal. Our previous work (AAS 13-276) treated the probability density function of the direction cosine as a discrete set of disconnected segments, and introduced the Multiple Mode Combinatorial Hypothesis Least Squares technique. In this paper, we extend the analysis to a much broader set of samples, introduce orbit-based priors, and compare the technique with existing multimodal analysis techniques given in the literature, and with a single-mode (traditional) least squares.

16:15 AAS 13-829 Spacecraft Navigation using Extrasolar Planetary Systems

George Hindman, Keystone Aerospace; Lila Glaser, Keystone Aerospace

Innovative navigation techniques and systems that improve on-orbit Position, Navigation and Timing (PNT) for spacecraft are highly desired. This paper outlines a new spacecraft hardware and software navigation system that allows for standalone calculation of a spacecraft's location by using in situ Doppler Spectroscopy observations. This system provides onboard orbit self determination through use of specialized reference stars that have exoplanetary companions. Over 800 extrasolar planets have been discovered within the past 15 years. Exoplanet motion around a reference star's barycenter provides a stable, highly predictable natural signal pattern which can be incorporated into a navigation solution.

16:35 AAS 13-830 Using Signals of Opportunity in Deep Space Satellite Navigation: Breadth of Coverage and Solution Accuracy

Ryan Handzo, Colorado Center for Astrodynamics Research; Jeffrey Parker, University of Colorado; George Born, University of Colorado at Boulder; Kenn Gold

This paper considers a new resource for use in satellite navigation, free signals of opportunity. Signals of opportunity are any signals transmitted into a satellite's environment that are not intended to be used for navigation purposes. The most promising signals of opportunity, digital television signals, are the focus of this study. This paper studies how often signals may be available for a satellite to use, and how the uncertainty of the signals estimate of the satellite's orbit evolves with time. These free signals provide a new option for precise orbit determination for satellites beyond GPS effectiveness.

16:55 <No talk scheduled>

Session 16: Attitude Guidance and Control

Chair: Don Mackison, University of Colorado – Boulder

13:30 AAS 13-832 Repetitive Control of Digital Systems Having Fast Phase Change Produced by the Discretization

Bejamas Panomrutanarug, King Mongkut's University of Technology Thonburi; Richard Longman, Columbia University

Repetitive control (RC) can be used for active vibration isolation in spacecraft, using knowledge of reaction wheels or control moment gyro rotation speed. Previous research developed very effective FIR compensator design methods. These designs place zeros in specific patterns that could be approximately explained in terms of Taylor series properties expanding discrete time transfer functions. This paper examines situations not previously studied, where a zero is introduced into the discrete time transfer function by conversion from continuous time, and it is near the unit circle in the z-plane. Properties of this new class of compensator design are studied.

13:50 AAS 13-833 Investigation of Discrete Time Emulation Techniques to Simplify Repetitive Control Design

Pitcha Prasitmeeboom, Columbia University; Richard Longman, Columbia University

Repetitive control (RC) is a control method specifically designed to eliminate the effects of periodic disturbances on control systems. In spacecraft they can be used for active vibration isolation. The authors and coworkers have developed several simple RC design methods that are somewhat analogous to PID controller design in classical control. This paper investigates other simplified approaches based on discrete time emulation of continuous system. Making use of knowledge obtained in RC compensator design, a simple and effective zero-pole mapping design method is developed and shown to be particularly effective.

14:10 AAS 13-834 Single-Axis Pointing of a Spacecraft With Two Skew Control Moment Gyros

Haichao Gui, Beihang University; Lei Jin, Beihang University; Shijie Xu, Beihang University

Single-axis pointing of a spacecraft using two skew single-gimbal control moment gyros (CMGs) is addressed. First, two types of restrictions are enforced on gibmal motions of two skew CMGs, with each restriction yielding a single-axis output torque. Moreover, these two torque vectors are orthogonal to each other. Then, a two-step eigenaxis rotating strategy, executing by the two single-axis torques respectively, is designed to point an arbitrary body-fixed axis along a desired direction. The amplitudes of each rotation are analytically derived and CMG singularities are avoided by limiting the maximum slew rate for each rotation.

14:30 **AAS 13-835** **Feedback Control and Steering Laws for Spacecraft Using Canfield Joint Attitude Manipulators**

Eamonn Moyer, University at Buffalo, State University of New York; Manoranjan Majji, University at Buffalo, State University of New York

A novel attitude control system using a reaction wheel mounted on a Canfield joint is introduced. The rotational equations of motion for a rigid-body spacecraft with a pair of Canfield joint attitude manipulators are derived. Lyapunov stability theory is used to form the feedback control laws for the system. The steering laws that generate the required torque for feedback control are derived and are used in conjunction with the feedback control laws to simulate certain maneuvers numerically.

14:50 **AAS 13-836** **Quaternion Based Optimal Spacecraft Reorientation Under Complex Atitude Constrained Zones**

Unsik Lee, University of Washington; Mehran Mesbahi, University of Washington

The paper addresses the quaternion based fuel and time optimal spacecraft reorientation in the presence of complex attitude constrained zones. Designing a optimal reorientation trajectory for a spacecraft is posed as a nonlinear optimal control problem. In this direction, attitude constrained zones are defined in two types–forbidden and mandatory–from the onboard sensor point of view and presented as quadratic inequality constraints in unit quaternions. The optimal control problem is then solved using a pseudospectral method. The unwinding phenomenon necessarily embedded in quaternion based control is discussed and novel algorithm is proposed. The paper concludes with extensive simulation results.

15:10 **Session Break**

15:35 **AAS 13-837** **Suboptimal Delayed Feedback Attitude Stabilization of Rigid Spacecraft with Disturbance Torques and Unknown Time-Varying Delays**

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

The stabilization of spacecraft attitude dynamics in the presence of disturbance torques and unknown time-varying measurement delays is considered. By employing a linear delayed state feedback control, a delay-dependent Lyapunov-Krasovskii functional, and Ito's differential formula, a stochastic delay-differential equation is obtained with a stability condition in terms of a linear matrix inequality whose solution yields the control gains. In addition, a quadratic cost function is applied to achieve a suboptimal control performance. An estimate of the region of attraction of the controlled system is found, and the proposed controller is studied via attitude dynamics simulations.

15:55 **AAS 13-838** **Adaptive Attitude-Tracking Control of Spacecraft with Uncertain Time-Varying Inertia Parameters**

Divya Thakur, The University of Texas at Austin; Srikant Sukumar, Indian Institute of Technology Bombay; Maruthi Akella, The University of Texas at Austin

Adaptive control schemes for spacecraft attitude tracking are abundant in control literature. However, very few are designed to guarantee consistent performance for a spacecraft with time-varying inertia components. In this paper, a certainty-equivalence based adaptive control scheme is proposed for the attitude control of a spacecraft characterized by a time-varying inertia matrix with known time-variation but unknown bounds. A complete derivation of the control law is provided along with a thorough stability analysis and numerical simulations to highlight the performance benefits when compared with an adaptive control scheme that does not account for inertia variations.

16:15 **AAS 13-839** **Stability Analysis and Sun-Tracking Attitude Control of Spacecraft under Solar Radiation Pressure**

Naohiro Hayashi, The University of Tokyo; Go Ono, University of Tokyo; Yuya Mimasu, Japan Aerospace Exploration Agency; Jun'ichiro Kawaguchi, Japan Aerospace Exploration Agency

In an interplanetary mission, the influence of solar radiation pressure (SRP) is a dominant disturbance in terms of the attitude control of a spacecraft. A continuous disturbance shortens their mission life time. The objective of this study is to establish attitude control methods of a spacecraft by actively using the SRP. At first, we analyze the stability of attitude motion under the SRP. Next, we derive appropriate attitude control laws for each configuration of a spacecraft. As a case study, we verify the control methods by applying them to a model of the Venus climate orbiter AKATSUKI.

16:35 **AAS 13-840** **A Hybrid CMG-RW Attitude Control Strategy for Agile Small Satellites**

Kunal Patankar, University of Florida; Norman Fitz-Coy, University of Florida

This paper discusses a COTS-based momentum exchange devise which operates in a hybrid control moment gyroscope (CMG) and reaction wheel (RW) mode to achieve rapid retargeting as well as precision pointing by selectively using the torque amplification capabilities of the single gimbal CMGs or direct torque capabilities of the flywheel motors. The system switches from CMG to RW mode based the slew rate and the pointing stability requirements. The paper discusses a comprehensive control strategy for the mode change backed by high fidelity simulations. It also discusses the practical considerations of hardware design of such system for small satellites.

16:55 **AAS 13-841** **On the High Precision Steering Law of VSCMGs**

Xinghong Huang, Beihang University; Shijie Xu, Beihang University

Although Control moment gyros can provide the spacecraft attitude control system with a larger torque, they also bring in a larger torque error. To solve this problem, a steering law is proposed for variable speed control moment gyros. Two kinds of work mode are designed: CMG/RW hybrid mode for the large torque situation and single RW mode for the small torque. In hybrid mode, the torque error is compensated by RW submode. In single RW mode, the motion of gimbals is locked, and this guarantees a better torque precision. Transition process between the two work modes is programmed.

Session 17: SSA III: Orbit Debris Modeling and Mitigation

Chair: Glenn Peterson, The Aerospace Corporation

8:00 **AAS 13-842** **Space Debris as an Epidemic, Complexity and Dynamical Systems in the Debris Problem**

David Finkleman, Center for Space Standards and Innovation

We use classical mathematical techniques to examine the stability of nonlinear governing equations which are a super-set of Kessler's equations. We prove that the solutions are unconditionally stable "logistical" attractors with chaotic and unpredictable limiting solution trajectories. This is analogous to a tipping point, but debris growth is not exponential. Behavior during the approach to equilibrium depends on initial conditions, implying that active debris removal should consider the parameters of the more comprehensive nonlinear prescription. Comprehensive numerical simulations of several independent investigators confirm such behavior. This work applies principles and techniques well developed in complexity and dynamical systems.

8:20 **AAS 13-843** **COBRA: A Covariance-Based Debris Risk Assessment Model**

Felix Hoots, Aerospace Corporation; Brian Hansen, The Aerospace Corporation

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 present a new method for determining the risk posed by the cloud to resident spacecraft. This covariance based method provides improved accuracy and efficiency.

8:40 **AAS 13-844** **Summarizing the General Effects of Breakup Debris in GEO**

Brian Hansen, The Aerospace Corporation; Marlon Sorge, The Aerospace Corporation

A major breakup event in GEO could occur at any time due to an explosion or collision of resident space objects. While much research has been done on breakup debris in LEO, where events like this have occurred, relatively little has been done for GEO. This paper seeks to document and build upon several recent studies to further our understanding of debris cloud evolution and expected risk following a GEO breakup. This includes comprehensive analysis of fundamental differences between GEO and LEO that affect debris risk, and parametric analysis indicating which perturbations are most important for GEO debris cloud modeling.

9:00 **AAS 13-845** **Use of Slowly Varying Orbit Elements for Spread Velocity Reconstruction of Historical Orbital Breakups**
Glenn Peterson, The Aerospace Corporation

This paper examines multiple historical explosions and collisions of on-orbit objects to determine their breakup characteristics. These parameters, primarily spread velocity distribution, can then be utilized in validation and verification of hypervelocity impacts codes such as IMPACT. Typically this is performed by using debris objects that are identified shortly after the event, but by using slowly varying orbit elements rather than short-term conjunction assessment, debris objects that appear months to years after the event can be effectively included in determining the spread velocity. Results show that both methods yield event breakup characteristics that are very similar in nature.

9:20 **AAS 13-846** **Space Debris Visualization, Characterization, and Volume Modeling**
Ryan McKennon-Kelly, The Aerospace Corporation; Felix Hoots, Aerospace Corporation

This paper presents a method of generating a temporally evolving 3-Dimensional (3D) surface that encloses a collection of orbital debris particles. The method described produces a 3D model of the debris cloud, which can incorporate the use of color and transparency to provide a more accurate visualization of the cloud's extent and potential danger. The method produces a closed 3D cloud; further methods may be applied to determine whether or not a particle is located within the model. This provides an efficient way to quickly determine if a satellite of interest passes through the debris field.

9:40 **Session Break**

10:05 **AAS 13-847** **Autonomous 6-DOF Relative Estimation for Proximity Operations with an Uncooperative Space Object**
Dae-Min Cho; Panagiotis Tsiotras; Marcus Holzinger, Georgia Institute of Technology

In this paper SLAM/SfM (Simultaneous Localization and Mapping / Structure from Motion) techniques using a monocular, calibrated camera are studied for autonomous relative navigation with respect to an unknown on-orbit space object. Autonomous relative navigation and perception plays a crucial role in space object inspection, capture, and servicing, however there are significant challenges when the target is uncooperative and provides neither navigational cues nor has communication links. We adopt a multi-view geometry technique to automatically find and update new feature points to track the target space object; a smoother is used to find MAP (Maximum a Posteriori) estimates

10:25 **AAS 13-848** **Effects of the Rotational Motions of Debris Objects on the Prediction of Their Orbital Motions**
John E. Cochran, AUBURN UNIVERSITY; Thomas Walsh, Auburn University

Since the launch of the first satellites, the coupling of translational and rotational motions of objects moving in relative low orbits about the Earth has been recognized as an important factor in the calculation of accurate orbits. In the case of debris, it may not be possible to include rotational motion explicitly because of lack of knowledge of the physical characteristics of a debris object. In this paper, we use analytical methods, a six-degree-of-freedom simulation, and an orbit determination program to study the effects the rotational motion of debris objects on the prediction their orbital motions.

10:45 AAS 13-849 A Mathematical Formulation to Describe Density of Particles in an Inhomogeneous Distribution

Ken Chan, Chan Aerospace Consultants

A mathematical formulation is developed to define the number density of particles distributed in a system that exhibits pronounced clustering in regions whose dimensions are small compared to those of the whole system. This is the case when a spacecraft traverses a cloud of space debris generated from a collision or an explosion at some time after the event has occurred. A parameter which is an indication of the coarseness of resolution is introduced to enable the definition of the density in rigorous terms. This parameter is useful in describing the regions of non-uniformities of a distribution of particles.

11:05 AAS 13-850 Orbit Determination of ETS-8 by Pegasus Observatory in Kyushu University

Hideaki Hinagawa, Kyushu University

Orbital debris removal has been suggested for sustainable space development and utilization for human being to deal with the recent orbital debris problem. Kyushu University in Japan has introduced Meade telescope in 2012, and started working on investigation of knowledge on how objects to be removed are tumbling using light curve. However, the estimation of attitude motion needs orbit determination first since attitude estimation requires a geometrical relationship among the Sun, the observer, and the target debris. This paper introduces the telescope, and presents an established orbit determination tool, and tests the tool by observing ETS-8, geostationary satellite.

11:25 AAS 13-851 Space-based characterization of debris in Low-Earth orbit via LWIR imaging

Paul McCall, Air Force Research Labratory/Florida International University; Madeleine Naudeau; Malek Adjouadi, Florida International University

Every space launch may increase the overall amount of space debris, especially if circumstances result in the orbital objects being stranded in orbit with no de-orbiting capabilities. Studies contributing to the understanding of space debris further efforts to help spacecraft operators mitigate risk associated with Earth-orbiting debris objects. Accurately characterizing the debris threat to a spacecraft is of vital importance in maximizing the lifespan and mission capabilities of the spacecraft. This investigation aims to build LWIR radiometric models of typical debris and use these models to develop techniques for detecting and characterizing the objects by signal analysis of

Session 18: Spacecraft Guidance, Navigation, and Control

Chair: Dr. Maruthi Akella, University of Texas - Austin

8:00 **AAS 13-852** **Heuristic Suboptimal Solutions to Reduce Velocity Pointing Errors for Spinning, Thrusting Spacecraft**

Kaela Martin, Purdue University; James Longuski, Purdue University

During axial thrusting of a spinning spacecraft, misalignments and center-of-mass offset result in velocity pointing errors. These pointing errors cause the spacecraft to deviate from its desired trajectory. Typically the axial thrust behaves like a step function, jumping from zero to its maximum value. Alternatively, by ramping-up the axial thrust from zero to its maximum value, the velocity pointing errors are significantly reduced compared to those arising from the step function. Various ramp-up profiles (such as exponential, sinusoidal, and parabolic) are considered to heuristically find a suboptimal solution to minimize the velocity pointing error.

8:20 **AAS 13-853** **Image Processing of Illuminated Ellipsoid**

Daniele Mortari, Texas A&M University; Francesco de Dilectis, Texas A&M University; Christopher D'Souza, NASA - Johnson Space Center

This paper contains the theory of data processing using a visible camera in Earth/Moon trajectories, such as using the docking camera of the Orion visible camera. Using knowledge of time, spacecraft attitude (from attitude sensors), and a rough estimation of position, it is possible to provide useful information to perform initial trajectory estimation in a three-body gravitational environment.

8:40 **AAS 13-859** **A Least Squares Solution for Estimation of a Planar Homography**

Manoranjan Majji, University at Buffalo, State University of New York; Martin Diz, University of Buffalo; David Truong, University of Buffalo

This paper presents a solution to the planar homography problem for vision based navigation systems. The solution presented here differs considerably from the approach used by other researchers in the sense that it produces a closed form solution to the relative pose parameters directly from the minimum measurements (4). Applications for the planar homography solution include camera calibration, LADAR system calibration and navigation problems pertaining to relative spacecraft rendezvous and proximity operations (RPO).

9:00 **AAS 13-855** **Thrusters Time-delayed Control Allocation for Soft-landing of Lunar Lander**

Jae-wook Kwon, Korea Aerospace Research Institute; Bong Un Lee, AP Aerospace Inc.; Hyochoong Bang, Korea Advanced Institute of Science and Technology; Gwanghyeok Ju, Korea Aerospace Research Institute

During the Entry, Descent and Landing (EDL) Phase, the thruster is the main actuator responsible for ensuring a soft landing at the end of the phase. If the lunar lander can generate only a few levels of fixed constant force with a low control frequency, it is difficult to make a soft landing. In order to get a soft landing without changing the hardware system, the modified controller was designed and verified through a simulation. The Proposed controller is to introduce time-delayed and allocated control to the set of the assigned thruster.

9:20 **AAS 13-856** **Operations Concept, Hardware Implementation and Ground-Test Verification of a Hazard Detection System for Autonomous and Safe Precision Lunar Landing**

John M. Carson, NASA; Erik Bailey, NASA/JPL; Nikolas Trawny, NASA/JPL; Andrew Johnson, NASA/JPL; Eric Roback, NASA; Farzin Amzajerdian, NASA Langley Research Center; Robert Werner, NASA/JPL

The Autonomous Landing Hazard Avoidance Technology (ALHAT) project developed a Hazard Detection System (HDS) for real-time landing-site detection and site-relative navigation during robotic- or crewed-vehicle precision landing. Design requirements were: detect sites free of 30cm hazards within a hectare Lunar region from a 1km slant range, 30-degree approach angle, under any lighting conditions. The current HDS uses a gimbaled flash lidar with narrow angle optics and dedicated IMU to achieve operational requirements. This paper describes the HDS implementation, operation and calibration to achieve pointing performance necessary for terrestrial flight-testing on the NASA Morpheus vehicle.

9:40 **Session Break**

10:05 **AAS 13-857** **On Six D.O.F Relative Orbital Motion Parametrization Using Rigid Bases of Dual Vectors**

Daniel Condurache, Technical University of Iasi; Adrian Burlacu, Technical University of Iasi

The relative orbital motion is a 6-DOF motion, generated by the coupling of the relative translational motion with the rotational one. This paper is focused on developing a new relative orbital motion parametrization method using dual rigid bases. Our studies showed that, in the dual tensors free module, the dual rigid bases can completely characterize the relative orbital motion from the Euclidean three dimensional space. The combination between a dual rigid basis and its reciprocal provides a natural computational instrument that can be used to solve many problems in the kinematics, dynamics and control of relative orbital motion setups.

10:25 **AAS 13-858** **Adaptive Position and Attitude Tracking Controller for Satellite Proximity Operations using Dual Quaternions**

Nuno Filipe; Panagiotis Tsiotras

In this paper, we propose a nonlinear adaptive position and attitude tracking controller for satellite proximity operations. This controller requires no information about the mass and inertia matrix of the satellite, and takes into account the gravitational acceleration, the gravity-gradient torque, the perturbing acceleration due to Earth's oblateness, and other constant -- but otherwise unknown -- disturbance forces and torques. We give sufficient conditions for mass and inertia matrix identification. The controller is shown to be almost globally asymptotically stable and can handle large error angles and displacements. Unit dual quaternions are used to simultaneously represent the absolute and

10:45 AAS 13-860 Halo Orbit Targeting Guidance via Higher Order Sliding Techniques

Jules Simo, University of Strathclyde; Roberto Furfaro, The University of Arizona; Daniel Wibben, The University of Arizona

In this paper, the Multiple Sliding Surface Guidance (MSSG) algorithm has been implemented and simulated to verify the ability to target the insertion point of a suitable halo orbit in the vicinity of the Sun-Earth libration points. Based on Higher-Order Sliding Control (HOSC) theory, the proposed MSSG algorithm computes an acceleration command that target a specified state by considering only knowledge of the current and desired position and velocity. Preliminary results show that the guidance scheme is able to successfully target a suitable state for proper orbital insertion.

11:05 AAS 13-861 Distributed Internet-enabled Simulation/Testbed Architecture

Marcelo Gonzalez, Emergent Space Technologies; Darren Zanon, Emergent Space Technologies; Ravishankar Mathur, Emergent Space Technologies

This research introduces DISTA, an architecture that allows simulations to connect to existing hardware testbeds over the internet and perform closed-loop simulations. Benefits include the ability to create a distributed testbed without the time and expense of manually developing custom hardware. Key aspects of real-time network communications are discussed, such as latency mitigation, security, and standardized data representation. Also developed are dynamic and kinematic compatibility tests that determine whether particular testbeds are compatible with a simulation's requirements. An example is shown of a simulation driving a hardware testbed over the internet in a closed-loop test run.

11:25 <No talk scheduled>

Session 19: Orbit Dynamics

Chair: Tom Starchville, The Aerospace Corporation

8:00 **AAS 13-862** **The Two Body Problem Elevated to the Complex Domain**

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

Here, elliptical orbits of the Two Body Problem in 2 dimensions are elevated to the Complex Domain of 4 dimensions. So x(t) and y(t) are elevated to x(t,tau)+ ip(t,tau) and y(t,tau) + iq(t,tau) respectively. Using our newly Discovered Perturbation Derivatives for all complex analytic functions, it is found that p and q are automatically the solution of perturbation equations for x and y respectively. The exponential divergence of neighboring trajectories is clearly shown. Kepler's Equation is raised to two variables, E1 and E2 and is solved easily by iteration.

8:20 **AAS 13-863** **Trajectory Dynamics of Gas Molecules and Galaxy Formation**

James Miller, Consultant; Gerald Hintz, University of Southern California; Pedro Llanos, GMV

Navigation of interplanetary spacecraft requires models of the acceleration caused by gas molecules that are either expelled or impact a spacecraft. Examples of molecules expelled from a spacecraft are gas trapped in a parachute or released by venting events. Molecules that impact a spacecraft come from planetary or comet atmospheres. In this paper, the velocity probabilty distribution of gas molecules in a closed container is described. The result is a probability density function that is close to the Maxwell distribution function. Verification of the simulation model is obtained by comparison with the velocity distribution associated with stars during galaxy formation.

8:40 **AAS 13-864** **Searching for orbits that can be controlled by natural forces**

Thais Oliveira; Antonio Fernando Prado; Evandro Rocco; Arun Misra

This paper provides maps of orbits that may use atmospheric drag and solar radiation pressure for stationkeeping. The results show the integral over the time of the perturbing forces. This integral represents the total change of velocity per orbit the satellite receives from the perturbing forces. Atmospheric drag, solar radiation, J2 to J4 zonalharmonics terms and lunisolar perturbation are considered. The results provide the magnitude of each perturbing forces, so it's possible to see if drag and radiation pressure added together are larger than the others on the average and so can be used to control the other forces.

9:00 **AAS 13-865** **Long-term Dynamics and Stability of GEO Orbits: The Primacy of the Laplace Plane**

Aaron Rosengren, University of Colorado at Boulder; Daniel Scheeres, University of Colorado; Jay McMahon, University of Colorado

The geosynchronous orbit is in a region of space where the perturbing effects due to Earth's oblateness and lunisolar gravitational forces are comparable. On the classical Laplace plane, the secular orbital evolution driven by the combined effects of these perturbations is zero, so that the orbits are frozen. We explore the dynamics and stability of GEO orbits, and show how solar radiation pressure modifies the Laplace plane equilibrium. We discuss the implications of these results for high area-to-mass ratio debris, and show how the classical Laplace plane can be used as a robust long-term disposal orbit.

9:20 **<No talk scheduled>**

9:40 **Session Break**

10:05 **AAS 13-867** **The Eccentric Behavior of Nearly Frozen Orbits**

Theodore H Sweetser, Jet Propulsion Laboratory; Mark Vincent, Raytheon

Frozen orbits are orbits which have only short-period changes in their mean eccentricity and argument of periapse, so that they basically keep a fixed orientation within their plane of motion. Nearly frozen orbits are those whose eccentricity and argument of periapse have values close to those of a frozen orbit. We call them ”nearly” frozen because their eccentricity vector (a vector whose polar coordinates are eccentricity and argument of periapse) will stay within a bounded distance from the frozen orbit eccentricity vector. This paper shows how eccentricity and argument of periapse of a nearly frozen orbit evolve with time.

10:25 **AAS 13-868** **Application of High-Order STTS Uncertainity Propagation on Perturbed Two-Body Problem**

Ahmad Bani Younes, Texas A&M University

The proposed work focuses on utilizing an efficient and high-fidelity numerical method to propagate the state uncertainty of the perturbed satellite motion (inverse square gravity field added to the (200, 200) Earth Gravitational Model EGM 2008). The method is approached 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.

10:45 **AAS 13-869** **Approximation of Probability Density Functions Propagated Through the Perturbed Two-Body Problem**

Michael Mercurio, University at Buffalo; Reza Madankan; Puneet Singla, University at Buffalo; Manoranjan Majji, University at Buffalo, State University of New York

In this paper, we will make use of method of characteristics to analytically solve Fokker-Planck equation in a modified equinoctial frame. The two-body orbit will include J2 perturbations, as well as atmospheric drag. The method of characteristics provides the evolution of probability along a state trajectory in a computationally efficient manner in the presence of orbit perturbations. Our approach yields points that always lie on the probability density function. These values are then interpolated using the Global-Local Orthogonal Polynomial Mapping (GLO-MAP) process to obtain approximate probability density function that evolves in the time of interest.

11:05 AAS 13-870 Orbit Uncertainty Propagation with Separated Representations

Marc Balducci, CCAR - CU Boulder; Brandon Jones, University of Colorado, Boulder; Alireza Doostan, University of Colorado Boulder

Most approximations for high-dimensional, non-Gaussian stochastic differential equations suffer from the curse of dimensionality, thereby increasing uncertainty propagation computation costs. In astrodynamics, this results in reduced probability density function propagation accuracy. However, the computation cost of a separated representation varies linearly with dimension, thereby improving tractability. Generation of a separated representation requires the propagation of a small number of samples and yields an approximate solution to a given stochastic differential equation. This paper considers the application of separated representations for orbit uncertainty propagation, discusses the theory behind their generation, and presents results quantifying their benefits in astrodynamics.

11:25 AAS 13-871 Cylindrically and Spherically Constrained Families of non-Keplerian Orbits

Jeannette Heiligers, Advanced Space Concepts Laboratory, University of Strathclyde; Colin McInnes, Advanced Space Concepts Laboratory, University of Strathclyde

As an extension to the well-known circular displaced non-Keplerian orbits (NKOs), this paper introduces new, three-dimensional families of NKOs that are confined to a cylindrical or spherical surface. By imposing geometrical constraints and constraints on the angular velocity and acceleration magnitude, feasible orbits are found using either solar electric propulsion or solar sailing. Families of orbits are identified through the system's phase space and Poincaré maps are employed to establish the periodicity of these orbits. The wealth of novel orbits and resulting space applications is significant, including interplanetary communication, astronomical observations, solar physics and many more.

Session 20: Atmospheric Flight and Entry, Descent, and Landing

Chair: Angela Bowes, NASA Langley Research Center

8:00 AAS 13-872 Trajectory Design Considerations for Precision Landing on Mars

Zhong-Sheng Wang, China Academy of Space Technology; Melissa Gambal; Adly Espinoza; Robert Hook

A spacecraft achieves a circular or elliptical orbit after the Mars orbit insertion maneuvers, then enters an elliptical entry orbit for descent. It is demonstrated in the paper that a phasing maneuver or orbit plane adjustment plus a three-by-three targeting sequence can be used in helping achieve a precision landing on the Martian surface. It is essential to use an accurate descent dynamic model and have accurate information of the guidance law applied in the descent. Also addressed is the orbit and trajectory design consideration of the tracking access conditions in planning the maneuvers.

8:20 AAS 13-873 Atmosphere Assessment for Mars Science Laboratory Entry, Descent and Landing Operations

Alicia Dwyer Cianciolo, NASA; Michael Mischna

The Mars Science Laboratory rover, Curiosity, successfully landed on the surface of Mars August 6, 2012. The Entry, Descent and Landing (EDL) sequence was designed using atmospheric conditions estimated from mesoscale numerical models and validated against observations at Mars. In the weeks and days prior to entry, the “Council of Atmospheres” evaluated real-time Mars data to determine how the current conditions compared to the model estimates. This paper summarizes the atmosphere observations and comparison to the models used in the performance simulation. Options to modify the atmosphere model and a description of the EDL atmosphere decision process are also

8:40 AAS 13-874 A Navigation Scheme for Pinpoint Mars Landing Using Radar Altimetery, a Digital Terrain Model, and a Particle Filter

Brian Gaudet, University of Arizona; Roberto Furfaro, The University of Arizona

Future science-driven missions to Mars will require advanced guidance and navigation algorithms that are able to adapt to more demanding mission requirements by landing at selected locale with pinpoint accuracy while autonomously flying fuel-efficient trajectories. Current practice for navigation as applied to the powered descent phase of a Mars landing results in downrange and crossrange position uncertainties on the order of several kilometers. In this paper we present a novel real-time navigation algorithm that uses radar altimetry, a digital terrain model, and a particle filter to estimate the lander’s position to an accuracy of several meters.

9:00 **AAS 13-875** **Neural-based Trajectory Shaping Approach for Terminal Planetary Pinpoint Guidance**

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

In this paper, we present an approach to pinpoint landing based on what we consider to be the next evolution of path shaping methodologies based on potential functions. We employ neural network methodologies to learn the relationship between current spacecraft position and the optimal velocity field required to shape the path to the surface in a fuel efficient fashion. By ensuring that the velocity field is convergent to the desired target, a first-order guidance algorithm is designed to track the optimal velocity field.

9:20 **AAS 13-876** **Satellite Attitude Control by Center-of-Mass Shifting**

Simone Chesi, University of California Santa Cruz; Qi Gong, University of California, Santa Cruz; Marcello Romano, NPS

This paper introduces a novel control technique that uses active variation of the aerodynamic torque through center of mass shifting, together with reaction wheels and magnetic torquers. In this paper, we demonstrate how to use three shifting masses as actuators so that the aerodynamic disturbance torque can act as a control torque. Two control laws are introduced: one using aerodynamic torque and reaction wheel, the other using aerodynamic torque and magnetic torque. This method is based on adaptive nonlinear feedback control and its control authority is proportional to the value of the external disturbance force acting on the satellite.

9:40 **Session Break**

10:05 **AAS 13-877** **Development of the Hybrid Navigation System for the Third SHarp Edge Flight EXperiment (SHEFEX-3)**

Malak Samaan, German Aerospace Center; Stephan Theil, DLR German Aerospace Center

The SHEFEX-3 mission is proposed to pursue the technology development for reentry vehicles and, in particular the key concept of REX-Free Flyer using the extended flight experiment and shall be launched in 2016 in a suborbital trajectory. The accurate control of the SHEFEX-3 vehicle using the control flaps and moving masses requires a high-accuracy measurement of the angle of attack and the side slip angle. Both angles can only be derived from the flight path and an accurate inertial attitude measurement. The presented work will describe the concept of the integrated hybrid navigation system.

10:25 **AAS 13-878** **Modeling Satellite Drag Coefficients with Response Surfaces**

Piyush Mehta, Los Alamos National Laboratory; Andrew Walker, Los Alamos National Laboratory; Earl Lawrence; Richard Linares, University at Buffalo, State University of New York; David Higdon; Josef Koller, Los Alamos National Laboratory

Drag coefficient (CD) is a major source of uncertainty in predicting the drag force on a satellite in low Earth orbit (LEO). Accurately predicting the orbit requires detailed knowledge of the CD. Computational methods are important tools in computing drag coefficient but are computationally intensive for real-time predictions. Therefore, analytic or empirical models that can accurately predict CD are desired. This work uses response surfaces to model CD. The response surface for the CD of a sphere is derived for the entire parameter space. The model performs well in predicting the CD with a maximum error of 0.3%.

10:45 **AAS 13-879** **Solution of Yaroshevskii's Planetary Entry Equation via a Perturbative Method**

Sarag Saikia, School of Aeronautics and Astronautics, Puurdue University; James Longuski, Purdue University; Jeffrey Rhoads, Purdue University

An analytical solution for ballistic entry problems at circular speed is obtained for Yaroshevskii's planetary entry equation. Using the Poincaré-Lindstedt meth-od, explicit expressions for velocity, altitude, flight path angle, deceleration, and aerodynamic heating are found. Using a similar approach, an analytical solution is developed for lifting entry at circular speed. The solutions for both the ballistic and lifting cases are verified to be highly accurate via numerical simulation.

11:05 **AAS 13-880** **Analytical Theory for Ballistic Entry At Circular Speed for Various Flight Path Angles**

James Longuski, Purdue University; Sarag Saikia, School of Aeronautics and Astronautics, Puurdue University

Two distinct analytical solutions are developed via perturbative methods for ballistic entry at small to large initial flight path angles. Two separate solutions are needed to avoid a singularity. The theory has applications to an entry which may have an arbitrary constant ballistic coefficient. The classical Yaroshevskii's solution enters as the zero order term in the solutions. Explicit analytical expressions for deceleration and heating are also developed. The accuracy of the solutions is verified via numerical integration of the exact equations of motion.

11:25 **AAS 13-881** **Analytical Theory for Ballistic Entry At Moderate to Large Initial Flight Path Angles**

James Longuski, Purdue University; Sarag Saikia, School of Aeronautics and Astronautics, Puurdue University

Universal planetary entry equations are used to develop an analytical theory for ballistic entry at circular speed for moderate to large initial flight path angles. Chapman's altitude variable is used as the independent variable. Poincaré's method of small parameters is used to develop analytical solutions for the velocity and the flight path angle. Expressions for deceleration and aerodynamic heating are also developed. The classical approximate solution of Chapman's entry equation appears as the zero order term in the new solution. The theory is very accurate for large entry angles and has a wide range of applications.

Session 21: Lunar Mission Design and Concepts

Chair: Roby Wilson, Jet Propulsion Laboratory

13:30 AAS 13-882 Trajectory Design for MoonRise: A Proposed Lunar South Pole-Aitken Basin Sample Return Mission

Jeffrey Parker, University of Colorado; Tim McElrath, JPL/Caltech; Rodney Anderson, NASA / Caltech JPL; Theodore H Sweetser, Jet Propulsion Laboratory

This paper presents the mission design for the proposed MoonRise New Frontiers mission: a lunar farside lander and return vehicle, with an accompanying communication satellite. Both vehicles are launched together, but fly separate low-energy transfers to the Moon. The communication satellite enters lunar orbit immediately upon arrival at the Moon, whereas the lander stages in a libration orbit; the lander descends to the surface and touches down 17 days after the communication satellite enters orbit. The lander remains on the surface for nearly two weeks before lifting off and returning to Earth via a low-energy return.

13:50 AAS 13-884 Calculation of an Optimal Two Impulse Earth-Moon Trajectory

John McGreevy, University at Buffalo; Manoranjan Majji, University at Buffalo, State University of New York

In this paper, an optimal control approach utilizing the Hamiltonian is applied to the the two-impulse Earth-Moon trajectory problem. Advantages of the circular-restricted three-body problem are utilized to solve the optimal control problem for this orbital transfer. The free terminal time problem is solved by performing calculations using a fixed terminal time approach, and determining the optimal terminal time from the results of the fixed-time calculations.

14:10 AAS 13-885 Lunar L1 Earth-Moon Propellant Depot. Orbital and Transfer Options Analysis

Hsuan-chen Wan, University of California Irvine; Benjamin Villac, University of California, Irvine

One concept in support human exploration beyond low Earth orbit consists of placing fuel depots in the region of the Earth-Moon or Earth-Moon-Sun libration points given their high accessibility. While several studies have considered this concept on halo orbits, the full range of libration point orbits has not been considered. This study further explores the broader range of quasi-periodic orbits near the LL1 point, and their associated set of transfers from the lunar surface and low lunar orbits.

14:30 **AAS 13-886** **Far-side Lunar Ascent Trajectory Design to Earth-Moon L2 Orbit**
Ann Dietrich, University of Colorado Boulder; Jeffrey Parker, University of Colorado; George Born, University of Colorado at Boulder

Samples returned from the Lunar far-side South Pole-Aitken Basin (SPAB) has been deemed a high priority this decade by the National Research Council. The Orion/MoonRise mission concept involves a lander in the SPAB that would retrieve samples, and then ascend to rendezvous with the Orion capsule in a halo orbit about the Earth-Moon L2 point. This paper analyzes different ascent trajectories, varying the halo orbit insertion point and flight time, and studying the fuel costs, azimuth, and flight path angle. The results are expected to aid in the development of the mission planning for the Orion.

14:50 **AAS 13-887** **Preliminary Design of the Phasing Strategy of a Lunar Orbit Rendezvous Mission**
Zhong-Sheng Wang, China Academy of Space Technology; Zhanfeng Meng; Shan Gao; Decheng Liu; Adly Espinoza

The preliminary design of the phasing strategy of a lunar orbit rendezvous mission is discussed in this paper. A 4-impulse maneuver scheme is selected as the baseline design to help achieve the basic goal of the phasing stage for the chaser, and an optimal nominal phasing strategy is developed based on the tracking access and other considerations. Also discussed are the computation of the lunar surface ascent window and the analysis of the influence of the tracking and orbit control errors on the aim point dispersion using Monte Carlo numerical simulations.

15:10 **<No talk scheduled>**

Session 22: Attitude Determination and Dynamics II

Chair: Jay McMahon, University of Colorado - Boulder

13:30 **AAS 13-888** **Covariance-Matrix Adaptive Method for Approximate Time-Optimal Reorientation Maneuvers**

Robert Melton, The Pennsylvania State University

The Covariance Matrix Adaptive-Evolutionary Strategy (CMA-ES) method is shown to provide a much higher quality estimate of the control solution for a satellite reorientation problem that includes multiple path constraints. The CMA-ES algorithm offers two significant advantages over heuristic methods such as Particle Swarm or Bacteria Foraging Optimization: it builds an approximation to the covariance matrix for the probability distribution of optima in the search space, and uses that to determine a direction of maximum likelihood for the search, reducing the chance of stagnation; and it achieves second-order, quasi-Newton convergence behavior.

13:50 **AAS 13-889** **Shadow Set Considerations for Modified Rodrigues Parameter Attitude Filtering**

Stephen O'Keefe, University of Colorado; Hanspeter Schaub, University of Colorado

Rigid body attitude estimation algorithms have been previously formulated using Modified Rodrigues Parameter attitude sets. MRP attitude estimation algorithms are attractive because they have been shown to have equal accuracy to and faster initial convergence than similar quaternion based filters and they avoid the quaternion constraint problem. Unfortunately, the non-uniqueness of MRPs can lead to significant attitude estimation errors through improper calculation of the measurement residual. The present work examines the details required for proper implementation of a MRP attitude estimation algorithm, specifically the technical details of when and how to switch to and from the MRP shadow set.

14:10 **AAS 13-890** **Iterative Model and Trajectory Refinement for Attitude and Shape Control of a Dumbbell Spacecraft**

Jennifer Hudson, Western Michigan University; Ilya Kolmanovsky, University of Michigan

An Iterative Model and Trajectory Refinement (IMTR) strategy is applied to control the orientation of an elastic dumbbell spacecraft. IMTR uses two models of a system -- a high-fidelity model and a low-fidelity model -- to converge on an optimized trajectory. This approach is applied to attitude and shape control of a spacecraft consisting of two masses connected by an elastic link, with normal and longitudinal control inputs. Targeting problems are solved near local equilibria.

14:30 AAS 13-891 Sun Heading Estimation Using Underdetermined Set of Coarse Sun Sensors

Stephen O'Keefe, University of Colorado; Hanspeter Schaub, University of Colorado

A comparison of two different methods to estimate the sun direction vector using an underdetermined set of coarse sun sensors is presented. Both a geometric solution and an extended Kalman filter approach are combined with a simple control law and shown to be capable of reorienting a spacecraft from any initial unknown attitude to a power positive state in time scales much less than one orbit. The EKF approach takes longer to converge but provides pointing accuracy less than one degree.

14:50 AAS 13-892 Motion Estimation from Blurred Images

Manoranjan Majji, University at Buffalo, State University of New York; Jonathan Rogers, Texas A&M University

In several problems of aerospace engineering, it is of interest to estimate the angular velocity and attitude of a rigid body using cheap camera systems. Using traditional feature extraction and tracking methods for attitude estimation in this class of problems is fraught with difficulties because of the large errors in feature extraction and matching. To address this problem, we use the traditional perspective projection model to produce a mathematical model of the feature blurring process. The models thus developed are used for attitude estimation purpose using a nonlinear least squares approach. Experimental results will be used to demonstrate the algorithms.

15:10 AAS 13-893 Attitude Determination by Minimizing Polynomial Functions Based on Semidefinite Relaxation

Yang Cheng, Mississippi State University

Many optimal attitude determination problems can be formulated as minimization problems with polynomial objective functions and constraints, which in general have multiple local minima. For these problems, gradient-based local search methods can converge to local minima but cannot guarantee that the global minimum is found. The Wahba problem, the general Wahba problem, and the GPS attitude determination problem are solved as both sum-of-squares problems and generalized problems of moments based on semidefinite relaxation. The semidefinite relaxation based attitude solutions are shown to be identical to the globally optimal attitude solutions.

Session 23: Solar Sails, Tethers, and Large Space Structures II

Chair: Theodore Sweetser, Jet Propulsion Laboratory

13:30 **AAS 13-894** **Vibration suppression of Large Space Truss Structure**

Lu Zhou, China Academy of Space Technology (CAST); Haichao Gui, Beihang University; Xinbing Hou, China Academy of Space Technology (CAST)

Multi-function and high-power are the trends of modern spacecraft, of which structures have the characteristics of large size, weak stiffness and low damping, such as the large space truss structure. When these structures working on the orbit are disturbed, vibration with low frequency and high amplitude is easily stirred. for the purpose of simplifying the damping configuration of large space truss structure, this article adopts the energy finite element analysis method to study the ability of dampers which absorb and dissipate vibration energy in different locations, and optimizes the configuration with the dissipation energy factor.

13:50 **AAS 13-896** **Applications of the Electrodynamic Tether Sling**

Michael Mueterthies, Purdue University; James Longuski, Purdue University; Jason Vaughn, NASA/Marshall Space Flight Center

The electrodynamic tether sling is a novel method for propellantless spacecraft propulsion which combines a tether sling with an electrodynamic tether. The electrodynamic force allows the tether to be spun up and a payload thrown with all momentum (ultimately) coming from the rotation of the Earth. The performance of the electrodynamic tether sling is considered for various tether parameters and various tether orbits. The mass of the tether and the time to reset between launches will be considered. The performance of the electrodynamic tether sling will be compared to conventional propellants.

14:10 **AAS 13-897** **Active Disturbance Rejection Control for the Attitude Stabilization of a Space Tethered Platform**

Wenlong Li; Zhao Yushan, Beijing University of Aeronautics and Astronautics; Shi Peng, Beijing University of Aeronautics and Astronautics

An active disturbance rejection control method based on linear extended state observer (LESO) is proposed for the attitude stabilization of a tethered platform which endures time-varying disturbance torque arising from the offset. The total disturbance is treated as an extended state which can be estimated by the LESO. The control law is obtained by subtracting the extended state from an optimal control law designed on the assumption with no uncertainties. Simulation results show that the method not only estimates and compensates the disturbances, but also applies to different kinds of disturbances. The controller meets the requirements of high stability.

14:30 AAS 13-898 Piecewise Optimal Control of Fast Deorbit Nano-Satellite Using Short Electrodynamic Tethers

Rui Zhong; ZhengHong Zhu

This paper studies the dynamics and optimal control of nano-satellite deorbit by a short electrodynamic tether. The long term deorbit process is discretized into intervals and within each interval a two-phased optimal control law is proposed to achieve stability and short deorbit time simultaneously. The first-phase formulates an open-loop fast-deorbit control trajectory using model simplifications. The second phase uses finite receding horizon control method to track the optimal trajectory derived in the first phase. Simulation results prove that the libration stability is achieved during the long term process and the deorbit time reduces significantly.

14:50 AAS 13-899 Lyapunov Orbits in the Jupiter System Using Electrodynamic Tethers

Kevin Bokelmann, University of Texas at Austin; Ryan Russell, The University of Texas at Austin; Gregory Lantoine, NASA / Caltech JPL

The use of electrodynamic tethers has been proposed for power generation and capture from interplanetary transfers. The effect of tether forces on periodic orbits in Jupiter-satellite systems are investigated. A perturbation force is added to the restricted three-body problem model. A series of simplifications allows development of a conservative system that retains the Jacobi integral. Expressions are developed to find modified locations of equilibrium positions. Modified families of Lyapunov and Halo orbits are generated as functions of tether size and Jacobi integral. Zero velocity curves and stability analyses are used to evaluate the dynamical properties of various systems.

15:10 <No talk scheduled>

Session 24: Special Session: High-performance and On-board Computing Architectures

Chair: Benjamin Villac, University of California - Irvine

13:30 AAS 13-900 Cloud Computing Techniques for High Performance Computing
Juan Arrieta, NASA / Caltech JPL; Juan Senent, Jet Propulsion Laboratory

I explain how can the three elements of cloud computing (abstraction, elasticity, and virtualization) can be utilized to build high-performance computing solutions. In addition, I cover potential gains in team productivity which are often not discussed in the HPC: standardization and deployment of datasets; development of virtualized analytical bundles for collaboration; and the abstraction of basic space-flight algorithms as on-line services with well defined interfaces. Finally, I cover a case study currently under development: the design and optimization of spacecraft trajectories powered by gravity assists.

13:50 AAS 13-901 Multiple High-Fidelity Space Trajectories using GPU Computing and Fast Perturbation Models
Nitin Arora, Georgia Institute of Technology; Ryan Russell, The University of Texas at Austin; Vivek Vittaldev, The University of Texas at Austin

To achieve both speed and accuracy in multi-object trajectory simulations, a solution methodology is presented that takes advantage of 1) new high-fidelity geopotential and third-body perturbation models that efficiently trade memory for speed and 2) a Graphics Processing Unit(GPU) based integrator to achieve parallelism across multiple objects. The two methods combined lead to multiplicative speedups, making the tool almost five orders in magnitude faster, in some cases, compared to the same simulation performed in serial on a single CPU. The methodology is highly relevant to the conjunction problem, covariance realism, particle filters, and Monte-Carlo analyses.

14:10 AAS 13-902 GPU Accelerated Conjunction Assessment with Applications to Formation Flight and Space Debris Tracking
Abel Brown, a.i.solution, Inc; Jason Tichy, a.i. solutions, Inc.; Michael Demoret, a.i. Solutions, Inc.; David Rand, a.i. solutions, Inc.

The primary purpose of conjunction assessment (CA) is to prevent the collision of objects in space. Typical collisions scenarios involve satellites with space debris or a formation of satellites with each other. Due to computational limitations mission design and maneuver planning are often sandwiched between minimal fidelity force models and insufficient sample sets. Here we investigate massively parallel orbit propagation utilizing general purpose graphical processing units (GPGPU) which provide orders of magnitude performance increase over similar CPU based implementations. Applications to space debris tracking and formation flight are demonstrated in large-scale simulations having hundreds of thousands of objects.

14:30 AAS 13-903 Enhanced Visualization and Autonomous Extraction of Poincare Map Topology

Wayne Schlei, Purdue University; Kathleen Howell; Xavier Tricoche, Purdue University; Christoph Garth, University of Kaiserslautern

Poincare maps supply vital descriptions of dynamical behavior in spacecraft trajectory analysis, but the puncture plot, the standard display method for maps, requires significant external effort to extract topology. This investigation presents adaptations of topology-based methods to compute map structures in multi-body dynamical environments. In particular, a scalar field visualization technique enhances the contrast between quasi-periodic and chaotic regimes. Also, an autonomous method is outlined to extract map topology in the planar circular restricted three-body problem. The resulting topological skeleton supplies a network of design options through the interconnectivity of orbital structures.

14:50 AAS 13-904 Automated Stable Region Detection

Navid Nakhjiri, University of California, Irvine; Benjamin Villac, University of California, Irvine

This paper presents efficient algorithms to extract the stable region from stability maps and generate a representation of the stable region for a dynamical system. Different algorithms and hardware architecture are considered for both map generation and the process of extracting the region. Sample computations are presented around small bodies and planetary moons.

15:10 AAS 13-905 A Comparison of Implicit Integration Methods for Astrodynamics

Jonathan Herman, University of Colorado at Boulder; Brandon Jones, University of Colorado, Boulder; George Born, University of Colorado at Boulder; Jeffrey Parker, University of Colorado

This paper presents a thorough and equitable comparison of modern implicit Runge-Kutta numerical integration techniques. These methods have promising applications in areas such as Space Situational Awareness, low-thrust trajectory optimization, and planetary protection. Each of these methods has already proved to match or outperform traditional integration methods in a serial implementation, with even greater improvements enabled through their parallelization. However, these methods have never been tested against each other. This paper establishes such a comparison, allowing readers to make an informed decision as to what technique to adopt for their future applications of high performance numerical integration.

Session 25: SSA IV: Collisions and Conjunctions

Chair: W. Todd Cerven, The Aerospace Corporation

8:00 **AAS 13-906** **Space Traffic Management**
Duane Bird, None

The future is here. The real question is, "Are we ready for it?" In the past 20 months, three Russian Breeze-M upper stages have failed to deliver their payloads to their proper orbits, leaving over 100 pieces of debris in orbit. In 2007 & 2009, between FY-1C & Iridium-Cosmos, over 5500 pieces of debris have been created. This paper will discuss the current circumstances around the possible, eventual development of a non-military, space traffic management entity to complement the growing commercial space transportation industry by providing space traffic control services to enhance safety of spaceflight.

8:20 **AAS 13-907** **Blits : A Forensic Analysis of a Probable Collision**
Roger Thompson, The Aerospace Corporation; Glenn Peterson, The Aerospace Corporation; John McVey; Robert Markin; Marlon Sorge, The Aerospace Corporation

On January 22, 2013, the Ball Lens In The Space (BLITS) satellite experienced an unanticipated change in orbit elements. BLITS is a small spherically shaped satellite used in passive laser ranging and so has no on-board propulsion, attitude control, batteries, etc. from which a internal explosion event could originate. Therefore, it's orbit elements could only be changed by an external source. This paper attempts to reconstruct the BLITS event, and identify possible causes. It was found that a collision with a small-untracked particle is consistent with the observed orbit changes and breakup of the BLITS spacecraft.

8:40 **AAS 13-908** **Non-Gaussian Collision Probability**
Ken Chan, Chan Aerospace Consultants

In many applications, the probability density functions (pdfs) of the Cartesian positions of both conjuncting objects are assumed to be Gaussian. Using this model, the collision probability may be easily formulated because the relative separation of two Gaussian pdfs is also given by a Gaussian pdf. However, when the pdfs of the two objects are non- Gaussian, their relative separation is not Gaussian and the simpler approach breaks down. Hence, more general formulation is required. This paper discusses the formulation of the problem in accordance with probability theory of non-Gaussian pdfs and the efficient computation of the collision probability.

9:00 AAS 13-910 Collision Risk Assessment and Avoidance Maneuvers – First Experience with ESA's New Tool CORAM

Klaus Merz, ESA; Noelia Sánchez-Ortiz, Deimos Space S.L. ; Ignacio Grande Olalla, Deimos Space S.L. ; Juan Antonio Pulido, Deimos Space S.L.

ESA's new CORAM tool, developed by DEIMOS Space, addresses two main aspects for the implementation of an appropriate collision avoidance mechanism for identified conjunction events. The first issue regards the computation of the actual collision risk associated to an event. The second is the implementation of appropriate avoidance manoeuvres considering operational constraints. The paper gives an overview of the algorithms reviewed and implemented, covering e.g. low velocity encounters, complex object shapes and various types of input data for orbital information and manoeuvre constraints. Next, first experience gained with the new toolset in the operational ESA environment is reported.

9:20 <No talk scheduled>

9:40 Session Break

10:05 AAS 13-911 A Non-combinatorial Approach for Efficient Conjunction Analysis

Michael Mercurio, University at Buffalo; Puneet Singla, University at Buffalo; Abani Patra, University at Buffalo

Conjunction analysis is the study of possible collisions between objects in space, and is aimed at reducing the number of collisions between manmade objects and debris orbiting the Earth. It has been found that kd-tree based methods significantly reduce computational cost while obtaining comparable results. This research extends the applicability of the tree-based approach by accounting for non-Gaussian uncertainties, as well as correcting the probabilistic nearest-neighbor search. Employing these modifications, it is expected that the favorable computational efficiency of the tree-based approach is maintained, while extending the applicability of the proposed method.

10:25 AAS 13-912 Recommended Risk Assessment Techniques and Thresholds for Launch COLA Operations

Matthew Hejduk, a.i. solutions; Dragan Plakalovic, a.i. solutions, Inc.; Lauri Newman, NASA Goddard Space Flight Center; Jarmaine Ollivierre, NASA/KSC; Mark E. Hametz, a.i. solutions; Brian Beaver, NASA/KSC; Roger Thompson, The Aerospace Corporation

NASA has conducted a year-long study on launch collision avoidance (LCOLA) practices. The first part of the study was presented at the Kauai conference; the second part, whose purpose is develop launch window closure criteria and is presented here, examines differences between TLE- and SP-vector-based Pc calculations; trade spaces among Pc screening threshold, launch window duration, and average percent of launch window closed; differences observed in using maximum versus cumulative Pc calculations; percentile-based associations between Pc and miss distances, and the difficulties these present; and an assessment of the overall improvement in risk

10:45 AAS 13-913 Analytical Non-Linear Conjunction Assessment via State Transition Tensors in Orbital Element Space

Kohei Fujimoto, University of Colorado at Boulder; Daniel Scheeres, University of Colorado

One common assumption in existing probabilistic conjunction assessment methods is the linear propagation of Gaussian uncertainty up to the time of closest approach. In this paper, this simplification is relaxed by propagating the uncertainty non-linearly via a special solution analytic to the Fokker-Planck equation for deterministic systems and expressing the resulting probability density function with a Gaussian mixture model representation. The probability of collision computed using the proposed CA technique for two objects in low Earth orbit converges upon Monte Carlo results, demonstrating both the potential accuracy and efficiency of an analytical approach.

11:05 <No talk scheduled>

11:25 <No talk scheduled>

Session 26: Formation Flying and Relative Motion II

Chair: Hanspeter Schaub, University of Colorado - Boulder

8:00 **AAS 13-914** **Satellite Cluster Flight Design Consideration**

Jason Schmidt, Emergent Space Technologies; Michael Phillips, Emergent Space Technologies

The challenges of cluster flight are presented under several key considerations including passive safety, stability, packing density, minimization of the inter-module cone angles, scal- ability, and observability with relative range measurements. A short primer on relative orbit elements (ROEs) and relative satellite motion precedes a discussion of the weakness of the string-of-pearl configuration and the concept of safety ellipses. ROE and safety ellipse con- cepts can be used to intuitively construct several different cluster geometries that optimize different constraints such as packing density, stability, or inter-module cone angles.

8:20 **AAS 13-915** **Development of Integrated Orbit and Attitude Hardware-In-The-Loop Simulator System for Satellite Formation Flying**

Han-Earl Park, Yonsei University; Sang-Young Park, Yonsei University; Sung-Woo Kim, Yonsei University ; Chandeok Park, Yonsei University

Development and experiment of an integrated orbit and attitude HILS system for satellite formation flying are presented. The integrated system consists of an orbit HILS and an attitude HILS, and involves four processes (orbit determination, orbit control, attitude determination, and attitude control). Integrated simulations are performed for a formation reconfiguration scenario. By performing the four processes adequately, the desired formation reconfiguration from a baseline of 500m to 1000m was achieved with meter-level position error and millimeter-level relative position navigation. Consequently, the integrated HILS system can be used in a real-time environment to validate satellite formation flying algorithms.

8:40 **AAS 13-917** **New Research Methodology for Earth Periodic Coverage and Regularities in Parametric Localization of Optimal Low-Earth-Orbit Satellite Constellations**

Yury Razoumny

Due to the fact that Earth periodic coverage optimization is extremely complex, for many years the solutions of this problem have been searched for among a priori fixed constellation types successfully implemented before for continuous coverage, with continuous coverage seeming to be much easier than the periodic one. The new research methodology for Earth periodic coverage aiming on creating methods for optimization arbitrary constellations, alternatively to traditional approach considering narrow classes of constellations to be analyzed, is described. The unknown before regularities in Earth periodic coverage and localization of optimal low-Earth-orbit satellite constellations parameters are presented and illustrated.

9:00 **AAS 13-918** **Coordinated Control of Autonomous Vehicles in Three-Dimensional Rotating Formations**
Divya Thakur, The University of Texas at Austin; Maruthi Akella, The University of Texas at Austin

Coordinated control of multiple autonomous spacecraft and unmanned air vehicles have many potential applications, many of which are feasible only through decentralized formations. Among these, rotating formations are of significant interest in aerospace engineering. While various results are available for circular planar formations, few results exist for three-dimensional (3D) formations. The focus of this paper is collective 3D motions where agents converge on a common plane in desired circular orbits. A Lyapunov-based approach is employed to develop a decentralized, globally stabilizing control protocol under limited inter-agent communication.

9:20 **AAS 13-923** **Distributed Constrained Discrete-Time State-Dependent Riccati Equation Control and its Applications to Spacecraft Formation Flying**
Insu Chang, University of Illinois at Urbana-Champaign; Joseph Bentsman, University of Illinois at Urbana-Champaign; Sang-Young Park, Yonsei University; Chandeok Park, Yonsei University

The objective of this paper is to investigate the constrained discrete-time state-dependent Riccati equation (CD-SDRE) technique for decentralized multi-agent systems and apply it to reconfiguration problems of spacecraft formation flying (SFF) under limited actuator performances. A brief review of the CD-SDRE control is provided and its extension to a decentralized multi-agent system subject to input constraints is studied in detail. The decentralized scheme of the CD-SDRE shows how it works systematically in a formation under input saturation. Simulation results demonstrate the effectiveness of the proposed CD-SDRE in the decentralized control of SFF.

9:40 **Session Break**

10:05 **AAS 13-919** **Sliding Mode Control for Decentralized Spacecraft Formation Flying Using Geometric Mechanics**
Daero Lee, New Mexico State University; Eric Butcher, New Mexico State University; Amit Sanyal, New Mexico State University

This paper proposes a sliding mode control scheme for decentralized spacecraft formation flying using geometric mechanics. The configuration space for a spacecraft is the Lie group of positions and orientations of the rigid spacecraft in three-dimensional Euclidean space. Each spacecraft in the formation has a desired trajectory that maintains a constant relative configuration with respect to the virtual leader. The relative configuration between a spacecraft and the virtual leader is described in terms of the exponential coordinates on the Lie group of rigid body motions. Numerical simulation demonstrates the effectiveness of this control scheme for a selected rigid spacecraft

10:25 AAS 13-920 Optimal Collision Avoidance Maneuver for Fractionated Spacecraft within Networked System

Ran Dai, Iowa State University

This paper examines the space debris collision avoidance problem for a collection of fractionated spacecraft modules initially connected within a networked system. The objective is to find trajectory corrections that will prevent the collision from potentially hazardous object using minimum control efforts while maintaining the communication topology of the original network. The collision avoidance problem with topology constraint is firstly formulated as a general quadratically constrained quadratic programming problem. A semidefinite relaxation method followed by a convex iterative approach is developed to search for the optimal solution with fast convergence. Simulation results for the concerned problem are provided and discussed.

10:45 AAS 13-921 O3b Constellation Orbit Raising and Maintenance

Sebastien Herbiniere, Thales Alenia Space

O3b satellite constellation is a new MEO telecommunication mission. The paper describes the flight dynamics strategy design for the orbit raising and orbit keeping phases. The operational orbit is quasi circular and equatorial at 8069 km altitude. Starting from the separation orbit 240 km below, a five maneuvers strategy performs the orbit raising and phasing, while keeping a low eccentricity and correcting the launcher inclination dispersions if required. On the operational orbit, there is an inclination equilibrium point, thus the out-of-plane control is passive. The in-plane control requires only small and unfrequent tangential maneuvers.

11:05 <No talk scheduled>

11:25 <No talk scheduled>

Session 27: Low-thrust Trajectory Design

Chair: Jon Sims, Jet Propulsion Laboratory

8:00 **AAS 13-924** **Robust Global Optimization of Low-Thrust, Multiple-Flyby Trajectories**
Donald Ellison, University of Illinois at Urbana-Champaign Aerospace Engineering Department; Jacob Englander, NASA Goddard Space Flight Center; Bruce Conway, University of Illinois at Urbana-Champaign

There are many challenging aspects of the design of multiple flyby, low-thrust trajectories that can negatively impact the robustness of a numerical optimizer. This paper introduces modifications that can be made to a multiple flyby trajectory optimizer employing the Sims-Flanagan transcription to improve its performance on challenging problems. These improvements include full specification of the problem Jacobian sparsity pattern and analytical expressions for many of its entries as well as refinements to how the problem constraints are scaled. The improvements are then quantified by solving two challenging problems: a notional solar electric mission to Mercury and a Jovian

8:20 **AAS 13-925** **Optimization of Preliminary Low-Thrust Trajectories from GEO-Energy Orbits to Earth-Moon, L1, Lagrange Point Orbits Using Particle Swarm Optimization**
Andrew Abraham, Lehigh University; David Spencer, The Pennsylvania State University; Terry Hart, Lehigh University

A technique for the preliminary global optimization of a low-thrust transfer trajectory from Earth orbit to a nominal, collinear Lagrange point orbit in the Earth-moon system is presented. The initial Earth orbit has a Jacobi energy equal to that of a geosynchronous Earth orbit (GEO-energy). Particle swarm optimization (PSO) is utilized to quickly locate the globally optimal "patch-point" where the low-thrust trajectory is terminated and the spacecraft begins to ballistically coast along the stable manifold. The results of the PSO algorithm are compared with that of a stochastic Monte Carlo algorithm.

8:40 **AAS 13-926** **Low-Thrust Trajectory Optimization Using a Legendre-Gauss-Radau Orthogonal Collocation Method**
Kathryn Schubert, University of Florida; Anil Rao, University of Florida

The goal of this research is to perform a numerical optimization study of a low-thrust transfer using the relatively new class of variable-order Gaussian orthogonal collocation methods for solving optimal control problems.

9:00 **AAS 13-927** **Techniques for Designing Many-Revolution, Electric-Propulsion Trajectories**
Anastassios Petropoulos, NASA / Caltech JPL; Gregory Lantoine, NASA / Caltech JPL; Zahi Tarzi, Jet Propulsion Laboratory

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.

9:20 AAS 13-932 Continuous Low-Thrust Control of Martian Constellations of Artificial Frozen Orbiters and Artificial Sun-Synchronous Orbiters
Zhigang Wu, Tsinghua University

The analysis for the continuous low-thrust control of Martian constellations of artificial Frozen Orbiters (Orb-As) and artificial Sun-Synchronous Orbiters (Orb-Bs) is described that the constellations provide efficient coverage and consistent communication in this article.The first part focuses on the continuous low-thrusts control strategies of artificial frozen and Sun-Synchronous orbit based on J2, J3, and J4 perturbation of Mars.The second part focuses on the optimal structure of the Martian constellations of Orb-As and Orb-Bs.The control strategies are found to maintain the special plane of the constellation the last part.

9:40 Session Break

10:05 AAS 13-928 Preliminary Sample Return Mission Design for Asteroid (216) Kleopatra
Frank Laipert, Purdue University; James Longuski, Purdue University; David Minton, Purdue University

A study is performed to design a robotic sample return mission to the asteroid (216) Kleopatra. A range of trajectory options, including electric and chemical propulsion, are assessed for a desirable combination of propellant usage and time of flight. A launch vehicle is selected from models available today or in the near future. The sample return hardware is assumed to be similar in size to that of OSIRIS-REx, and is required to collect samples at different locations on Kleopatra and from the two natural satellites orbiting the asteroid.

10:25 AAS 13-929 Utilizing Thrust Fourier Coefficients for Sequential Targeting in a Jupiter Orbit Trajectory
Zachery Prax, Western Michigan University; Jennifer Hudson, Western Michigan University

The trajectory dynamics of a low-thrust spacecraft can be evaluated using averaged secular equations in a finite set of thrust Fourier coefficients. These equations are applied to targeting a sequence of orbital states. The target states are selected to represent flybys of a secondary body in orbit about a primary. The secular equations determine a low-thrust control to ensure flybys on sequential revolutions at different points along the secondary's orbital path.

10:45 AAS 13-931 Solution of Optimal Continuous Low-Thrust Transfer Using Lie Transforms
Manuel Sanjurjo-Rivo, Universidad Carlos III; Daniel Scheeres, University of Colorado; Martin Lara; Jesus Pelaez, Technical University of Madrid (UPM)

This paper addresses the problem of optimal continuous low-thrust transfer in the two-body problem. Using the Pontriagyn's principle, the problem is formulated as a two point boundary value problem for a Hamiltonian system. Lie transforms obtained through the Deprit method allow us to obtain the canonical mapping of the phase flow as a series in terms of the thrust applied. The reachable set of states starting from a given initial condition using optimal control policy is obtained analytically and explicitly. Additionally, a particular optimal transfer can be computed as the solution of a non-linear algebraic equation.

11:05 <No talk scheduled>

11:25 <No talk scheduled>

Session 28: Primitive Body Mission Design and Concepts

Chair: Roberto Furfaro, University of Arizona

8:00 **AAS 13-934** **An Archetypal Mission for Exploration and Mitigation of Potentially Hazardous Near Earth Asteroids**

David Hyland, Texas A&M University; Haithem Altwaijry, King Abdulaziz City for Science and Technology; Hyerim Kim, Texas A&M University; Shen Ge, Experimental Center for Applied Physical Systems, LLC; Neha Satak, Experimental Center for Applied Physical Systems, LLC

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 Earth-crossing objects.

8:20 **AAS 13-935** **Preparatory Study on Accessing Asteroids on Horseshoe Orbits and Applications**

Guillaume Rivier, Univ. of Tokyo; Jun'ichiro Kawaguchi, Japan Aerospace Exploration Agency

There are a handful number of particular asteroids on "Horseshoe Orbits". Extremely a type of them run through even L1 or L2 points, and the spacecraft originated there may fly along the horseshoe orbits with infinitesimally small departure/return delta-V. So, if flight period becomes long but admissible, should be good targets for exploration and also for capture missions. From the synodic period point of view, they are hardly accessible and not practical, but the paper presents typical missions illustrations with the use of electric propulsion for both already known objects and potential targets on the horseshoe orbits.

8:40 **AAS 13-936** **Trajectory Design for the Exploration of Phobos and Deimos**

Brent Barbee, NASA Goddard Space Flight Center; Damon Landau, NASA / Caltech JPL

The two moons of Mars, Phobos and Deimos, are among the potential destinations currently under consideration by NASA for future human exploration missions. This paper presents results from recent studies in the areas of orbit analysis and trajectory design for human space flight missions to explore Phobos and Deimos. The evolution of the moons' orbits under natural perturbations are analyzed, which informs the design of trajectories to arrive at Mars in a highly elliptical orbit, rendezvous with each moon in turn, and then depart Mars. The abilities of each moon to support captured orbits during proximity operations are also considered.

9:00 **AAS 13-937** **Optimized Free-Return Trajectories To Near-Earth Asteroids Via Lunar Flyby**

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

An algorithm is presented to generate an initial guess and converge a trajectory to reach a near-Earth asteroid in a fuel-optimal sense with emphasis on manned-mission risk reduction. The trajectory is designed such that the departing vehicle will return to Earth with no extra maneuvers, and incorporates a Lunar flyby on the outbound segment to reduce fuel cost. The nominal mission departs the free-return trajectory to rendezvous with the asteroid for some period of time before returning to Earth. The optimization scheme incorporates a full ephemeris model and analytical gradients for accurate convergence.

9:20 **AAS 13-938** **Trajectory Optimization for a Mission to the Trojan Asteroids**

Shivaji Gadsing, western michigan university; Jennifer Hudson, Western Michigan University

A dynamic programming algorithm is developed for the problem of finding a minimum-fuel trajectory for a mission to the Jovian Trojan asteroids. The problem is formulated as a modified traveling salesman problem. The General Mission Analysis Tool (GMAT) is employed within the direct graph algorithm for finding the optimum trajectory with minimal fuel consumption. The selection of a minimum-fuel trajectory, and the associated target asteroids, will be a key factor in determining feasibility and scientific value of a Trojan tour and rendezvous mission.

9:40 **Session Break**

10:05 **AAS 13-939** **Following Sungrazing Comets: Exploration of a Mission Concept**

Adam Shutts, University of California, Irvine; Benjamin Villac, University of California, Irvine

This paper investigates a space mission concept that would follow a sungrazing comet along its orbit trajectory while consistently remaining within the shadow of the object. By locating the spacecraft within the shadow of the comet at its L2 equilibrium point, the spacecraft can be shielded from the immense radiation of the Sun. This will provide a new vantage point to observe comet/Sun interactions while investigating the effects of outgassing and exploring the physical consequences of close perihelion passage. Shadow sizing, calculation of the L2 point, station-keeping methods, and temperature analysis will be examined.

10:25 **AAS 13-940** **Solar Sail Trajectory Design for Exploration of Asteroids from/to Space Port around L2 Point**

Taku Hamasaki, Department of Aeronautics and Astronautics, Graduate School of Engineering, University of Tokyo

This paper focuses on the trajectory design for a round-trip exploration by solar sailing. Nowadays, sample return missions are gathering attention owing to the great achievement by Hayabusa. Meanwhile, solar sail technology, which obtains acceleration by making use of solar radiation pressure, is developing. For such a low thrust system, it is considered efficient to construct Deep Space Port around L2 point in the Sun-Earth system. In this context, this paper is on a round-trip originating from and ending at L2 point. This trajectory design method is useful for asteroid fly-by and sample return missions.

10:45 AAS 13-942 Detection and Characterization of Near Earth Asteroids Using Stellar Occultation

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

This paper describes a technique to detect and characterize Near Earth Asteroids (NEAs), using a formation of telescope-carrying cube-sats that observe the intensity patterns of stellar occultations. Advanced processing of the recorded intensity data is employed to deduce the size, shape, and albedo of detected NEAs. The technique greatly extends conventional occultation technology to produce sharp silhouettes of NEAs even when their shadows in starlight are heavily diffracted. The work concentrates on asteroids that are small enough that only a small fraction have been detected, yet are large enough to cause significant destruction in the event of an

11:05 AAS 13-943 NEA Mitigation via the Yarkovsky Effect

David Hyland, Texas A&M University; Haithem Altwaijry, King Abdulaziz City for Science and Technology; Hyerim Kim, Texas A&M University; Shen Ge, Experimental Center for Applied Physical Systems, LLC; Neha Satak, Experimental Center for Applied Physical Systems, LLC

To alter the orbit of a Near Earth Asteroid (NEA) over an extended period, we propose to alter the NEA albedo to either diminish or enhance the Yarkovsky effect. At present, the albedo change mechanism that appears the most effective involves a device that dispenses ionized powder onto the NEA surface – which is itself ionized by ultraviolet radiation. Electrostatic attraction provides the dominant force that attracts and bind the powder to the surface. The albedo change dispenser described here is based upon triboelectric powder dispensing technology. We describe the design details and the constraints on particle size and dispensing speed.

11:25 <No talk scheduled>

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				10:45
1	Ballroom A	AAS 13-708	Wilkins et al.	Towards an Artificial Space Object Taxonomy
2	Ballroom B	AAS 13-717	Wagner et al.	Cassini Solstice Mission Maneuver Experience: Year Three
3	Ballroom C	AAS 13-728	Arora, Russell	A Fast and Robust Multiple Revolution Lambert Algorithm ...
4	Ballroom D	AAS 13-738	Hesar et al.	Application of LiAISON Orbit Determination Architecture...
				11:05
1	Ballroom A	AAS 13-709	McCall et al.	On-orbit trajectory analysis of Local Area LEO objects
2	Ballroom B	AAS 13-720	Jones	Post-Maneuver Collision Probability Estimation Using ...
3	Ballroom C	AAS 13-729	Lee, Mortari	Improved Uniform Points On A Sphere With Application ...
4	Ballroom D	AAS 13-739	Roscoe et al.	Force Modeling and State Propagation for Navigation and ...
				11:25
2	Ballroom B	AAS 13-854	Kim et al.	A Homotopy Method for Optimal Actuator Failure Control
4	Ballroom D	AAS 13-740	Jagat et al.	Optimal One and Two-Impulse Maneuvers for Relative ...

Monday, August 12, 2013 (PM)

Session	Room	Doc. #	Author	Title
			13:30	
5	Ballroom A	AAS 13-741	Sperber, Eke	Multibody Modeling of the Attitude Dynamics of Large ...
6	Ballroom B	AAS 13-746	Walker et al.	The Effect of Different Adsorption Models on Satellite Drag ...
7	Ballroom C	AAS 13-751	Carter, Humi	Geometry of Transformed Variables in the Impulsive ...
8	Ballroom D	AAS 13-756	Mazmanyan	Attitude Motion Of A Spinning Spacecraft With Fuel Slosh...
			13:50	
5	Ballroom A	AAS 13-742	Fu, Eke	A Reorientation Scheme For Large Solar Sails
6	Ballroom B	AAS 13-747	Dell'Elce, Kerschen	Uncertainty quantification of the orbital lifetime of a LEO ...
7	Ballroom C	AAS 13-752	Carter, Humi	Optimal Open Two-Impulse Transfers in a Plane
8	Ballroom D	AAS 13-757	Lara	Fast, Simple and Efficient Asteroid Attitude Propagation by ...
			14:10	
5	Ballroom A	AAS 13-743	Guerrant et al.	Earth Escape Capabilities of the Heliogyro Solar Sail
6	Ballroom B	AAS 13-748	Spiridonova	Precise determination of mean orbital elements for LEO ...
7	Ballroom C	AAS 13-753	Anthony et al.	Impulsive Guidance for Optimal Manifold-Based Transfers ...
8	Ballroom D	AAS 13-758	Lee	Star tracker anomalies: root causes and mitigation strategies
			14:30	
5	Ballroom A	AAS 13-744	Elgohary, Turner	Dynamics And Controls Of A Generalized Frequency Domain ...
6	Ballroom B	AAS 13-749	Morand	Semi Analytical Implementation Of Tesseral Harmonics ...
7	Ballroom C	AAS 13-754	Changxuan et al.	Precise Determination of the Reachable Domain for a ...
8	Ballroom D	AAS 13-759	Chujo et al.	Solar Sail Attitude Dynamics Considering Sail Deformation
			14:50	
5	Ballroom A	AAS 13-745	Huang, Xu	Free Floating Space Robot Kinematic Modeling and Analysis
6	Ballroom B	AAS 13-750	Goh, Lau, Low	An Optimization Method for Nano-satellite and Pico- ...
7	Ballroom C	AAS 13-755	Jianwen et al.	Optimal Earth-Mars Trajectory Control Strategy Design ...
8	Ballroom D	AAS 13-760	Wang, Gui, Xu	Stability of the Relative Equilibria of a Rigid Body in a J2 ...

Tuesday, August 13, 2013 (AM)

Session	Room	Doc. #	Author	Title
				8:00
9	Ballroom A	AAS 13-761	Cerven	Improved Empirical Covariance Estimation
10	Ballroom B	AAS 13-771	Vicario et al.	A Linear-Time-Varying Approach for Exact Identification ...
11	Ballroom C	AAS 13-781	Villac et al.	Automating Initial Guess Generation for High Fidelity ...
12	Ballroom D	AAS 13-791	Ohtsuka, Uchiyama	Orbital Maneuver For Spacecraft Using Generalized ...
				8:20
9	Ballroom A	AAS 13-762	Tanygin	Efficient Covariance Interpolation Using Blending Of ...
10	Ballroom B	AAS 13-772	Pardal et al.	Orbit Determination Using Nonlinear Particle Filter And ...
11	Ballroom C	AAS 13-782	Haapala et al.	Trajectory Selection Strategy for Tours in the Earth-Moon ...
12	Ballroom D	AAS 13-793	Yan et al.	State Transition Matrix for Relative Motion with Higher ...
				8:40
9	Ballroom A	AAS 13-763	McMahon et al.	High-fidelity Solar Radiation Pressure Effects for High Area-...
10	Ballroom B	AAS 13-776	Parker et al.	LiAISON-Supplemented Navigation of a Crewed Vehicle in ...
11	Ballroom C	AAS 13-784	Elgohary, Turner	State Transition Tensor Models for the uncertainty ...
12	Ballroom D	AAS 13-794	Douglass et al.	Formation Control Problems for Decentralized Spacecraft ...
				9:00
9	Ballroom A	AAS 13-764	Park et al.	The Effect Of Dynamical Accuracy For Uncertainty Propagation
10	Ballroom B	AAS 13-778	de Dilectis et al.	Trajectory Determination with Unknown Perturbations
11	Ballroom C	AAS 13-831	Davis et al.	Coverage from Satellites in Earth-Moon Libration Point Orbits
12	Ballroom D	AAS 13-795	Kim, Park, Park	Semi-Analytical Global Search Algorithm For Fuel-Optimal...
				9:20
9	Ballroom A	AAS 13-765	Gehly et al.	Comparison Of Multitarget Filtering Methods As Applied ...
11	Ballroom C	AAS 13-785	Feldhacker et al.	Limits Of Linear Approximations For Near-Field Approach ...
12	Ballroom D	AAS 13-796	Sherrill et al.	Calibration of Hill-Clohessy-Wiltshire Initial Conditions for ...
				Session Break: 9:40 - 10:05
				10:05
9	Ballroom A	AAS 13-766	Vishwajeet et al.	Adaptive Split and Merge Algorithm for Gaussian Mixture ...
10	Ballroom B	AAS 13-774	McMahon et al.	Improving Orbit Determination with Low-order Fourier ...
11	Ballroom C	AAS 13-786	Llanos et al.	Heteroclinic, Homoclinic Connections Between The Sun-...
12	Ballroom D	AAS 13-797	Finley, Redfern	Techniques for LEO Constellation Deployment and Phasing ...
				10:25
9	Ballroom A	AAS 13-767	Roscoe et al.	Parallel Track Initiation for Optical Space Surveillance using ...
10	Ballroom B	AAS 13-779	Zhongkai	A Novel Set of Broadcast Ephemeris for Compass?
11	Ballroom C	AAS 13-787	Anderson et al.	Broad Search for Unstable Resonant Orbits in the Planar ...
12	Ballroom D	AAS 13-798	Nazari et al.	On Control of Spacecraft Relative Motion in the Case of an ...
				10:45
9	Ballroom A	AAS 13-768	Highsmith et al.	Refined Orbit Prediction for Catalog Objects
10	Ballroom B	AAS 13-780	Zhongkai	Space-based Autonomous Navigation Utilizing Asymmetry ...
11	Ballroom C	AAS 13-788	Deleflie et al.	Structure of the web of resonance within the MEO and GTO ...
12	Ballroom D	AAS 13-799	Bando, Ichikawa	Formation Flying Along an Elliptic Orbit by Pulse Control
				11:05
9	Ballroom A	AAS 13-769	Setty et al.	Investigating the Suitability of Analytical and Semi-...
11	Ballroom C	AAS 13-789	Bokelmann, Russell	Connecting Halo Orbits with Low Altitude Science Orbits ...
12	Ballroom D	AAS 13-800	Sherrill et al.	Continuous-Thrust Control of Satellite Relative Motion in ...
				11:25
9	Ballroom A	AAS 13-770	Cheng	Comparisons of PHD Filter and CPHD Filter for Space Object ...
11	Ballroom C	AAS 13-790	Bani Younes	Analytic High-Order Reversion of Series Solution Algorithm ...

Tuesday, August 13, 2013 (PM)

Session	Room	Doc. #	Author	Title
				13:30
13	Ballroom A	AAS 13-801	Strange et al.	Design of Initial Inclination Reduction Sequence for Uranian …
14	Ballroom B	AAS 13-812	Castelliniet al.	Optical Navigation For Rosetta Operations Near Comet …
15	Ballroom C	AAS 13-822	Binz, Healy	Uncertainty Characterization for Angles-Only Initial Orbit …
16	Ballroom D	AAS 13-832	Panomrutanarug et al.	Repetitive Control of Digital Systems Having Fast Phase …
				13:50
13	Ballroom A	AAS 13-802	Lyne et al.	Mission Opportunities to trans-Neptunian Objects – Part III, …
14	Ballroom B	AAS 13-813	Arnal Fort et al.	Exploration of a graph-based method to orbit transfers near …
15	Ballroom C	AAS 13-823	Karimi, Mortari	A Performance Based Comparison of Angle-only Initial…
16	Ballroom D	AAS 13-833	Prasitmeeboom et al.	Investigation of Discrete Time Emulation Techniques to …
				14:10
13	Ballroom A	AAS 13-803	Lynam	Broad-search Algorithms for the Spacecraft Trajectory…
14	Ballroom B	AAS 13-815	Lantoine et al.	Design of Quasi-terminator Orbits near Primitive Bodies
15	Ballroom C	AAS 13-824	Shoemaker et al.	Application Of Optical Tracking And Orbit Estimation …
16	Ballroom D	AAS 13-834	Gui, Jin, Xu	Single-Axis Pointing Of A Spacecraft With Two Skew Control …
				14:30
13	Ballroom A	AAS 13-804	Lynam	Broad-search Algorithms for the Spacecraft Trajectory…
14	Ballroom B	AAS 13-816	Wallace, Broschart	Circular-orbit Maintenance Strategy for Primitive Body …
15	Ballroom C	AAS 13-825	Woodburn et al.	Effect of Coordinate Selection on Orbit Determination
16	Ballroom D	AAS 13-835	Moyer, Majji	Feedback Control and Steering Laws for Spacecraft Using …
				14:50
13	Ballroom A	AAS 13-805	Hughes et al.	Preliminary Analysis Of Ballistic Trajectories To Neptune …
14	Ballroom B	AAS 13-817	Narita, Kawaguchi	On An Idea about the Method of Absorbing Spin Motion of …
15	Ballroom C	AAS 13-826	Adurthi, Singla	Principle of Maximum Entropy for Probability Density …
16	Ballroom D	AAS 13-836	Lee, Mesbahi	Quaternion Based Optimal Spacecraft Reorientation …
				Session Break: 15:10 - 15:35
				15:35
13	Ballroom A	AAS 13-807	Rogers, Longuski	Preliminary Analysis of Establishing Cycler Trajectories …
14	Ballroom B	AAS 13-818	Kidd et al.	Non-Linear Pulsed Guidance for Asteroid Close-Proximity …
15	Ballroom C	AAS 13-827	McLaughlin et al.	Effects of Orbit Ephemeris Error and Limited Data on …
16	Ballroom D	AAS 13-837	Samiei, Butcher	Suboptimal Delayed Feedback Attitude Stabilization of …
				15:55
13	Ballroom A	AAS 13-808	Folta et al.	Optimal Round-Trip Trajectories For Short Duration Mars …
14	Ballroom B	AAS 13-819	Gaudet, Furfaro	Real-Time State Estimation For Asteroid Close-Proximity…
15	Ballroom C	AAS 13-828	Healy, Binz	Bayesian inference on multimodal distributions from an …
16	Ballroom D	AAS 13-838	Thakur et al.	Adaptive Attitude-Tracking Control of Spacecraft with …
				16:15
13	Ballroom A	AAS 13-809	Burke et al.	A High Power Solar Electric Propulsion - Chemical Mission …
14	Ballroom B	AAS 13-820	Nazari et al.	Observer-Based Body-Frame Hovering Control over a …
15	Ballroom C	AAS 13-829	Hindman, Glaser	Spacecraft Navigation using Extrasolar Planetary Systems
16	Ballroom D	AAS 13-839	Hayashi et al.	Stability Analysis and Sun-Tracking Attitude Control of …
				16:35
13	Ballroom A	AAS 13-810	Gangestad et al.	A High Earth, Lunar Resonant Orbit for Lower Cost Space …
14	Ballroom B	AAS 13-821	Lee et al.	Spacecraft Hovering Control For Body-Fixed Hovering Over …
15	Ballroom C	AAS 13-830	Handzo et al.	Using Signals Of Opportunity In Deep Space Satellite …
16	Ballroom D	AAS 13-840	Patankar, Fitz-Coy	A Hybrid CMG-RW Attitude Control Strategy For Agile …
				16:55
13	Ballroom A	AAS 13-811	Rogers et al.	A Proposed Mission to Detect Solar Influences on Nuclear …
16	Ballroom D	AAS 13-841	Huang, Xu	On the High Precision Steering Law of VSCMGs

Wednesday, August 14, 2013 (AM)

Session	Room	Doc. #	Author	Title
				8:00
17	Ballroom A	AAS 13-842	Finkleman	Space Debris as an Epidemic, Complexity and Dynamical ...
18	Ballroom B	AAS 13-852	Martin, Longuski	Heuristic Suboptimal Solutions to Reduce Velocity Pointing ...
19	Ballroom C	AAS 13-862	Hitzl, Zele	The Two Body Problem Elevated to the Complex Domain
20	Ballroom D	AAS 13-872	Wang et al.	Trajectory Design Considerations for Precision Landing on Mars
				8:20
17	Ballroom A	AAS 13-843	Hoots, Hansen	COBRA: A Covariance-Based Debris Risk Assessment Model
18	Ballroom B	AAS 13-853	Mortari et al.	Image Processing of Illuminated Ellipsoid
19	Ballroom C	AAS 13-863	Miller, Hintz, Llanos	Trajectory Dynamics of Gas Molecules and Galaxy Formation
20	Ballroom D	AAS 13-873	Dwyer Cianciolo et al.	Atmosphere Assessment For Mars Science Laboratory Entry, ...
				8:40
17	Ballroom A	AAS 13-844	Hansen, Sorge	Summarizing the General Effects of Breakup Debris in GEO
18	Ballroom B	AAS 13-859	Majji et al.	A Least Squares Solution for Estimation of a Planar ...
19	Ballroom C	AAS 13-864	Oliveira et al.	Searching for orbits that can be controlled by natural forces
20	Ballroom D	AAS 13-874	Gaudet, Furfaro	A Navigation Scheme For Pinpoint Mars Landing Using ...
				9:00
17	Ballroom A	AAS 13-845	Peterson	Use of Slowly Varying Orbit Elements for Spread Velocity ...
18	Ballroom B	AAS 13-855	Kwon et al.	Thrusters Time-delayed Control Allocation for Soft-landing ...
19	Ballroom C	AAS 13-865	Rosengren et al.	Long-term Dynamics and Stability of GEO Orbits: The ...
20	Ballroom D	AAS 13-875	Furfaro et al	Neural-based Trajectory Shaping Approach for Terminal ...
				9:20
17	Ballroom A	AAS 13-846	McKennon-Kelly et al.	Space Debris Visualization, Characterization, and Volume ...
18	Ballroom B	AAS 13-856	Carson et al.	Operations Concept, Hardware Implementation and ...
20	Ballroom D	AAS 13-876	Chesi et al	Satellite Attitude Control by Center-of-Mass Shifting
				Session Break: 9:40 - 10:05
				10:05
17	Ballroom A	AAS 13-847	Cho et al.	Autonomous 6-DOF Relative Estimation for Proximity ...
18	Ballroom B	AAS 13-857	Condurache et al.	On six D.O.F relative orbital motion parametrization using ...
19	Ballroom C	AAS 13-867	Sweetser, Vincent	The Eccentric Behavior of Nearly Frozen Orbits
20	Ballroom D	AAS 13-877	Samaan, Theil	Development of the Hybrid Navigation System for the third ...
				10:25
17	Ballroom A	AAS 13-848	Cochran, Walsh	Effects of the Rotational Motions of Debris Objects on the ...
18	Ballroom B	AAS 13-858	Filipe, Tsiotras	Adaptive Position and Attitude Tracking Controller for ...
19	Ballroom C	AAS 13-868	Bani Younes	Application Of High-Order STTS Uncertainity Propagation ...
20	Ballroom D	AAS 13-878	Mehta et al.	Modeling Satellite Drag Coefficients with Response Surfaces
				10:45
17	Ballroom A	AAS 13-849	Chan	A Mathematical Formulation to Describe Density of Particles ...
18	Ballroom B	AAS 13-860	Simo et al.	Halo Orbit Targeting Guidance via Higher Order Sliding ...
19	Ballroom C	AAS 13-869	Mercurio et al.	Approximation of Probability Density Functions Propagated ...
20	Ballroom D	AAS 13-879	Saikia et al.	Solution Of Yaroshevskii's Planetary Entry Equation Via ...
				11:05
17	Ballroom A	AAS 13-850	Hinagawa	Orbit Determination of ETS-8 by Pegasus Observatory in ...
18	Ballroom B	AAS 13-861	Gonzalez et al.	Distributed Internet-enabled Simulation/Testbed Architecture
19	Ballroom C	AAS 13-870	Balducci et al.	Orbit Uncertainty Propagation With Separated ...
20	Ballroom D	AAS 13-880	Longuski, Saikia	Analytical Theory For Ballistic Entry At Circular Speed ...
				11:25
17	Ballroom A	AAS 13-851	McCall et al.	Space-based characterization of debris in Low-Earth orbit ...
19	Ballroom C	AAS 13-871	Heiligers, McInnes	Cylindrically and spherically constrained families of ...
20	Ballroom D	AAS 13-881	Longuski, Saikia	Analytical Theory For Ballistic Entry At Moderate To Large ...

Wednesday, August 14, 2013 (PM)

Session	Room	Doc. #	Author	Title
				13:30
21	Ballroom A	AAS 13-882	Parker et al.	Trajectory Design for MoonRise: a Proposed Lunar South ...
22	Ballroom B	AAS 13-888	Melton	Covariance-Matrix Adaptive Method for Approximate ...
23	Ballroom C	AAS 13-894	Zhou, Gui, Hou	Vibration suppression of Large Space Truss Structure
24	Ballroom D	AAS 13-900	Arrieta, Senent	Cloud Computing Techniques for High Performance Computing
				13:50
21	Ballroom A	AAS 13-884	McGreevy, Majji	Calculation of an Optimal Two Impulse Earth-Moon Trajectory
22	Ballroom B	AAS 13-889	O'Keefe, Schaub	Shadow Set Considerations For Modified Rodrigues ...
23	Ballroom C	AAS 13-896	Mueterthies et al.	Applications of the Electrodynamic Tether Sling
24	Ballroom D	AAS 13-901	Arora et al.	Multiple High-Fidelity Space Trajectories using GPU ...
				14:10
21	Ballroom A	AAS 13-885	Wan, Villac	Lunar L1 earth-moon propellant depot. Orbital and transfer ...
22	Ballroom B	AAS 13-890	Hudson et al.	Iterative Model and Trajectory Refinement for Attitude and ...
23	Ballroom C	AAS 13-897	Li, Yushan, Peng	Active Disturbance Rejection Control for the Attitude ...
24	Ballroom D	AAS 13-902	Brown et al.	GPU Accelerated Conjunction Assessment with Applications ...
				14:30
21	Ballroom A	AAS 13-886	Dietrich et al.	Far-side Lunar Ascent Trajectory Design to Earth-Moon L2 Orbit
22	Ballroom B	AAS 13-891	O'Keefe, Schaub	Sun Heading Estimation Using Underdetermined Set of ...
23	Ballroom C	AAS 13-898	Zhong, Zhu	Piecewise Optimal Control of Fast Deorbit Nano-Satellite ...
24	Ballroom D	AAS 13-903	Schlei et al.	Enhanced Visualization and Autonomous Extraction of ...
				14:50
21	Ballroom A	AAS 13-887	Wang	Preliminary Design of the Phasing Strategy of Lunar Orbit ...
22	Ballroom B	AAS 13-892	Majji, Rogers	Motion Estimation from Blurred Images
23	Ballroom C	AAS 13-899	Bokelmann et al.	Lyapunov Orbits In The Jupiter System Using Electrodynamic ...
24	Ballroom D	AAS 13-904	Nakhjiri, Villac	Automated Stable Region Detection
				15:10
22	Ballroom B	AAS 13-893	Cheng	Attitude Determination by Minimizing Polynomial ...
24	Ballroom D	AAS 13-905	Herman et al.	A comparison of implicit integration methods for ...

Thursday, August 15, 2013 (AM)

Session	Room	Doc. #	Author	Title
				8:00
25	Ballroom A	AAS 13-906	Bird	Space Traffic Management
26	Ballroom B	AAS 13-914	Schmidt, Phillips	Satellite Cluster Flight Design Consideration
27	Ballroom C	AAS 13-924	Ellison et al.	Robust Global Optimization Of Low-Thrust, Multiple-Flyby ...
28	Ballroom D	AAS 13-934	Hyland et al.	An Archetypal Mission for Exploration and Mitigation of ...
				8:20
25	Ballroom A	AAS 13-907	Thompson et al.	Blits : A Forensic Analysis Of A Probable Collision
26	Ballroom B	AAS 13-915	Park et al.	Development Of Integrated Orbit And Attitude Hardware- ...
27	Ballroom C	AAS 13-925	Abraham et al.	Optimization of Preliminary Low-Thrust Trajectories from ...
28	Ballroom D	AAS 13-935	Rivier, Kawaguchi	Preparatory Study on Accessing Asteroids on Horseshoe ...
				8:40
25	Ballroom A	AAS 13-908	Chan	Non-Gaussian Collision Probability
26	Ballroom B	AAS 13-917	Razoumny	New Research Methodology for Earth Periodic Coverage ...
27	Ballroom C	AAS 13-926	Schubert, Rao	Low-Thrust Trajectory Optimization Using a Legendre-Gauss-...
28	Ballroom D	AAS 13-936	Barbee, Landau	Trajectory Design for the Exploration of Phobos and Deimos
				9:00
25	Ballroom A	AAS 13-910	Merz et al.	Collision Risk Assessment and Avoidance Maneuvers – ...
26	Ballroom B	AAS 13-918	Thakur, Akella	Coordinated Control of Autonomous Vehicles in Three-...
27	Ballroom C	AAS 13-927	Petropoulos et al.	Techniques for Designing Many-Revolution, Electric-...
28	Ballroom D	AAS 13-937	Bradley, Hernandez	Optimized Free-Return Trajectories To Near-Earth Asteroids ...
				9:20
26	Ballroom B	AAS 13-923	Chang et al.	Distributed Constrained Discrete-Time State-Dependent ...
27	Ballroom C	AAS 13-932	Wu	Continuous Low-Thrust Control Of Martian Constellations ...
28	Ballroom D	AAS 13-938	Gadsing, Hudson	Trajectory Optimization For A Mission To The Trojan Asteroids
				Session Break: 9:40 - 10:05
				10:05
25	Ballroom A	AAS 13-911	Mercurio et al.	A Non-combinatorial Approach for Efficient Conjunction ...
26	Ballroom B	AAS 13-919	Lee et al.	Sliding Mode Control For Decentralized Spacecraft ...
27	Ballroom C	AAS 13-928	Laipert et al.	Preliminary Sample Return Mission Design for Asteroid (216) ...
28	Ballroom D	AAS 13-939	Shutts, Villac	Following Sungrazing Comets: Exploration of a Mission ...
				10:25
25	Ballroom A	AAS 13-912	Hejduk et al.	Recommended Risk Assessment Techniques and Thresholds ...
26	Ballroom B	AAS 13-920	Dai	Optimal Collision Avoidance Maneuver for Fractionated ...
27	Ballroom C	AAS 13-929	Prax, Hudson	Utilizing Thrust Fourier Coefficients for Sequential Targeting ...
28	Ballroom D	AAS 13-940	Hamasaki	Solar Sail Trajectory Design for Exploration of Asteroids ...
				10:45
25	Ballroom A	AAS 13-913	Fujimoto, Scheeres	Analytical Non-Linear Conjunction Assessment via State ...
26	Ballroom B	AAS 13-921	Herbiniere	O3b constellation orbit raising and maintenance
27	Ballroom C	AAS 13-931	Sanjurjo-Rivo et al.	Solution of Optimal Continuous Low-Thrust Transfer using ...
28	Ballroom D	AAS 13-942	Altwaijry, Hyland	Detection and Characterization of Near Earth Asteroids ...
				11:05
28	Ballroom D	AAS 13-943	Hyland et al.	NEA Mitigation via the Yarkovsky Effect

RECORD OF MEETING EXPENSES

Astrodynamics Specialist Conference
Hilton Head Marriott Resort & Spa, Hilton Head Island, South Carolina
11 – 15 August 2013

Name:_____________________________ Organization: _____________________________

Category	Early Registration (through 10 Jan 2012)	Regular Registration
Full - AAS or AIAA Member	$530	$580
Full - Non-member	$630	$680
Retired*	$165	$165
Student*	$165	$165

Registration Fee: ___________________

Conference Proceedings (Hard Cover)[1]

___ @ $290 (domestic) ___________________

___ @ $380 (international) ___________________

Extra CD Conference Proceedings[1] ___ @ $50 ___________________

Special Event Guest Ticket ___@ $75 ___________________

TOTAL: ___________________

Recorded by: ___________________________________

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

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