Conference Program

23rd AAS / AIAA

Space Flight Mechanics Meeting

February 10 – 14, 2013 | Kauai, Hawaii

AAS General Chair
Thomas Starchville
The Aerospace Corporation

AIAA General Chair
Lauri K. Newman
NASA Goddard Space Flight Center

AAS Technical Chair
Sergei Tanygin
Analytical Graphics, Inc.

AIAA Technical Chair
Ryan Park
Jet Propulsion Laboratory

American Astronautical Society

AIAA
The World's Forum for Aerospace Leadership

Front Cover Image:

Top Right: The Mars Science laboratory Curiosity Rover successfully landed in Gale Crater on August 6, 2012. Credit: NASA /Jet Propulsion Laboratory.

Upper Middle: The Dragon spacecraft became the first commercial vehicle in history to successfully attach to the International Space Station May 25, 2012. Credit: Space Exploration Technologies (SpaceX).

Lower Middle: The Dawn Spacecraft enters orbit about asteroid Vesta on July 16, 2011. Credit: Orbital Sciences Corporation and NASA/Jet Propulsion Laboratory, California Institute of Technology.

Lower Right: GRAIL-A and GRAIL-B spacecraft, which entered lunar orbit on December 31, 2011 and January 1, 2012, fly in formation above the moon. Credit: Lockheed Martin and NASA/Jet Propulsion Laboratory, California Institute of Technology.

Lower Left: The Dawn Spacecraft launch took place September 27, 2007. Credit: Orbital Sciences Corporation and NASA/Jet Propulsion Laboratory, California Institute of Technology.

Program sponsored and provided by:

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Software for Space, Defense & Intelligence

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CONFERENCE INFORMATION

REGISTRATION

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

In order to encourage early registration, we have implemented the following conference registration rate structure: **Register by 15 Jan 2013 and save $50!**

Category	Early Registration (through 15 Jan 2013)	Regular Registration
Full - AAS or AIAA Member	$530	$580
Full - Non-member	$630	$645
Retired*	$120	$170
Student*	$120	$170
Special Event Guest Ticket	$75	$75
Special Event Child Ticket (6-12 yrs)	$40	$40

The receptions are included for all registrants. The Tuesday night Special Event is included only for Full registration fees. The Special Event is free for children under the age of 6. On-site sales of special event tickets will be limited.

The Special Event on Tuesday will be a luau held onsite at the Marriott. The Event starts at 7pm.

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

- Sunday Feb. 10 3:00 PM - 7:00 PM
- Monday Feb. 11 8:00 AM - 2:00 PM
- Tuesday Feb. 12 8:00 AM - 2:00 PM
- Wednesday Feb. 13 8:00 AM - 2:00 PM
- Thursday Feb. 14 8:00 AM - 10:00 AM

We will accept registration and credit card 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.

Schedule of Events

Day	Start	End	Function	Room
Sun. 10 Feb.	3pm	7pm	Registration	Puna Foyer Desk
	6pm	9pm	Early Bird Reception	Luau Gardens

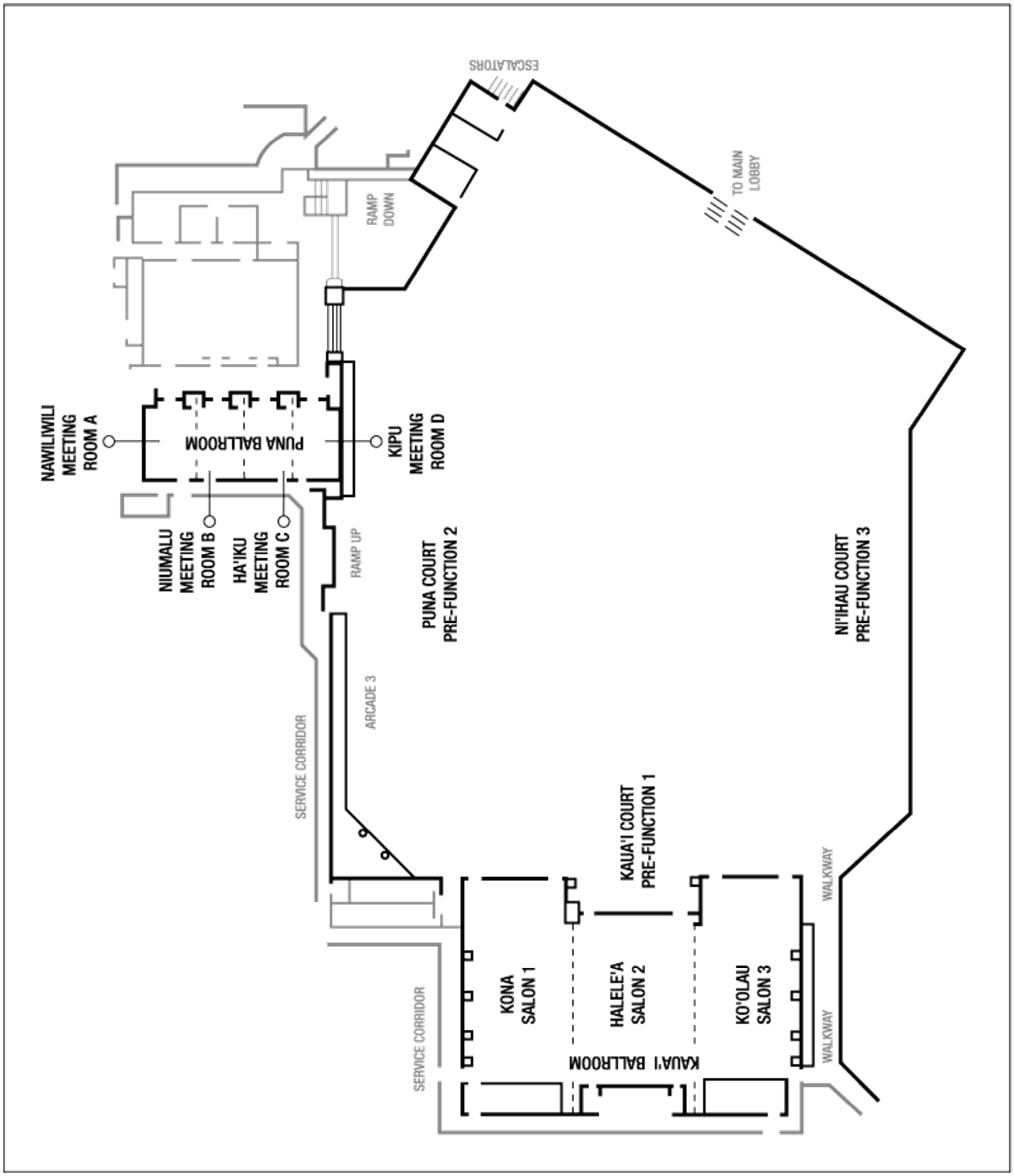
Day	Start	End	Function	Room
Monday 11 February	7am	8am	Speakers Breakfast	Puna Court
	8am	11:45am	Session 1: Orbit Determination and Estimation Theory -- I	Kauai Salon 1
	8am	11:25am	Session 2: Attitude Determination, Dynamics, and Control -- I	Kauai Salon 2
	8am	11:45am	Session 3: Trajectory Optimization -- I	Kauai Salon 3
	8am	11:45am	Session 4: Special Session: Mars Science Laboratory (MSL) -- I	Puna Room C&D
	9:40am	10:05am	Morning Break	Reindeer Bar
	Noon	1:30pm	Joint Technical Committee Lunch	Puna Room A&B
	1:30pm	3:55pm	Session 5: Space-surveillance Tracking	Kauai Salon 1
	1:30pm	5:15pm	Session 6: Low-thrust Trajectory Design	Kauai Salon 2
	1:30pm	4:55pm	Session 7: Orbital Dynamics Near Small-body	Kauai Salon 3
	1:30pm	4:15pm	Session 8: Special Session: Gravity Recovery And Interior Laboratory (GRAIL)	Puna Room C&D
	3:10pm	3:35pm	Afternoon Break	Reindeer Bar

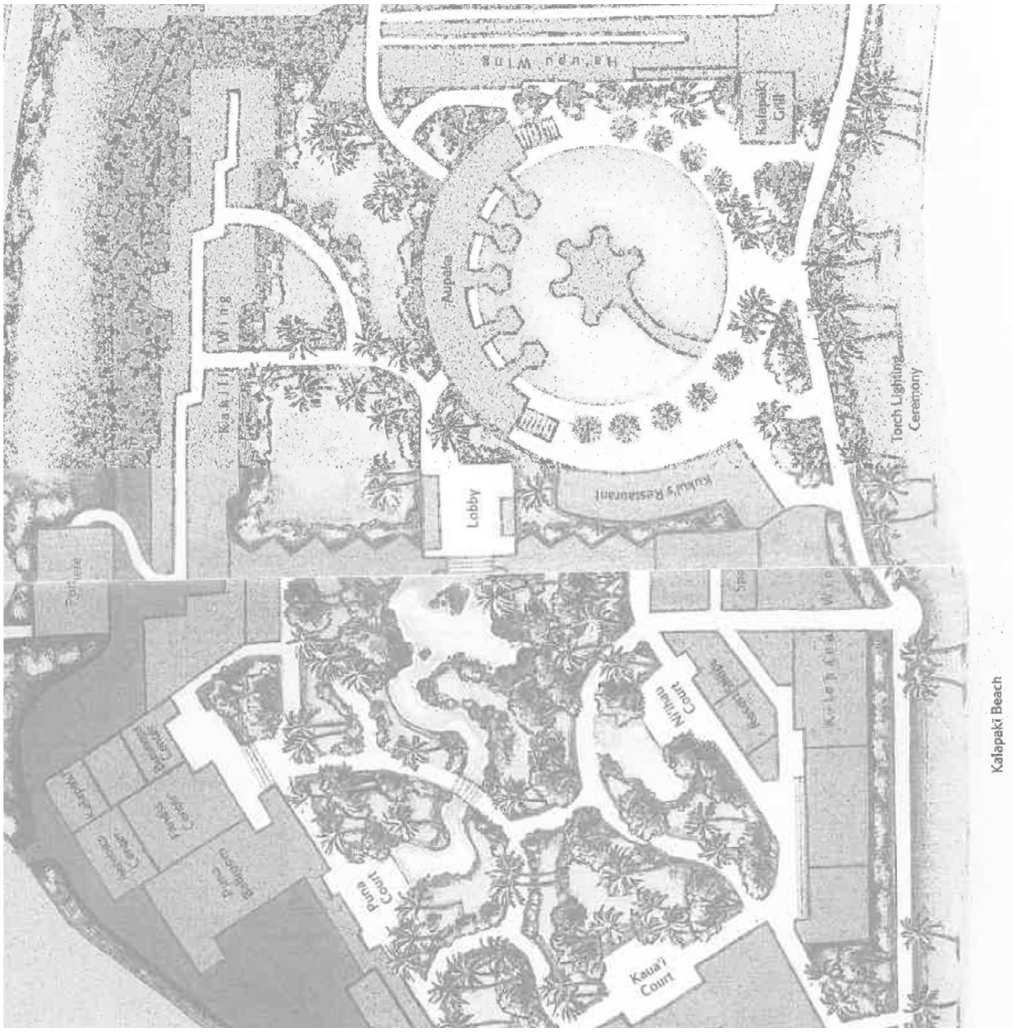
Day	Start	End	Function	Room
Tuesday 12 February	7am	8am	Speakers Breakfast	Puna Court
	8am	11:45am	Session 9: Orbit Determination and Estimation Theory -- II	Kauai Salon 1
	8:20am	10:45am	Session 10: Attitude Determination, Dynamics, and Control -- II	Kauai Salon 2
	8am	11:25am	Session 11: Trajectory Optimization -- II	Kauai Salon 3
	8am	11:25am	Session 12: Special Session: Mars Science Laboratory (MSL) -- II	Puna Room C&D
	9:40am	10:05am	Morning Break	Reindeer Bar
	Noon	1:30pm	AAS Spaceflight Mechanics Committee Lunch	Puna Room A&B
	1:30pm	5:15pm	Session 13: Orbital Dynamics and Space Environment -- I	Kauai Salon 1
	1:30pm	5:15pm	Session 14: Spacecraft Guidance, Navigation, and Control -- I	Kauai Salon 2
	1:30pm	5:15pm	Session 15: Dynamical Systems Theory	Kauai Salon 3
	1:30pm	4:55pm	Session 16: Special Session: Dawn	Puna Room C&D
	3:10pm	3:35pm	Afternoon Break	Reindeer Bar
	6pm	7pm	Award Ceremony and Brower Lecture	Kauai Ballroom
	7pm	9pm	Luau	Luau Gardens

Day	Start	End	Function	Room
Wednesday 13 February	7am	8am	Speakers Breakfast	Puna Court
	8am	11:05am	Session 17: Space Situational Awareness and Conjunction Analysis -- I	Kauai Salon 1
	8am	11:45am	Session 18: Attitude Determination, Dynamics, and Control -- III	Kauai Salon 2
	8am	11:45am	Session 19: Orbital Dynamics and Space Environment -- II	Kauai Salon 3
	8:20am	11:25am	Session 20: Interplanetary Mission Studies	Puna Room C&D
	9:40am	10:05am	Morning Break	Reindeer Bar
	Noon	1:30pm	AIAA Astrodynamics Technical Committee Lunch	Puna Room A&B
	1:30pm	4:55pm	Session 21: Rendezvous and Formation Flying	Kauai Salon 1
	1:30pm	4:35pm	Session 22: Flight Dynamics Operations and Spacecraft Autonomy	Kauai Salon 2
	1:30pm	4:55pm	Session 23: Small-body Missions	Kauai Salon 3
	1:30pm	4:35pm	Session 24: Special Session: Mars Science Laboratory (MSL) -- III	Puna Room C&D
	3:10pm	3:35pm	Afternoon Break	Reindeer Bar
	5:30pm	6:30pm	Conference Administration Subcommittee	Kauai Salon 1
	5:30pm	6:30pm	Technical Administration Subcommittee	Kauai Salon 2
	5:30pm	6:30pm	Website Administration Subcommittee	Kauai Salon 3

Day	Start	End	Function	Room
Thursday 14 February	7am	8am	Speakers Breakfast	Puna Court
	8am	11:05am	Session 25: Space Situational Awareness and Conjunction Analysis -- II	Kauai Salon 1
	8am	11:05am	Session 26: Attitude Determination, Dynamics, and Control -- IV	Kauai Salon 2
	8am	11:05am	Session 27: Spacecraft Guidance, Navigation, and Control -- II	Kauai Salon 3
	8am	11:25am	Session 28: Mission/maneuver Design	Puna Room C&D
	9:40am	10:05am	Morning Break	Reindeer Bar
	1:00pm	5:00pm	MSL Reconstruction Meeting	Kauai Salon 1

CONFERENCE CENTER LAYOUT




Lobby
Kukui's Restaurant
Torch Lighting Ceremony
Kalapakī Beach
Puna Court
Kaua'i Court

SPECIAL EVENTS

EARLY BIRD RECEPTION

Sunday, 10 February 6 – 8pm
Location: Luau Gardens

AWARD CEREMONY, DIRK BROUWER AWARD LECTURE

Tuesday, 12 February 6-7pm
Location: Kauai Ballroom Salons 1 & 2

DIRK BROUWER AWARD HONOREE

Dan Scheeres is the A. Richard Seebass Endowed Chair Professor in the Department of Aerospace Engineering Sciences at the University of Colorado at Boulder and a member of the Colorado Center for Astrodynamics Research. Prior to this he held faculty positions in Aerospace Engineering at the University of Michigan and Iowa State University, and was a Senior Member of the Technical Staff in the Navigation Systems Section at the California Institute of Technology's Jet Propulsion Laboratory. He was awarded PhD. (1992), M.S.E. (1988) and B.S.E (1987) degrees in Aerospace Engineering from the University of Michigan, and holds a B.S. in Letters and Engineering from Calvin College (1985). Scheeres is a Fellow of the American Astronautical Society and an Associate Fellow of the American Institute of Aeronautics and Astronautics. He is the past Chair of the American Astronomical Society's Division on Dynamical Astronomy, vice-president of the Celestial Mechanics Institute, and a member of the International Astronomical Union and the International Astronautical Federation. Asteroid 8887 is named "Scheeres" in recognition of his contributions to the scientific understanding of the dynamical environment about asteroids.

Award Lecture: The Mechanics of Exploring Asteroids

The exploration of asteroids using spacecraft is motivated by significant themes: the scientific study of solar system formation and evolution, the exploration of the solar system, and the protection of society against future hazardous impactors. This endeavor involves significant challenges across a range of technical issues: development of new models for mathematically describing the environment, understanding the basic mechanics of asteroids, and describing and predicting orbital motion in these highly perturbed environments. This talk will introduce the technical challenges the asteroid environment poses, review progress which has occurred over the last two decades, and indicate where research is still needed.

SOCIAL EVENT – LUAU

Tuesday, 16 February 7-9pm includes show and buffet dinner
Location On site at Kauai Marriott Luau gardens

Conference Location

Kauai Marriott Resort Hotel Accommodations

The conference is located at the Kauai Marriott Resort in Lihue, HI, 1 mile from the Lihue airport.

Kauai Marriott Resort
on Kalapaki Beach
3610 Rice Street
Lihue, HI 96766

Phone:1 808-246-5071
Fax: 1-808-245-2993
Toll-free: 1-800-220-2925

https://resweb.passkey.com/Resweb.do?mode=welcome_ei_new&eventID=9467418

The Conference rate for the conference is $243 plus applicable taxes currently at 13.4166%. Please request the AAS/AIAA Space Flight Mechanics Meeting rate. (The deadline for securing the conference rate at the hotel is 11 January.)

Transportation Info

By Airport Shuttle

A courtesy 10-passenger resort shuttle is available to and from the airport.

By Bus

The Kaua'I Bus (PHONE: 808/241-6410; EMAIL: thekauaibus@kauai.gov; http://www.kauai.gov/Government/Departments/CommunityAssistance/TransportationAgency/BusSchedules/tabid/208/Default.aspx). Note that carry-ons on the bus are limited to 9" x 14" x 22".

By Taxi

Fares vary among companies but run around $3.00 per mile, and .40 per minute. Taxi stands are located at airport and hotels, otherwise you must call and reserve one:

Akiko's Taxi: 808-822-7588 or 808-651-1472; akikostaxi@gmail.com

Pono Taxi: 808-634-4744

DIRECTIONS

From Airport

Lihue - LIH

1. Head **northeast** on **Mokulele Loop**

0.2 mi

2. Turn left toward **Ahukini Rd**

0.1 mi

3. Continue straight onto **Ahukini Rd**

0.2 mi

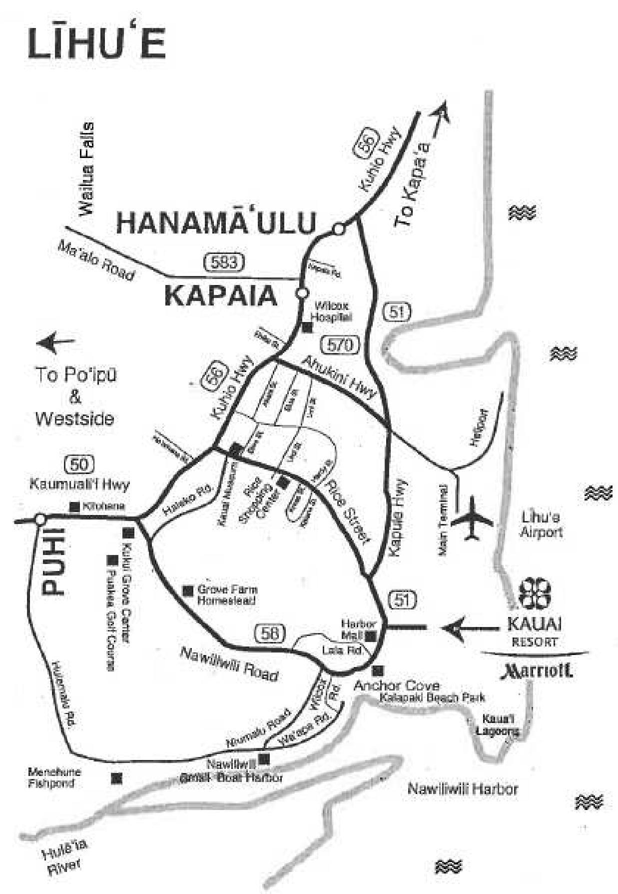
4. Turn left onto **HI-51 S**

1.1 mi

5. Turn left onto **Rice St**

0.6 mi

6. Turn left
Destination will be on the right



ARRIVAL INFORMATION

Check-In and Checkout

- Check-in: 4:00 PM
  Check-out: 12:00 PM

Hotel Amenities

- Children's program
- Fitness center
- Rental car
- Business center
- Concierge
- Tour desks
- Valet/self-park (with fee)
- Complimentary shuttle to/from airport

High-Speed Internet Access

- Guest rooms: Wired (for business)
- Public areas: Wireless
- Meeting rooms: Wired, Wireless

RESTAURANTS & SHOPPING

Hotel

- Kukui's Restaurant and Bar (breakfast, dinner & evening cocktails poolside)
- Aupaka (breakfast)
- Kalapaki Grill (lunch: light fare, pizza, burgers and grilled snacks by the pool)
- Duke's Canoe Club & Barefoot Bar (local island fare, fresh fish and steaks)
- Café Portofino (international cuisine)
- Toro-Tei Sushi Bar

Local Area

Gaylord's (American)

Gaylord's menu includes foods and preparations to interest the traditional diner, or the more adventuresome.

- Open for lunch and dinner
- Dress code: Casual
- Phone: 1-808-245-9593

JJ's Broiler (American)

Within walking distance, the breathtaking view from this Lihue, Kauai, restaurant sets the stage for a panorama of savory regional and hearty American meals, including fresh island fish, garden salads, sandwiches and pasta entrees.

- Open for lunch and dinner
- Dress code: Casual
- Phone: 1-808-246-4422

Kalapaki Joe's (American)

Kalapaki Joe's is within walking distance from the resort. It is known as Kauai's premier bar & grill with emphasis on sports. The casual restaurant serves fresh island food along with American-Mexican fare.

- Open for breakfast, lunch and dinner
- Dress code: Casual
- Phone: 1-808-245-6266

Kalapaki Beach Hut (American)

The best deal in town and within walking distance from the resort. Enjoy a local favorite like Loco Moco or grilled sandwiches, fish and chips and hearty burgers.

- Open for breakfast, lunch and dinner
- Phone: 1-808-246-6330

Mariachi's (Mexican)

- Open for breakfast, lunch and dinner
- Dress code: Casual
- Phone: 1-808-246-1570

Deli & Bread Connection

Freshly made bread, delicious deli meats, soups, salads and sandwiches available.

- Open for breakfast, lunch and dinner
- Dress code: Casual
- Phone: 1-808-245-7115

Brick Oven Pizza

Two locations on Kauai at Wailua and Kalaheo. Fresh hearth-baked pizza with whole wheat or white crust brushed with garlic butter. Besides great pizza, there are also soup, salad, sandwiches and dessert available.

- Open for lunch and dinner
- Dress code: Casual
- Phone: 1-808-823-8561

Kountry Kitchen (American)

Excellent for breakfast, famous for the polynesian omelet, eggs benedict and pancakes.

- Open for breakfast, lunch and dinner
- Dress code: Casual
- Phone: 1-808-822-3511

Restaurant Kintaro (Japanese)

Japanese sushi bar, regular dining or Teppanyaki. Fun, interactive teppanyaki is always exciting, but their tempura, steak and lobster or variety of sushi rolls are scrumptious.

- Open for dinner
- Dress code: Casual
- Phone: 1-808-822-3341

Shivalik Indian Cuisine

Authentic Indian cusine in elegant setting at Waipouli Town Center. Offers buffet lunch, dinner and a la carte menu options.

- Open for lunch and dinner
- Dress code: Casual
- Phone: 1-808-821-2333

RECREATION

Swimming

- 26,000 square-foot pool, the largest single-level pool in Hawaii
- 5 whirlpools

Activities

- Kaua‘i Lagoons Golf Club
- Hiking nearby
- Horseback riding nearby
- Jogging/fitness trail
- Kayaking
- Scuba diving nearby
- Snorkeling nearby
- Surfing
- Tennis
- Volleyball
- Water-skiing nearby
- Nearby BBQ picnic area

Attractions & Landmarks

- **Huleia National Wildlife Refuge** – The site of Indiana Jones daring escape in Raiders of the Lost Ark.
- **Menehune (Alekoko) Fishpond** – Said to have been built by the ancient Menehune, the mysterious ‘little people’ who predated the arrival of the Hawaiian people.
- **Fern Grotto** – Fern-fringed cave up the Wailua River. A favorite site for romantic weddings.
- **Lydgate State Park** – Ideal swimming beach and picnic area.
- **Wailua Falls** – Dramatic 80-foot waterfalls featured in the opening of the television series Fantasy Island.
- **Bell Stone** – Used to announce the birth of a child of the alii (royalty). When struck sharply, the stone would emit a sound that resonated throughout Wailua Valley.
- **Sleeping Giant** – A mountain ridge resembling a man lying on his back. Legend has it that this was once a pesky giant who demanded constant feeding from the villagers. Fed up, the villagers tricked him into swallowing rocks. The giant was so full that he lay down to take a nap and fell into an eternal sleep. We hope.
- **Kilauea Point National Wildlife Refuge** – The island’s northern most point, home to an array of protected sea birds.
- **Captain Cook’s Monument** – Located in the town of Waimea, the site where British Captain James Cook first landed in Hawaii in 1778.
- **Russian Fort Elizabeth** – Fort built in 1815 by George Scheffer, a Russian doctor – unfortunately (for him) without support from the Czar.
- **Waimea Canyon** – Ten miles long and about 3,600-feet deep. Mark Twain called it “Grand Canyon of the Pacific.” An absolute must see!
- **Kalalau Lookout** – Dramatic view of cliffs and gorges dropping 4,000 feet into the ocean. Located in Kokee State Park.
- **See the Na Pali Coast** – A photographer’s dream, it features majestic cliffs, sea caves and other natural wonders. Best seen by hiking or boating.
- **Visit Old Kapaa Town** – For a more relaxing adventure, stroll the streets of this quaint 19th century plantation town. Discover charming shops selling local wares, and outstanding restaurants.

ADDITIONAL INFORMATION

SPEAKER ORIENTATION

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

VOLUNTEERS

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

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.

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

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

PREPRINTED MANUSCRIPTS

Physical copies of preprinted manuscripts are no longer available or required for the Space Flight Mechanics Meetings. Electronic preprints are available for download at least 72 hours before the conference at https://www.xcdsystem.com/SFMC/ for registrants who use the online registration system. The hotel provides conference guests with free wireless internet access in guest rooms and the conference meeting space. Registrants without an internet-capable portable computer, or those desiring traditional paper copies should download and print preprint manuscripts before arriving at the conference.

CONFERENCE PROCEEDINGS

All registrants will receive a CD of the proceedings mailed to them after the conference (extra copies are available for $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 even if they delay their order until after the conference. Cost of Proceedings:

- Conference Rate (US shipping) **$290**
- Conference Rate (international shipping) **$380**
- Post-Conference Rate **$750** (approx.)
- Authors (post-conference) **$375** (approx.)

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

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

Journal of Spacecraft and Rockets
Editor-in-Chief: E. Vincent Zoby, NASA Langley Research Center
Manuscripts can be submitted via: http://mc.manuscriptcentral.com/aiaa-jsr

Journal of the Astronautical Sciences
Editor-in-Chief: Kathleen C. Howell
Manuscripts can be submitted via: https://www.rapidreview.com/AAS/SMLogon.jsp

MEETINGS

Committee seating is limited to committee members and invited guests. Committee meetings will be held according to the following schedule in the Puna Ballroom Room A&B:

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

Conference Administration Subcommittee - Wednesday, Kauai Ballroom Salon 1 5:30-6:30pm
Technical Administration Subcommittee - Wednesday, Kauai Ballroom Salon 2 5:30-6:30pm
Website Administration Subcommittee - Wednesday, Kauai Ballroom Salon 3 5:30-6:30pm

MSL Reconstruction Meeting - Thursday, Kauai Ballroom Salon 1 1:00-5:-0pm

SESSION 1: ORBIT DETERMINATION AND ESTIMATION THEORY -- I

Chair: Dr. Michael Gabor, TASC

8:00 AAS 13-200 Nonlinear filtering based on Taylor differential algebra
Roberto Armellin, Politecnico di Milano; Monica Valli, Politecnico di Milano; Pierluigi di Lizia, Politecnico di Milano; Michele Lavagna, Politecnico di Milano; Renato Zanetti, Draper Laboratory

Nonlinear filtering plays an important role in various space-related applications. An innovative filter based on Taylor differential algebraic (DA) technique is proposed. This is based on updating the entire conditional probability density function whenever a new measurement becomes available. The update is performed applying Bayes' rule. The probability density function is represented as an arbitrary order Taylor series. The process is enabled by the DA evaluation of the involved probability density functions. The case of an Earth orbiting satellite with realistic initial orbit uncertainties and nonlinear measurements is presented to discuss the performances of the proposed filtering algorithm.

8:20 AAS 13-201 Chebyshev Interpolation for VLS
James Wright, Analytical Graphics, Inc.; William Chuba, Analytical Graphics, Inc.

The variable lag smoother (VLS) is a forward running filter-smoother for sequential orbit determination. Multiple smoothed state estimates are updated at distinct fixed epochs simultaneously with each filter state estimate update. But smoothed estimates must be interpolated. Uniform time-grid Lagrange interpolation is unacceptably slow due to required computation of many fixed-epoch smoothers. But the number of VLS fixed epoch smoothers required for non-uniform Chebyshev series interpolation is far fewer. Thus computer wall time through-put is significantly faster with Chebyshev. The results of a LEO simulation with an interpolation interval of five hour duration are presented.

8:40 AAS 13-477 On the Expected Value of Sensed Data
James D. Turner, Texas A&M University; Ahmad Bani Younes, Texas A&M University

Tensor-based state transition power series solutions are developed for propagating the uncertainty in the system initial conditions and parameters for nonlinear systems. The tensor power series are used to develop analytic models for the nonlinear statistical moments of the system behavior. A second-order expansion is developed for the system observation equation that accounts for the initial condition and parameter uncertainty. An analytic expectation operator is used to evaluate the expected value of the system observation equation, thereby producing a nonlinear prediction of the current value of the observed state that accounts for system dynamics.

9:00 AAS 13-203 Analytic Characterization of Measurement Uncertainty and Initial Orbit Determination on Orbital Element Uncertainty and Correlation

Ryan Weisman, Texas A&M University; Manoranjan Majji, University at Buffalo, State University of New York; Kyle T. Alfriend, Texas A&M University

This paper applies the transformation of variables technique to analytically map measurement domain probability density functions to nonlinearly related, but commonly utilized state domains for space surveillance. For full state construction, the Herrick-Gibbs initial orbit determination routine is employed with the transformation of variables technique applied to assess state uncertainty and correlation resulting from the application of the routine for objects residing in and transiting low Earth orbit. Results are reported for the Cartesian, osculating and mean orbital element domains and compared against Monte Carlo simulation results and the commonly utilized similarity transformation.

9:20 AAS 13-204 Statistical Tests for Gaussian Mean and Covariance in Orbit Propagation

Laura Henderson, The University of Texas at Arlington; Vincent Coppola, Analytical Graphics, Inc.

We are interested in determining the duration that a nominal orbit trajectory's propagated mean and covariance well-approximate the statistics of an ensemble, where the ensemble is propagated using the fully nonlinear dynamics. Two standard statistical tests are performed to determine the time at which the ensemble statistics are no longer well-approximated by the nominal. The initial covariance is chosen from a simulated orbit determination solution, so that it represents typical orbit uncertainty experienced in practice. Several examples, from different orbit regimes and represented in different coordinates, will be shown to be a guide for orbit determination practitioners.

9:40 Break

10:05 AAS 13-206 Improving Orbit Determination with Non-cannonball Solar Radiation Pressure Models

Jay McMahon, University of Colorado

Many orbit determination processes use the simple cannonball model to account for solar radiation pressure (SRP) perturbations. Due to the fact that this model is only an approximation of the true SRP interaction, orbit determination accuracy is limited, and actually degrades as longer arcs of data are processed. In this paper, we clearly demonstrate the errors that arise due to the cannonball model. We then present alternative SRP models that produce improved results. Models are identified that allow longer arcs of data to be processed, which has the positive side effect of decreasing the uncertainty of the estimated orbits.

10:25 AAS 13-207 Interplanetary Departure Stage Navigation by means of LiAISON Orbit Determination Architecture

Ryan McGranaghan, University of Colorado at Boulder; Jason Leonard, University of Colorado at Boulder; Kohei Fujimoto, University of Colorado at Boulder; Jeff Parker, University of Colorado at Boulder; Rodney Anderson, NASA / Caltech JPL; George Born, University of Colorado at Boulder

Autonomous orbit determination for departure stages of interplanetary trajectories is conducted by means of realistic radio measurements between the departing spacecraft and a satellite orbiting the first lunar libration point. Linked Autonomous Interplanetary Satellite Orbit Navigation (LiAISON) is used to calculate the orbit solution. This paper performs high-fidelity simulations exploring the utilization of LiAISON in providing improved accuracy for interplanetary departure missions. Comparisons with ground-based navigation are explored to assess autonomous navigation of interplanetary spacecraft with respect to supplementing current techniques. Results from simulations including the Mars Exploration Rover, Mars Science Laboratory, and Cassini are presented.

10:45 AAS 13-285 GOCE Fully-Dynamic Precise Orbit Recovery

Francesco Gini, Universita' di Padova; Francesca Panzetta, Universita' di Padova; Massimo Bardella, Universita' di Padova; Stefano Casotto, Universita' di Padova

GOCE was launched in 2009 at 250 km altitude to recover Earth's static gravity field. As part of the GOCE-Italy project, we carried out GPS-based, fully-dynamic POD of GOCE. Daily arcs were computed for about 500 days (November 1, 2009 - May 31, 2011). Results show an average post-fit RMS of zero-difference phase measurements of 8 mm. Most orbits compare to less than 6 cm 3D RMS with respect to the official kinematic/RD PSO orbits. These results form a solid basis for the reprocessing of GOCE tracking data for ocean tide parameters solutions.

11:05 AAS 13-208 Unscented Kalman Filter Robustness Assessment for Orbit Determination Using GPS Signals

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

In this work is presented the nonlinear unscented Kalman filter (UKF) evaluation for the satellite orbit determination problem, using GPS measurements. The assessment is based on the robustness of the filter. The main subjects for the evaluation are convergence speed and computational implementation complexity, which are based on comparing the UKF results against the extended Kalman filter (EKF) results for the same problem. After solving the real time orbit determination problem using actual GPS measurements, through the EKF and the UKF algorithms, the results obtained are compared in computational terms such as burden (complexity), convergence, accuracy, and relative CPU time.

11:25 AAS 13-209 Real Time Orbit Determination for Lunar and Planetary Missions

Ryo Nakamura, Japan Aerospace Exploration Agency

We develop a tool based on the Unscented Kalman Filter (UKF) for real-time orbit determination for lunar and planetary missions. The UKF has an advantage over the EKF in that it approximates the mean and covariance of state more accurately than EKF. The developed tool is evaluated through the orbit determination simulations during orbit insertion maneuvers of Japanese Venus Climate Orbiter “Akatsuki” and SELenological and ENgineering Explorer “Kaguya”. The results indicate that the tool works well and the UKF is superior to the EKF in both accuracy and stability of real-time orbit determination.

SESSION 2: ATTITUDE DETERMINATION, DYNAMICS, AND CONTROL -- I

Chair: Dr. Renato Zanetti, The Charles Stark Draper Laboratory

8:00 AAS 13-213 Comparison of Multiple-Period and Higher Order Repetitive Control Used to Produce Robustness to Period Fluctuations

Edwin Ahn, Naval Postgraduate School / Columbia University; Richard Longman, Columbia University; Jae Kim, Naval Postgraduate School

Repetitive control (RC) can be used for vibration isolation in spacecraft. In previous experiments with the Naval Postgraduate School Three-Axis Spacecraft testbed, Multiple-Period Repetitive Control (MPRC) was seen to eliminate disturbances at the period of interest, but also to rejecting neighboring frequencies as well when multiple periods were made identical. This offers a new method of addressing situations when the disturbance period fluctuates or is uncertain, and is shown here to be very effective. The existing RC method to address this is Higher Order Repetitive Control. The two methods are compared, and MPRC is shown to have advantages.

8:20 AAS 13-214 Stability of Spinning Satellite under Axial Thrust and Internal Motion Including Damping

Frank Janssens, Retired; Jozef van der Ha, Consultant

The paper provides new results on the stability boundaries of a spinning body under axial thrust augmented with a mass-spring-damper system. The stability of the linearized equations is investigated through the roots of the characteristic equation in complex variables. When damping is included this equation has also complex coefficients. We determine the stability boundaries and the region of asymptotic stability for both prolate and oblate spinners in terms of the numerical values of the spring constant and the thrust level.

8:40 Withdrawn

9:00 AAS 13-216 Switching Angular Velocity Observer for Rigid-body Attitude Stabilization and Tracking Control

Apurva Chunodkar, The University of Texas at Austin; Maruthi Akella, The University of Texas at Austin

This paper provides a new switching observer formulation to the classical rigid body attitude tracking control problem in the absence of angular rate measurements. Exponential convergence of state estimation errors is proven using a novel velocity estimation error definition through use of this switching-type observer. The observer is independent of controller design. Further, the maximum number of switches required by the observer is shown to be finite. A ``separation property'' type result is established, wherein a proportional-derivative controller utilizes angular velocity estimates from the proposed switching observer, ensuring almost global asymptotic stability for the closed-loop error dynamics.

9:20 AAS 13-483 Quaternion-based Backstepping for Line-of-Sight Tracking of Satellites Using Only Magnetorquers

Deepti Kannapan, Indian Institute of Technology; Sandipan Bandyopadhyay, Indian Institute of Technology; Arun Mahindrakar, Indian Institute of Technology

A new strategy for the design of tracking control laws is presented for line-of-sight (LoS) pointing control of satellites that use only magnetorquers. This strategy makes use of the backstepping approach, and applies to satellites that require the LOS of a single instrument, such as a transmission antenna or camera, to be pointed at a given time, but not both simultaneously. Asymptotic stability of the desired trajectory is proved, provided the target pointing-direction lies outside some critical range. A control law so developed is numerically simulated for a nanosatellite mission scenario to demonstrate feasibility.

9:40 Break

10:05 AAS 13-480 Experimental Characterization of a Miniature Laser Rangefinder for Resident Space Object Imaging

Bogdan Udrea, Embry-Riddle Aeronautical University; Michael Nayak, Space Development & Test Directorate, US Air Force; Ayham Baba, Embry-Riddle Aeronautical University; Timothy Grande, Embry-Riddle Aeronautical University; Kristia Harris, Embry-Riddle Aeronautical University; Christian Castillo, Embry-Riddle Aeronautical University; Joseph DiGregorio, Embry-Riddle Aeronautical University; Timothy Zuercher, Embry-Riddle Aeronautical University

This paper is focused on the use of experimental test data to characterize errors inherent within the MLR100. The algorithms developed for RSO imaging that parse the LRF point clouds into recognizable RSO shapes employ only simple error models, including stochastic and laser beam pulse dilation errors. The stochastic errors are modeled as normal (Gaussian) distributions and the pulse dilation errors as a linear function of the slope of the surface with respect to the LRF receiver optical axis. Results of the experiments and test data discussed in the current work are directly applicable to constraining error models.

10:25 AAS 13-217 Modeling of 3D Slosh Motion for Spacecraft with Multiple Liquid Stores

Ja Young Kang, Korea Aerospace University

Nowadays most of spacecraft including communication satellites carry large multiple propellant tanks for a longer space mission or an extended orbit life. When multiple liquid tanks are involved, it is most difficult part to derive the inertially decoupled equations of motion to describe the 3D slosh dynamics coupled with spacecraft dynamics. In this study the spherical pendulums are used as equivalent mechanical analogs and, based on Newton-Euler and Pseudo Inverse methods, inertially decoupled nonlinear equations of motion for spacecraft and liquid slosh will be derived. Numerical and analytical solutions for the spacecraft with two bipropellant tanks will be presented.

10:45 AAS 13-218 Fault Tolerant Attitude Control for Small Satellites by Using Single Gimbal Control Moment Gyros and Magnetic Torquers

Lei Jin, Beihang University; Khorasani Khashayar, Concordia University; Shijie Xu, Beihang University

A fault tolerant control scheme is proposed for attitude stabilization of a small satellite using single gimbal control moment gyros (SGCMGs) and magnetic torquers (MTs). By designing extended state observer, the dynamic uncertainties, external disturbances and partial loss of SGCMGs effectiveness are estimated and compensated. Based on singular value decomposition, the input torque is decomposed and distributed to SGCMGs and MTs respectively, and SGCMGs only need to output the torque orthogonal to the singular direction. Numerical simulations demonstrate that this scheme can tolerate potential SGCMGs faults and resolve the singularity problem, maintaining the desirable stability and performance of the satellite.

11:05 AAS 13-219 Nonlinear attitude stability of a spacecraft on a stationary orbit around an asteroid subjected to gravity gradient torque

Yue Wang, Beihang University; Shijie Xu, Beihang University

Equilibrium attitude and its nonlinear stability of a spacecraft on a stationary orbit around an asteroid are studied in the framework of geometric mechanics. Based on the natural symplectic structure, the non-canonical Hamiltonian structure of the problem is derived. Poisson tensor and the equations of motion are obtained in a differential geometric method. Equilibrium attitude is determined from a global viewpoint. Nonlinear stability of the equilibrium is investigated through energy-Casimir method. We find that nonlinear stability domain can be totally different from the classical Lagrange region in a central gravity field due to the non-central gravity field.

SESSION 3: TRAJECTORY OPTIMIZATION -- I

Chair: Dr. Thomas Eller, Astro USA, LLC

8:00 AAS 13-220 Loads Alleviation on European Launchers Using Wind Biased Trajectory Optimization

Benjamin Carpentier, CNES; Pierre-Emmanuel Haensler, ALTEN; Benoit Mazellier, CNES; Amaya Espinosa, CNES

In this paper is studied the use of wind-biased optimization for atmospheric phase trajectory of European launchers. Such methodology has been extensively used in US programs but was not on European launcher up to now. A benchmark is considered to evidence and quantify the interest of such an approach in terms of loads alleviation, and TVC deflection budget reduction. Two different approaches are discussed: the first one using a mean seasonally wind profile, the second one using a day-of-launch sounded wind profile. Pros and cons of each approach are discussed, as second one obviously implies operationnal constraints.

8:20 AAS 13-221 Time-Optimal Trajectory Design for a Dual-Satellite Sailcraft Interstellar Mission with Probe Release

Xiangyuan Zeng, Tsinghua University; Kyle T. Alfriend, Texas A&M University; Srinivas R. Vadali, Texas A&M University; Hexi Baoyin, Tsinghua University; Ying Zhan, Beijing Branch of PCTEL(Tianjin) Wireless Telecommunications Products Co., Ltd; Shengping Gong, Tsinghua University

A time-optimal trajectory design for a novel dual-satellite sailcraft is presented to accomplish interstellar missions by releasing a probe at the perihelion point. Consequently, the lightness number of the sail undergoes a positive jump at probe release, reaching a value significantly greater than one, thus allowing the sailcraft to reach a very high terminal speed at a sail-jettison distance of 5 AU. Such a discontinuous, time-optimal control problem is solved with an indirect method, involving the solution to a multi-point boundary value problem. A number of mission scenarios are investigated by varying relevant parameters.

8:40 AAS 13-222 Preliminary Development of an Optimized Lambert Problem Solver for Targets in Elliptical Orbits

David Spencer, The Pennsylvania State University; Brian Shank, The Pennsylvania State University

This paper investigates the solution of Lambert's Problem for targets in elliptical orbits. Preliminary efforts are made in developing a mission design software tool to determine the optimal interplanetary trajectory and final capture orbit based on mission constraints and requirements between a departure and arrival body. Integration of the Applied Research Laboratory Trade Space Visualizer software will permit a mission designer to visually inspect the multi-dimensional trade space and investigate regions of ideal trajectories.

9:00 **AAS 13-223** **L5 Mission Design Targeting Strategy**
Pedro Llanos, University of Southern California; James Miller, Consultant; Gerald Hintz, University of Southern California

A numerical method for targeting both the transfer orbit and Trojan orbit around the triangular points in the Sun-Earth system is implemented and then tested with a conic approach. This method generates end-to-end trajectories from a low Earth parking orbit at 200-km altitude and 28.5° inclination using a high fidelity model allowing for injection velocity corrections at the parking orbit by targeting either the position or velocity at arrival in the Trojan orbit around L5. During the injection velocity correction, we use the classical and hyperbolic elements to target the desired orientation and radius.

9:20 **AAS 13-224** **Mars Entry Trajectory Planning for Higher Elevation Landing**
Lluis Soler, University of California, Irvine; Kenneth Mease, University of California, Irvine

Achieving higher elevation landing sites requires parachute deployment altitude control. Bank profiles are computed that maximize an appropriate cost function that includes final altitude and also the important consideration of ensuring there is sufficient control authority in the final entry phase. Then a planning scheme is proposed that yields trajectories with near-optimal performance and yet is suitable for onboard rapid planning and re-planning. The bank profile is parametrized and the planning problem is posed and solved as a nonlinear programming problem. A comparison shows that the suboptimal solutions have only slightly reduced performance relative to the optimal solution.

9:40 **Break**

10:05 **AAS 13-225** **Minimum-time, Constant-thrust Transfers with Non-circular Boundary Conditions**
James Thorne, IDA

The accumulated velocity change under continuous thrust is nearly constant over a wide range of magnitudes for multi-revolution, time-optimal orbit transfers, approximately equal to the difference in initial and final circular velocities. For continuous-thrust transfers of less than one revolution, the approximate initial costates and final flight time are functions of thrust and final radius. If either the initial or final orbit is noncircular, chaotic behavior may be observed using continuation methods. This paper examines these chaotic discontinuities and offers techniques to help automate continuation parameter searches for minimum-time, continuous-thrust transfers between noncircular orbits.

10:25 **AAS 13-227** **Derivative Analysis and Algorithm Modification of the Transverse-Eccentricity-Based Lambert's Problem**
Wen Changxuan, Beijing University of Aeronautics and Astronautics; Zhao Yushan, Beijing University of Aeronautics and Astronautics; Shi Peng, Beijing University of Aeronautics and Astronautics

Classical Lambert's problem can be parameterized and solved through the transverse-eccentricity component. A further study was conducted to analyze the problem differentially and to modify the algorithms. Results show that the derivative of a direct transfer is positive and continuous, which verifies the monotonically increasing relationship between the transfer-time and the transverse eccentricity; however, the derivative of a multi-revolution case increases from negative to positive, indicating that the transfer-time decreases to the minimum firstly, and then increases to infinity. Simulations demonstrated the better computational efficiency and faster convergence of our modified algorithm.

10:45 AAS 13-228 Homotopy Method for Solving Minimum Consumption Orbit Transfer Problem

Hao Huang, Beihang University; Chao Han, Beihang University

Minimum consumption orbit transfer problem always leads to bang-bang opti-mal control problem, and difficult to solve with shooting methods. A homotopy approach is proposed to deal with these difficulties. Scaling techniques, global search for initial costates and modified RKF45 are combined with homotopy approach to reduce the searching space of costates, increase the possibility to get the global solution, and improve the precision of integration with discontinuous differential equations. A numerical example is solved to illustrate the effective of the method.

11:05 AAS 13-229 On-line Entry Trajectory Planning and Combined Prediction Guidance for Lunar Return

Biao Zhao, Harbin Institute of Technology; Naigang Cui, Harbin Institute of Technology; Jifeng Cuo, Harbin Institute of Technology; Ping Wang, China Academy of Space Technology (CAST)

For the lunar return mission, a concern of the entry guidance requirement is the full flight envelope applicability and landing accuracy control. The NPC method is not limited by the validity of the approximations, simplifications and empirical assumptions necessary for any analytical treatment, thus it holds greater potential to be more accurate and adaptive. However, the NPC algorithms in the literatures which merely predict based on the terminal condition cannot guarantee to meet the process constraints. To solve this problem, we combine NPC method with an analytical constant drag acceleration method, and propose a simple and effective integrated guidance.

11:25 AAS 13-226 On the Nature of Earth-Mars Porkchop Plots

Ryan Woolley, NASA / Caltech JPL; Charles Whetsel, NASA / Caltech JPL

Porkchop plots are a quick and convenient tool to help mission designers plan ballistic trajectories between two bodies. Parameter contours give rise to the familiar “porkchop” shape. Each synodic period the pattern repeats, but not exactly, primarily due to differences in inclination and non-zero eccentricity. In this paper we examine the morphology of Earth-to-Mars porkchop plots as they vary from opportunity to opportunity and its implications on trajectory design. These results are then compared to idealistic and optimized transfers. Conclusions are drawn about “good” opportunities versus “bad” opportunities for different mission applications.

SESSION 4: SPECIAL SESSION: MARS SCIENCE LABORATORY (MSL) -- I

Chair: Kenneth Williams, KinetX, Inc.

8:00 **AAS 13-236** **Mars Science Laboratory Entry, Descent and Landing System Overview**
Adam Steltzner, NASA / Caltech JPL

The Mars Science Laboratory project's Curiosity rover weighs over 900 kg and required the development of a new landing system. The MSL entry, descent and landing system is novel, using old technologies in a new application and pioneering the development of new technologies. This system allows for unprecedented landing accuracy and mass delivery to the surface of Mars.

This paper will present an overview to the MSL entry, descent and landing system and include a discussion of preliminary results of the flight reconstruction effort.

8:20 **AAS 13-237** **Mars Science Laboratory Entry, Descent and Landing System Margin, Risk and Development**
Adam Steltzner, NASA / Caltech JPL

The Mars Science Laboratory project's Curiosity rover weighs over 900 kg and required the development of a new landing system. The MSL entry, descent and landing system is novel, using old technologies in a new application and pioneering the development of new technologies. This system allows for unprecedented landing accuracy and mass delivery to the surface of Mars.

This paper will present a discussion of the development process, margin and risk management techniques for this high performance system.

8:40 **AAS 13-232** **Mars Science Laboratory Interplanetary Navigation Performance**
Tomas Martin-Mur, NASA / Caltech JPL

The MSL spacecraft, carrying the Curiosity rover, hit the top of the Martian atmosphere just 250 meters from where it had been predicted more than six days earlier, and 2.6 million kilometers away. This unexpected level of accuracy was achieved by a combination of factors including: spacecraft characteristics, tracking data processing, dynamical modeling choices, and navigation filter setup. This paper will describe our best understanding of what were the factors that contributed to this excellent interplanetary trajectory prediction performance. The accurate interplanetary navigation contributed to the very precise landing performance, and to the overall success of the mission.

9:00 **AAS 13-234** **2011 Mars Science Laboratory Trajectory Reconstruction and Performance from Launch Through Landing**

Fernando Abilleira, NASA / Caltech JPL

The Mars Science Laboratory (MSL) launched on an Atlas V 541 from Cape Canaveral in Florida on November 26th, 2011 and successfully landed inside Gale Crater on August 6th, 2012. After flying more than 550 million km, MSL entered the Martian atmosphere only ~900 m away from the optimal target and landed ~431 s later less than ~2.4 km away from its target. This paper summarizes in detail the actual trajectory performance in terms of launch vehicle events and trans-Mars injection accuracy, DSN/USN spacecraft lockup, trajectory correction maneuver performance, Entry, Descent, and Landing events, and overall trajectory

9:20 **AAS 13-235** **The MSL Entry Controller**

Paul Brugarolas, NASA / Caltech JPL; Alejandro San Martin, NASA / Caltech JPL; Edward Wong, NASA / Caltech JPL

The Mars Science Laboratory (MSL) Entry Descend and Landing (EDL) system delivered "Curiosity" at Gale crater (Mars) on August 5th, 2012. MSL EDL used an entry Guidance Navigation and Control (GN&C) system to achieve its landing target objectives. The entry guidance law guided the vehicle by modulating the lift vector through bank commands. The navigation filter integrated Descend Inertial Measurement Unit (DIMU) measurements to estimate position and attitude. The entry controller commanded the propulsive Reaction Control System (RCS) to achieve 3-axis attitude control. This paper describes the design and the as-flown performance of the entry controller.

9:40 **Break**

10:05 **AAS 13-238** **The Development of the MSL Guidance, Navigation, and Control System for Entry, Descent, and Landing**

Alejandro San Martin, NASA / Caltech JPL; Steven Lee, NASA / Caltech JPL; Edward Wong, NASA / Caltech JPL

On August 5, 2012, the Mars Science Laboratory (MSL) mission successfully delivered the Curiosity rover to its intended target. It was the most complex and ambitious landing in the history of the red planet. A key component of the landing system, the requirements for which were driven by the mission ambitious science goals, was the Guidance, Navigation, and Control (GN&C) system. This paper will describe the technical challenges of the MSL GN&C system, the resulting architecture and design needed to meet those challenges, and the development process used for its implementation and testing.

10:25 **Withdrawn**

10:45 AAS 13-419 Post-Flight EDL Entry Guidance Performance of the 2011 Mars Science Laboratory Mission

Gavin Mendeck, NASA Johnson Space Center; Lynn McGrew, NASA Johnson Space Center

The 2011 Mars Science Laboratory was the first successful Mars mission to attempt a guided entry, delivering the rover to a position approximately 2 km from its target within an ellipse of 19.1 km x 6.9 km. The Entry Terminal Point Controller guidance algorithm modulates the bank angle to control range flown. For Mars landers, it is critical to balance lift to minimize range error while ensuring safe deploy altitude. Process and improvements to generate optimized guidance settings are discussed. Dispersions driving deploy ellipse and altitude performance are identified. Performance sensitivities from range control to heading are presented.

11:05 AAS 13-420 Assessment of the Mars Science Laboratory Entry, Descent, and Landing Simulation

David Way, NASA Langley Research Center; Jody Davis, NASA Langley Research Center; Jeremy Shidner, Analytical Mechanics Associates, Inc.

On August 5, 2012, the Mars Science Laboratory (MSL) Curiosity rover successfully landed in Gale Crater on Mars. At 2000 lbs, Curiosity is the largest, most sophisticated rover ever delivered to another planet. The Program to Optimize Simulated Trajectories II (POST2) prime end-to-end Entry, Descent, and Landing (EDL) trajectory simulation tool for MSL. This paper will compare several selected models or aspects of the POST2 EDL simulation with flight data collected during Curiosity's Landing. The purpose is to evaluate the effectiveness of those models within the POST2 simulation in predicting the performance of the vehicle.

11:25 AAS 13-421 Mars Science Laboratory Entry, Descent and Landing Simulation Using DSENDS

P. Daniel Burkhart, NASA / Caltech JPL; Jordi Casoliva, NASA / Caltech JPL; Bob Balaram, NASA / Caltech JPL

Mars Science Laboratory (MSL) was the first use at Mars of a complete closed-loop Guidance Navigation and Control system that greatly reduces landing error relative to the selected Gale Crater target. The tool used for 6DOF EDL trajectory verification analysis is Dynamics Simulator for Entry, Descent and Surface landing (DSENDS) from JPL's Dynamics and Real-Time Simulation Laboratory. DSENDS inherent capability is augmented for MSL with project-specific models of atmosphere, aerodynamics, sensors and thrusters along with GN&C flight software. This paper documents the model integration and independent verification experience of the JPL EDL trajectory analysis team.

SESSION 5: SPACE-SURVEILLANCE TRACKING

Chair: Dr. David Spencer, Pennsylvania State University

13:30 AAS 13-239 Best Hypotheses Search on Iso-Energy-Grid for Initial Orbit Determination and Track Association

Jan Siminski, German Aerospace Center (DLR); Oliver Montenbruck, German Aerospace Center (DLR); Hauke Fiedler, German Aerospace Center (DLR); Martin Weigel, German Aerospace Center (DLR)

Multiple hypotheses filter methods have been developed to combine optical observation tracks in order to perform an initial orbit determination. These methods can become computationally intensive with an increasing number of initial hypotheses. This work introduces a new minimum search method to find the best fitting orbit hypotheses. The admissible region concept is used to determine an area of possible orbit solutions. This area is subdivided into smaller sections with each having at most one optimal orbit solution. Computational optimization methods are then exploited to obtain feasible orbits. The effectiveness of the presented method is assessed using simulated measurements.

13:50 AAS 13-240 A Catalogue-Wide Implementation of General Perturbations Orbit Determination Extrapolated from Special Perturbations Solutions

Matthew Hejduk, a.i. solutions

Legacy software and communications issues have generally restricted the distribution of satellite orbital information to the two-line element set format and thus imposed the accuracy limitations of SGP4. However, the use of the “extrapolation general perturbations (eGP)” methodology, in which pseudo-observations from a higher-order theory ephemeris are used to create an SGP4 mean element set, can greatly improve the SGP4 elset accuracy. The JSpOC is methodically transferring groups of satellites to this maintenance paradigm and thus improving the accuracy of the public catalogue. This paper will describe the eGP methodology and provide statements of expected accuracy improvement

14:10 AAS 13-241 Automated Uncorrelated Track Resolution with the Search And Determine Integrated Environment (SADIE)

Chris Sabol, Air Force Maui Optical and Supercomputing; Alan Segerman, Naval Research Laboratory; Aaron Hoskins, Naval Research Laboratory; Kathy Borelli, KJS Consulting; Jason Addison, Pasific Defense Solutions, LLC.; Bruce Duncan, Boeing; Kevin Roe, Boeing; Keric Hill, Pasific Defense Solutions, LLC.; Paul Schumacher, Air Force Research Laboratory; Shannon Coffey, Naval Research Laboratory

A new high performance computing software applications package called the Search and Determine Integrated Environment (SADIE) is being jointly developed and refined by the Air Force and Naval Research Laboratories to automatically resolve uncorrelated tracks and build a more complete space object catalog. SADIE is being developed to handle large catalog building challenges in all orbit regimes and includes the automatic processing of radar, fence, and optical data. Real data results are provided for the processing of low Earth radar and Air Force Space Surveillance System fence observations and for the processing of Space Surveillance Telescope optical data.

14:30 AAS 13-242 Gaussian Mixture PHD Filter for Space Object Tracking
Yang Cheng, Mississippi State University; Kyle DeMars, Air Force Research Laboratory; Carolin Früh, Air Force Research Laboratory

Sparse observations and long-term orbit propagation result in large non-Gaussian orbit uncertainty in space object tracking. Gaussian mixture filters such as Adaptive Entropy-based Gaussian-mixture Information Synthesis (AEGIS) are capable of providing an accurate Gaussian-mixture representation of the non-Gaussian orbit probability density and an effective solution to single space object tracking. In this paper, the Gaussian mixture filters are extended to multiple space object tracking: they are used to implement the Gaussian Mixture Probability Hypothesis Density (PHD) filter, which represents the intensity as a Gaussian mixture. Special issues of space object tracking are treated and a numerical example of tracking three space objects is presented.

14:50 AAS 13-245 Association of satellite observations using Bayesian inference
Christopher Binz, Naval Research Laboratory; Liam Healy, Naval Research Laboratory

Sensors to locate satellites sometimes will produce data on a satellite that cannot be associated with any known satellite, or that can be associated with multiple satellites. By using principles of probabilistic, or Bayesian, inference, we can assign numerical values of probability to the different possible associations. We present an analysis for a small number of observations and satellites, with a simplified motion and observation models and assume a sensor capable of detecting multiple satellites in all directions or staring in a fixed direction. We discuss how this technique scales up to many more satellites and observations.

15:10 Break

15:35 AAS 13-248 GEO Observability from Earth-Moon Libration Point Orbits
Nathan Parrish, University of Colorado at Boulder; Jeff Parker, University of Colorado at Boulder; Ben Bradley, University of Colorado at Boulder

The effectiveness and feasibility of performing Space-Based Space Surveillance (SBSS) from Earth-Moon libration point orbits (LPOs) about L¬1, L2, or L3 are examined. Using Satellite Tool Kit and MATLAB, observability was checked from an orbit about L3 to a target satellite in a circular Earth orbit with a range of inclinations and altitudes. It was determined that GEO is the best orbital regime to observe from an LPO. Observability and brightness were considered, finding that the entire GEO belt is visible for days on end, but at 5 magnitudes less bright than as seen from the ground.

SESSION 6: LOW-THRUST TRAJECTORY DESIGN

Chair: Dr. Hanspeter Schaub, University of Colorado

13:30 AAS 13-249 Quasi Time-Optimal Receding Horizon Control Algorithm Application to Continuous-Thrust Orbital Rendezvous

Piotr Felisiak, Wrocław University of Technology

The paper focuses on a sub-optimal strategy for the orbital rendezvous between an active chaser spacecraft with continuous-thrust propulsion and a passive target satellite. A proposal of solution is based on a Quasi Time-Optimal Receding Horizon Control (QTO-RHC) algorithm. In the survey an optimization performance measure is expressed by a compromise between the transfer time and integral of squared control signal (expenditure of fuel). The proposed method is noise resistant and able to effectively handle with various constraints. The problem includes constraints on amount of fuel, thrust magnitude and approach velocity.

13:50 AAS 13-256 Satellite Power Subsystem Requirements for Time-Constrained Electric Orbit-Raising with Minimal Radiation Impact

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

In this paper, we consider the problem of electric orbit-raising of telecommunication satellites. In order to minimize the impact of radiation during the orbit-raising maneuver, we formulate an optimization problem that minimizes radiation fluence along the trajectory, subject to an upper bound on the transfer time. We use a direct optimization approach to solve the problem for a variety of mission scenarios. For different choice of electric thrusters and injection orbits, we determine the satellite power subsystem requirements for orbit-raising and the Beginning-of-Life power of the satellite delivered to the Geostationary orbit.

14:10 AAS 13-250 A Study of the Hohmann Spiral Transfer with Low-Thrust Inclination Change

Steven Owens, University of Strathclyde; Malcolm Macdonald, University of Strathclyde

This paper presents an analysis of the Hohmann Spiral Transfer (HST), an orbit transfer method previously developed by the author incorporating both high and low-thrust propulsion systems, when the low-thrust system is also used to perform an inclination change. Critical specific impulse ratios are derived which dictate the point where the HST offers a fuel mass saving compared to a conventional high-thrust transfer. It is shown that under certain transfer requirements the HST can offer substantial fuel mass savings which could be used to extend the life of the platform or offer additional payload space.

14:30 AAS 13-251 Approximation of Constraint Low-Thrust Space Trajectories in Three Body Dynamic Models using Fourier Series

Ehsan Taheri, Michigan Technological University; Ossama Abdelkhalik, Michigan Technological University

Finite Fourier series has been implemented successfully in approximating two-dimensional continuous-thrust trajectories in two-body dynamic models. In this paper, the Finite Fourier series is implemented for rapid low-thrust trajectory approximation, in the presence of thrust acceleration constraints, in the three body dynamic model. This approximation enables the rapid feasibility assessment of low-thrust trajectories, especially in the presence of thrust level constraint. The resulting approximated trajectory can be used as initial guess in optimization techniques.

14:50 Withdrawn

15:10 Break

15:35 AAS 13-257 Multi-objective Optimisation of Many-revolution, Low-thrust Orbit Raising for Destiny Mission

Federico Zuiani, University of Glasgow / ISAS

This work will present a Multi-Objective approach to the design of the initial, Low-Thrust orbit raising phase for JAXA's proposed technology demonstrator mission DESTINY. The proposed approach includes a simplified model for Low Thrust, many-revolution transfers, based on an analytical orbital averaging technique and a simplified control parameterisation. This is combined with a stochastic optimisation algorithm which will solve optimisation problems in which conflicting performance figures of DESTINY's trajectory design are concurrently optimised.

15:55 AAS 13-255 A Low Energy, Low Thrust Unified Solver for Rapid Mission Design

Nitin Arora, Georgia Institute of Technology / NASA / Caltech JPL; Nathan Strange, NASA / Caltech JPL

Recent studies of a manned cislunar way point base at the moon are driving the need to rapidly compute low-Energy, low thurst (le-lt) trajectories to Earth-Moon L1/L2 Lagrange points. Existing methods are hard to setup and suffer from large compute times. We propose LOTUS a robust, near-optimal solver, capable of rapidly computing le-lt trajectories. LOTUS takes advantage of a low thrust feedback control law (Q-Law) along with a novel le-lt patch point strategy via a backward propagation algorithm. LOTUS is applied to a solar electric propulsion based, earth-moon L2 transfer problem.

16:15 AAS 13-472 Low-Thrust Egalitarian Peer-to-Peer Maneuvers for Servicing Satellites in Circular Constellations

Atri Dutta, Princeton University

The problem of determining optimal low-thrust Egalitarian Peer-to-Peer maneuvers for servicing a system of satellites is challenging because numerous low-thrust rendezvous problems need to be solved in order to set up a discrete global optimization problem that is itself computationally complex (NP-hard). In this paper, we present a formulation to determine the E-P2P maneuvers for servicing circular satellite constellations in minimum time. We present numerical solutions for varying number of satellites in the constellation, outline the advantages of E-P2P maneuvers over the baseline strategy and also discuss the computational aspects of the problem.

16:35 AAS 13-473 Minimum-Fuel Low-Thrust Rendezvous Trajectories via Swarming Algorithm

Mauro Pontani, University of Rome "La Sapienza"; Bruce Conway, University of Illinois at Urbana-Champaign

The particle swarm optimization (PSO) technique represents a very intuitive heuristic methodology for global optimization. In this research PSO is applied to determining minimum-fuel low-thrust orbit rendezvous. Hamiltonian methods are employed to translate the related optimal control problem into a parameter optimization problem, in which the parameter set is composed of the initial values of the costates. A switching function is defined, and determines the optimal sequence and durations of thrust and coast arcs. Despite its simplicity, the PSO proves to be effective, reliable, and numerically accurate in solving several qualitatively different test cases considered in this work.

16:55 AAS 13-258 Robust optimal control of low-thrust interplanetary transfers

Pierluigi di Lizia, Politecnico di Milano; Roberto Armellin, Politecnico di Milano; Franco Bernelli-Zazzera, Politecnico di Milano;

Continuous-thrust orbit transfers are designed by solving an optimal control problem (OCP) that minimizes fuel consumption while satisfying mission constraints. The optimal control problem is usually solved in nominal conditions: at the design stage, the dynamics modeling is supposed to exactly represent the reality. An algorithm to include uncertain parameters and boundary conditions is presented. This is based on the high-order expansion of the solution of the two-point boundary value problem associated to the OCP with respect to uncertainties. Interplanetary transfers to asteroids are presented as test cases.

SESSION 7: ORBITAL DYNAMICS NEAR SMALL-BODY

Chair: Dr. Steve Broschart, Jet Propulsion Laboratory

13:30 AAS 13-259 Comet Thermal Model for Navigation

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

We implement a numerical model to analyze the thermodynamics that can be used for navigation and orbit determination of future space missions to small bodies. Unlike past models that use a spherical homogeneous model, our model includes the real non-spherical shape of asteroid 433 Eros as an example. The surface temperature map is expressed as a function of latitude and longitude directions for different initial isothermal temperatures. The lack of spherical symmetry is modeled including the long and short term temperature variations as a consequence of the orbital and spin axis rotations of the body.

13:50 AAS 13-261 Multiple Sliding Surface Guidance Applied at Binary Asteroid Systems

Julie Bellerose, Carnegie Mellon University SV / NASA ARC; Roberto Furfaro, The University of Arizona; Dario Cersosimo, University of Missouri

Proximity operations at binary asteroid systems involve higher degrees of complexity due to added perturbations. In this paper, we adapt a Multiple Sliding Surface Guidance (MSSG) algorithm developed for close proximity operations at a single asteroid, and extend its applicability to binary asteroid systems. The advantage of using MSSG is that no trajectory is needed to be computed offline as the commands use the spacecraft accelerations directly. We show simulations of a two-sphere and sphere-ellipsoid binary systems. The velocity cost and associated transfer times show to be minimal.

14:10 AAS 13-262 ZEM/ZEV Guidance Approach for Asteroid Touch-and-go Sample Collection Maneuvers

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

The Osiris mission to 1999 RQ36 requires the spacecraft to touch down to the asteroid's surface to collect samples. Importantly, the final descent to the asteroid's surface must be unpowered in order to avoid sample contamination. Our proposal uses ZEM / ZEV guidance with selected waypoints to reach a point 30m above the desired landing site. The constraints imposed by the optical navigation system result in a small velocity error at the initiation of the coasting phase, which results in unacceptable landing accuracy. Nevertheless, we show that mission requirements can be met by hovering at the final waypoint.

14:30 AAS 13-264 Estimation of Asteroid Model Parameters using Particle Filters
Brian Gaudet, University of Arizona; Roberto Furfaro, The University of Arizona

Planning of open-loop maneuvers in an asteroid's dynamic environment requires the ability to estimate the forces acting on the spacecraft as a function of position and time. These forces can be estimated using a mathematical model of the asteroid provided that the model parameters may be accurately inferred. In this paper we demonstrate how a particle filter can accurately estimate these model parameters using the spacecraft's average commanded thrust whilst hovering at two locations in close proximity to the asteroid. The accuracy of the particle filter is then compared to that of two state of the art

14:50 AAS 13-265 Generalized Density Distribution Estimation for Small Bodies
Yu Takahashi, University of Colorado at Boulder; Daniel Scheeres, University of Colorado

In order to support the close proximity operations around small bodies, it is necessary to develop an accurate gravity field valid to the surface, which is a function of the density distribution and shape of the body. The measured gravity field can be used to constrain the internal density distribution, but its solution is generally not unique. We propose a generalized density estimation approach that dissects the body into a number of blocks and estimates the density in each block. The results show that we can retrieve accurate and consistent density distribution by altering the resolution of the block segmentation.

15:10 Break

15:35 AAS 13-335 Characteristics of Quasi-terminator Orbits near Primitive Bodies
Stephen Broschart, NASA / Caltech JPL; Gregory Lantoine, NASA / Caltech JPL; Daniel Grebow, NASA / Caltech JPL

"Quasi-terminator" orbits are quasi-periodic trajectories that exist in the vicinity of the well-known terminator orbit solutions to the solar pressure perturbed Hill dynamics around a primitive body. These trajectories follow three-dimensional tori that arise from the four stable eigenvalues associated with the stable branch of the periodic terminator orbits. The stable quasi-terminator orbits can often provide good viewing geometry of the sunlit side of a primitive body without any maneuvers being required. These characteristics make this type of orbit a good candidate for the global characterization phase of a primitive body mission.

15:55 AAS 13-492 Automated Design of Propellant-Optimal, End-to-End, Low-Thrust Trajectories for Trojan Asteroid Tours
Jeffrey Stuart, Purdue University; Kathleen Howell, Purdue University; Roby Wilson, NASA / Caltech JPL

The Sun-Jupiter Trojan asteroids are celestial bodies of great scientific interest as well as potential resources offering water and other mineral resources for long-term human exploration of the solar system. Previous studies have addressed the automated design of tours within the asteroid swarm. This investigation expands the current automation scheme by incorporating options for a complete trajectory design approach to the Trojan asteroids. Computational aspects of the design procedure are automated such that end-to-end trajectories are generated with a minimum of human interaction after key elements and constraints associated with a proposed mission concept are specified.

16:15 AAS 13-497 A Trajectory Optimization Strategy for a Multiple Rendezvous Mission with Trojan Asteroids

Lucas Bremond, The University of Tokyo / JAXA; Ryu Funase, Japan Aerospace Exploration Agency; Jun'ichiro Kawaguchi, Japan Aerospace Exploration Agency

The objective of this research is to study the extended mission trajectory of a spacecraft in the vicinity of L4 Trojan Asteroids. We consider a spacecraft that has already achieved a rendezvous with a Trojan Asteroid, and we would like to know which asteroids the spacecraft should visit next, considering the given mission constraints. This article will outline the used methodology and provide associated results.

16:35 AAS 13-484 Passive sorting of asteroid material using Solar Radiation Pressure

Daniel Garcia Yarnoz, Advanced Space Concepts Laboratory, University of Strathclyde; Joan Pau Sanchez Cuartielles, Advanced Space Concepts Laboratory, University of Strathclyde; Colin McInnes, Advanced Space Concepts Laboratory, University of Strathclyde

Understanding dust dynamics in asteroid environments is key for future science missions to asteroids and, in the long-term, for asteroid exploitation. This paper proposes a novel way of manipulating asteroid material by means of solar radiation pressure (SRP). We envisage a method for passively sorting material as a function of its grain size where SRP is used as a passive in-situ ‘mass spectrometer’. The analysis shows that the distance between re-impact points for different particle sizes allows an effective sorting of regolith material. This has immediate applications for sample return, and in-situ resource utilisation to separate

SESSION 8: SPECIAL SESSION: GRAVITY RECOVERY AND INTERIOR LABORATORY (GRAIL)

Chair: Tomas Martin-Mur, Jet Propulsion Laboratory

13:30 AAS 13-268 Execution-Error Modeling and Analysis of the GRAIL Spacecraft Pair
Troy Goodson, NASA / Caltech JPL

The GRAIL-A and GRAIL-B spacecraft completed their primary mission in June and extended mission in December 2012. The excellent performance of the propulsion and attitude control subsystems contributed significantly to the mission's success. In order to better understand this performance, the Navigation Team has analyzed and refined the execution-error models for these subsystems. This paper documents the evolution of the execution-error models employed for maneuvers, along with the analysis, procedures, and software associated with the model development.

13:50 AAS 13-269 Orbit Determination for the GRAIL Science Phase and Extended Mission
Mark Ryne, NASA / Caltech JPL; Peter Antreasian, NASA / Caltech JPL; Stephen Broschart, NASA / Caltech JPL; Kevin Criddle, NASA / Caltech JPL; Eric Gustafson, NASA / Caltech JPL; David Jefferson, NASA / Caltech JPL; Eunice Lau, NASA / Caltech JPL; Tung-Han You, NASA / Caltech JPL; Hui Ying Wen, NASA / Caltech JPL

The Gravity Recovery and Interior Laboratory Mission (GRAIL) is the 11th mission of the NASA Discovery Program. Its objective is to help answer fundamental questions about the Moon's internal structure, thermal evolution, and collisional history. GRAIL employs twin spacecraft, which fly in formation in low altitude polar orbits around the Moon. An improved global lunar gravity field is derived from high-precision range-rate measurements of the distance change between the two spacecraft. The purpose of this paper is to describe the strategies used by the GRAIL Orbit Determination Team to overcome challenges posed during spacecraft operations.

14:10 AAS 13-270 The Role Of GRAIL Orbit Determination In Preprocessing Of Gravity Science Measurements
Gerhard Kruizinga, NASA / Caltech JPL; Sami Asmar, NASA / Caltech JPL; Eugene Fahnestock, NASA / Caltech JPL; Nate Harvey, NASA / Caltech JPL; Daniel Kahan, NASA / Caltech JPL; Alex Konopliv, NASA / Caltech JPL; Kamal Oudrhiri, NASA / Caltech JPL; Meegyeong Paik, NASA / Caltech JPL; Ryan Park, NASA / Caltech JPL; Dmitry Strekalov, NASA / Caltech JPL; Michael Watkins, NASA / Caltech JPL; Dah-Ning Yuan, NASA / Caltech JPL

The Gravity Recovery And Interior Laboratory (GRAIL) mission has construct-ed a lunar gravity field with unprecedented uniform accuracy on the farside and nearside of the Moon. Lunar gravity field determination begins with prepro-cessing, applying corrections for time tag error, general relativity, coordinate reference frame, measurement noise and biases.

Orbit determination plays a piv-otal role in preprocessing, because preprocessed gravity science data quality de-pends directly on ephemeris accuracy. This paper describes the role of orbit de-termination in GRAIL preprocessing and the iterative process that has led to the latest GRAIL lunar gravity fields.

14:30 AAS 13-271 GRAIL Science Data System Orbit Determination: Approach, Strategy, and Performance

Eugene Fahnestock, NASA / Caltech JPL; Sami Asmar, NASA / Caltech JPL; Nate Harvey, NASA / Caltech JPL; Daniel Kahan, NASA / Caltech JPL; Alex Konopliv, NASA / Caltech JPL; Gerhard Kruizinga, NASA / Caltech JPL; Kamal Oudrhiri, NASA / Caltech JPL; Meegyeong Paik, NASA / Caltech JPL; Ryan Park, NASA / Caltech JPL; Dmitry Strekalov, NASA / Caltech JPL; Dah-Ning Yuan, NASA / Caltech JPL

This paper details orbit determination techniques and strategies employed within each stage of the larger iterative process (ref. Kruizinga et al., this meeting) of preprocessing raw GRAIL data into the gravity science measurements used within gravity field solutions. Each orbit determination pass used different data, corrections to it, and estimation parameters. We compare performance metrics among these passes, plus independent navigation team solutions. For the primary mission, the magnitude of residuals using our orbits progressed from ~20 to ~0.3 micron/s for inter-satellite range rate data and from ~0.7 to ~0.1 mm/s for Doppler data.

14:50 AAS 13-272 High-Resolution Lunar Gravity from the Gravity Recovery And Interior Laboratory Mission

Ryan Park, NASA / Caltech JPL; Alex Konopliv, NASA / Caltech JPL; Dah-Ning Yuan, NASA / Caltech JPL; Sami Asmar, NASA / Caltech JPL; Eugene Fahnestock, NASA / Caltech JPL; Gerhard Kruizinga, NASA / Caltech JPL; Meegyeong Paik, NASA / Caltech JPL; Michael Watkins, NASA / Caltech JPL; David Smith, NASA; Maria Zuber, Massachusetts Institute of Technology

This paper presents detailed models used to process the measurements from the Gravity Recovery And Interior Laboratory (GRAIL) mission. The inter-satellite and ground-based Doppler measurements during the three-month prime science phase were processed and a 420th degree and order lunar gravity field was computed. The errors in the non-gravitational forces were modeled to about \$10^{-12}\$ km/\$s^{2}\$ and the reconstruction accuracies were 0.05 micron/s for the inter-satellite data and 0.1 mm/s for the ground-based Doppler data.

15:10 Break

15:35 AAS 13-273 The Modeling and Precise Orbit Determination in Support of Gravity Model Development for the GRAIL Mission

Frank Lemoine, NASA Goddard Space Flight Center; Sander Goossens, CRESST / UMBC; Terence Sabaka, NASA Goddard Space Flight Center; Joseph Nicholas, Emergent Space Technologies; David Rowlands, NASA Goddard Space Flight Center; Erwan Mazarico, Massachusetts Institute of Technology / EAPS; Bryant Loomis, SGT Inc.; Douglas Chinn, SGT Inc.; Douglas Caprette, SGT Inc.; Gregory Neumann, NASA Goddard Space Flight Center; David Smith, NASA; Maria Zuber, Massachusetts Institute of Technology

The analysis of the Gravity Recover and Interior Laboratory (GRAIL) intersatellite Ka-band tracking data has allowed the derivation of new improved models of the lunar gravity field up to 420x420 in spherical harmonics. We discuss the measurement and force modeling applied to the analysis of the GRAIL data from the primary mission (March 1 to May 29, 2012), and the strategies chosen to develop the high degree solutions using the NASA GSFC Geodetic Parameter Estimation and Orbit Determination Program (GEODYN). We summarize the quality of the gravity models developed and their impact on GRAIL precision orbit determination (POD).

15:55 AAS 13-274 Improved Precision Orbit Determination of Lunar Orbiters from the GRAIL-derived Lunar Gravity Models

Erwan Mazarico, Massachusetts Institute of Technology / EAPS; Frank Lemoine, NASA Goddard Space Flight Center; Sander Goossens, CRESST / UMBC; David Rowlands, NASA Goddard Space Flight Center; Gregory Neumann, NASA Goddard Space Flight Center; Mark Torrence, Stinger Ghaffarian Technologies; David Smith, NASA; Maria Zuber, Massachusetts Institute of Technology

High-resolution global gravity field models of the Moon were obtained from precise Ka-band range-rate measurements between the twin Gravity Recovery and Interior Laboratory (GRAIL) spacecraft. We assess the geodetic improvements (tracking data fit, orbit reconstruction quality) for independent lunar orbiters, with the latest degree and order 420 spherical harmonics gravity field model developed at NASA GSFC. We focus in particular on Lunar Prospector, the Japanese SELENE spacecraft, and the Lunar Reconnaissance Orbiter (LRO). In the case of LRO, we use altimetric data from the Lunar Orbiter Laser Altimeter to provide independent estimates of the position accuracy.

SESSION 9: ORBIT DETERMINATION AND ESTIMATION THEORY -- II

Chair: Dr. Stefano Casotto, Università degli Studi di Padova

8:00 AAS 13-231 Mars Science Laboratory Orbit Determination Data Pre-Processing
Eric Gustafson, NASA / Caltech JPL; Gerhard Kruizinga, NASA / Caltech JPL; Tomas Martin-Mur, NASA / Caltech JPL

The Mars Science Laboratory (MSL) was spin-stabilized during its cruise to Mars. We discuss the effects of spin on the radiometric data and how the orbit determination team dealt with them. Additionally, we will discuss the unplanned benefits of detailed spin modeling including attitude estimation and spacecraft clock correlation.

8:20 AAS 13-233 Filter Strategies for Mars Science Laboratory Orbit Determination
Paul Thompson, NASA / Caltech JPL; Eric Gustafson, NASA / Caltech JPL; Gerhard Kruizinga, NASA / Caltech JPL; Tomas Martin-Mur, NASA / Caltech JPL

The Mars Science Laboratory (MSL) spacecraft had ambitious navigation delivery accuracy requirements for landing inside Gale Crater. Confidence in the orbit determination (OD) solutions was increased by investigating numerous filter strategies for solving the orbit determination problem. We will discuss the types of variations used: for example, data types, data weights, solar pressure model covariance, and estimating versus considering model parameters. This process generated a set of plausible OD solutions that were compared to the baseline OD strategy. Even implausible or unrealistic results were helpful in isolating sensitivities in the OD solutions to certain model parameters or data types.

8:40 AAS 13-276 Measurement uncertainty in satellite direction finding with an interferometer
Liam Healy, Naval Research Laboratory; Christopher Binz, Naval Research Laboratory

Interferometry produces measurements with inherent ambiguity in the form of a multimodal probability distribution function. Typically, this ambiguity is resolved by superimposing the results of multiple interferometer pairs, as in the Air Force Space Surveillance Fence. This complexity in hardware could conceivably be transferred to the processing step, if ambiguity resolution can be done algorithmically with a single interferometer pair. This work investigates the possibility of modeling the error of a single interferometer pair using a mixture of Gaussian distributions. Results are presented for interferometric estimation using the Kalman filter with linear system dynamics.

9:00 AAS 13-277 Range-only IOD
James Wright, Analytical Graphics, Inc.

This new two-body IOD algorithm uses only range measurements on a uniform time grid. Range-rate estimates are derived from range: A Lagrange interpolator is used to calculate range estimates on a non-uniform Chebyshev grid. Chebyshev series coefficients are derived and improved with an iterative search. Range-rate estimates are calculated with the Chebyshev interpolator. A linear least squares 3D search is performed to find 6D orbit estimates using minimum range residual RMS, closed form f and g expressions, a and e gates, and range and range-rate estimates on non-uniform Chebyshev time grid.

9:20 AAS 13-278 Navigation of NASA's Van Allen Probes Mission

Gene Heyler, The Johns Hopkins University Applied Physics Laboratory; Fazle Siddique, The Johns Hopkins University Applied Physics Laboratory

The Van Allen Probes Mission, part of NASA's Living With a Star Program, successfully launched on August 30th, 2012 from the Cape Canaveral Atlas-V Space Launch Complex 41. The two-year mission was designed, built, and operated by the Johns Hopkins University Applied Physics Laboratory to study ions, electrons, and the local magnetic and electric fields of Earth's radiation belts. The two spacecraft were placed in orbits that cause one spacecraft to lap the other approximately four times per year. This paper describes the ground assets, navigation data, OD software, the expected and actual early OD performance.

9:40 Break

10:05 AAS 13-279 Atmospheric Density Reconstruction Using Satellite Orbit Tomography

Michael Shoemaker, Los Alamos National Laboratory; Brendt Wohlberg, Los Alamos National Laboratory; Josef Koller, Los Alamos National Laboratory

Improved atmospheric density models are required to better predict LEO satellite orbits. Several estimation schemes have recently been studied to correct density models using satellite measurements. This research uses a new approach based on tomography, where the measurements come from satellite orbital elements separated over time. The advantage of a tomography-based approach is that measurements on the system boundaries are used to infer the state inside the system. We present simulation results where many satellites are tracked periodically and the resulting orbit states are used to reconstruct a more accurate density model.

10:25 AAS 13-280 Orbit Prediction Accuracy Using Vasicek, Gauss-Markov, and Random Walk Stochastic Models

Thomas Johnson, Analytical Graphics, Inc.

Accurate predicted orbits are a key concern for space situational awareness and catalog maintenance. A key element of this is estimation of the ballistic and solar radiation pressure coefficients when their behavior is dynamic and usually unknown. This paper analyzes the use of the Vasicek, Gauss-Markov, and random walk stochastic models for these coefficients and how they respond to signatures in these coefficients. The effect on the predicted orbit accuracy is compared to simulated truth under ideal tracking conditions and typical catalog maintenance tracking schedules. Guidelines for applying these models to operational orbit determination problems are then proposed.

10:45 Withdrawn

11:05 AAS 13-283 Applications of Unscented and Quadrature Consider Filters using a Modified Joseph Formulation

Kyle DeMars, Air Force Research Laboratory; Renato Zanetti, Draper Laboratory

Consider filters provide an approach for accounting for the effects of uncertain parameters within the measurement function when performing state updates. The consider parameters are the parameters which yield statistically important effects in updating the state of a system, but for which improved estimates are not required, e.g. sensor biases. This paper develops a general covariance update equation via a Joseph formulation that is valid when considering nonlinear measurements and studies the properties of the developed method. Simulation studies for both linear and nonlinear measurements are considered and compared for both unscented and quadrature formulations of the filtering step.

11:25 AAS 13-284 Drag Coefficient Modeling for GRACE using Direct Simulation Monte Carlo

Piyush Mehta, University of Kansas; Craig McLaughlin, University of Kansas

The drag coefficient of a satellite in LEO is a strong function of energy-accommodation, gas-surface interaction, attitude, satellite geometry, spacecraft relative velocity, atmospheric composition, atmospheric temperature, and spacecraft surface properties. The Direct Simulation Monte Carlo (DSMC) code, DS3V, is used to develop a drag coefficient model for GRACE. The code is validated with the analytical solution for the drag coefficient of a sphere and cylinder and drag coefficients derived for GRACE using a flat plate model. The energy-accommodation model assumes Maxwellian (diffuse) gas-surface interactions.

SESSION 10: ATTITUDE DETERMINATION, DYNAMICS, AND CONTROL -- II

Chair: Dr. Robert Melton, Pennsylvania State University

8:00 Withdrawn

8:20 AAS 13-287 A Generic Optimal Tracking Feedback Gain Solution for Various Attitude Error Parameterizations.

Ahmad Bani Younes, Texas A&M University; James D. Turner, Texas A&M University

An optimal nonlinear feedback control is developed where the feedback control is calculated by optimizing a universal quadratic penalty. Several attitude error representations are presented for describing the tracking orientation error kinematics. Transformation equations are presented that enable the development of nonlinear kinematic models that are valid for arbitrarily large relative rotations and rotation rates. By utilizing several attitude error kinematics, we introduce a universal quadratic penalties of tracking errors that is consistent in each of the coordinate choices.We utilize this universal attitude error measure expressed through approximate transformations as a positive function of each of the coordinate choice.

8:40 AAS 13-290 Free-Molecular Flow Induced Attitude Changes of Spinning Satellites in Elliptical Orbits

Jozef van der Ha, Consultant

The model presented is of interest to spinning satellites and rocket bodies in elliptical orbits with perigees below about 600 km. The change in the spin angular momentum vector is obtained by integrating an asymptotic series expansion of the torque vector over the perigee region. Simulations have been performed to understand the dependence of the resulting attitude changes on perigee altitude, semi-major axis, orientation of the spin axis to the orbit velocity at perigee, density and scale height variations, satellite geometrical configuration and free-molecular accommodation coefficients.

9:00 AAS 13-291 Using TableSat IC for the Analysis of Attitude Control and Flexible Boom Dynamics for NASA Magnetospheric MultiScale (MMS) Mission Spacecraft

Joshua Chabot, University of New Hampshire; Joseph Kelley, University of New Hampshire; Michael Johnson, University of New Hampshire; May-Win Thein, University of New Hampshire

The NASA Magnetospheric MultiScale (MMS) Mission consists of four spin-stabilized spacecraft (s/c) flying in precise formation. The UNH MMS TableSat IC, a limited 3-DOF rotation (full spin, limited nutation) table top prototype of the MMS s/c, is constructed to analyze the MMS s/c dynamics. A quaternion-based PID controller is implemented on

TableSat IC to observe the effects of spin rate and nutation control on the experimental s/c bus as well as the scaled booms. The experimental results of the s/c bus are expected to match those of predicted analytical results.

9:20 AAS 13-292 Three-axis Attitude Control using Redundant Reaction Wheels with Continuous Momentum Dumping

Erik Hogan, University of Colorado at Boulder; Hanspeter Schaub, University of Colorado

In this paper, a description of an attitude control system for a 3-axis stabilized spacecraft is presented. Using modified Rodgrigues parameters, a globally stabilizing nonlinear feedback control law that incorporates integral feedback is derived that enables tracking of an arbitrary, time-varying reference attitude. This new control avoids any quadratic rate feedback components. A cluster of four reaction wheels (RWs) is used to control the spacecraft, and three magnetic torque rods are used for purposes of continuous autonomous momentum dumping. The momentum dumping strategy can employ general torque rod orientations, and is developed for the case of 4 RWs.

9:40 Break

10:05 AAS 13-293 Internal Moving Mass Spherical Pendulum Concept for Re-entry Vehicle Attitude and Trajectory Control

Brad Atkins, Virginia Polytechnic Institute and State University; Troy Henderson, Virginia Polytechnic Institute and State University

We present a general formulation with respect to the instantaneous center of mass for a re-entry vehicle with n internal masses for attitude control. The masses are permitted to have inertia and both translate and rotate with respect to the base vehicle coordinate frame. An 8 DOF nonlinear simulation of a spherical pendulum configuration is provided using the formulation for a preliminary demonstration of the system to control the attitude and shape the vehicle trajectory of a re-entry vehicle. The full paper will include a LQR based autopilot algorithm for attitude stabilization and trajectory tracking.

10:25 AAS 13-295 Chattering Attenuation Sliding Mode Control of a Satellite's Attitude

Hamidreza Nemati, Kyushu University; Shinji Hokamoto, Kyushu University

This paper develops a new robust nonlinear control algorithm based on the theory of sliding mode to control the attitude of a satellite. The system comprises a satellite with three pairs of thrusters on the satellite's principal axes. Since the conventional sliding mode controller includes a discontinuous function, a significant problem called chattering is occurred. The main purpose of this paper is to design a new switching function in order to alleviate this drawback. Moreover, for increasing the robustness of it, a new slope-varying hyperbolic function is utilized. Simulation results highlight the effectiveness of the proposed control.

SESSION 11: TRAJECTORY OPTIMIZATION -- II

Chair: Dr. T.S. Kelso, Center for Space Standards and Innovation

8:00 AAS 13-296 Simplified Estimation of Trajectory Influence in Preliminary Staging Studies
Eric Bourgeois, CNES

Staging is a fundamental step for any launcher pre-design process. The total increment of speed to deliver is a key factor of these studies ; it depends mainly on the characteristics of the orbit to reach, and also on losses induced by gravity and atmosphere. The estimation of these losses generally require to perform a trajectory optimization, whom convergence is not always granted ; the goal of this paper is to present a quick and robust methodology allowing to estimate losses, with a reasonable accuracy. Description, design and test of this methodology are presented.

8:20 AAS 13-305 Indirect Optimization of Low-Thrust Earth Escape Trajectories
Hao Huang, Beihang University

Indirect optimization is used to compute fuel-optimal earth escape trajectory. Shooting backward in time converts the unknowns from initial Lagrange multipliers to orbit states at the final time. Combined with the idea of homotopy method and curve fits technology, starting from solving two-dimensional short-time fuel-optimal escape trajectory without control constraint, finally solved the three-dimensional long-time fuel-optimal escape trajectory with control constraint. This method is validated to be a high-accuracy, good-convergence and efficient algorithm for low thrust escape trajectory optimization.

8:40 AAS 13-298 Developing a tool for the Trajectory Planning of Cubesat missions
Alexander Ghosh, University of Illinois at Urbana-Champaign; Victoria Coverstone, University of Illinois at Urbana-Champaign

Developing a modern low thrust trajectory planning tool for applications to picosatellites poses a number of unique challenges. This work discusses the development of a propellant-minimum trajectory planning tool, which combines a high order integrator, algebraic differentiation techniques, adaptive step size control, a non-linear programming problem solver, and analysis of cumulative density functions of the control profile to generate a robust, extendable solution framework. Discussions of the lessons learned in merging these techniques, as well as a few demonstrated case studies will be included.

9:00 AAS 13-299 Automatic Algorithm for Accurate Numerical Gradient Calculation in General and Complex Spacecraft Trajectories
Ricardo Restrepo, The University of Texas at Austin; Cesar Ocampo, The University of Texas at Austin

An automatic algorithm for accurate numerical gradient calculations has been developed.

The algorithm is based on finite differences. The novelty of the method is an automated tuning of the step size perturbation required for the method. This automation guaranties the best possible solution using this approach without the requirement of user inputs. The algorithm treats the functions as a black box, which makes it extremely useful when general and complex problems are considered. This is the case of spacecraft trajectory design problems and complex optimization systems. An efficient procedure for the automatic implementation is presented.

9:20 AAS 13-300 SOURCE: A Matlab-Orientated Tool for Interplanetary Trajectory Global Optimization. Fundamentals (Part I)

Arnaud Boutonnet, ESA / ESOC; Waldemar Martens, ESA / ESOC; Johannes Schoenmaekers, ESA / ESOC

This is the first part of the presentation of SOURCE, a new MATLAB-based interplanetary global optimization tool with very short execution times. The fundamentals of the algorithm are presented: first the matrices generation, which is based on the evaluation and storage of porkchops representing the solution of Lambert problems. Special attention is given singularities (pi-transfer, full resonances) and limitations (transfer with not enough transfer time, DeltaV-GA). Then a series of filters based on matrices manipulations are presented. Finally the last step based on a pseudo dynamic programming technique is detailed

9:40 Break

10:05 AAS 13-301 SOURCE: A Matlab-orientated Tool for Interplanetary Trajectory Global Optimization, Applications (Part II)

Waldemar Martens, ESA / ESOC; Arnaud Boutonnet, ESA / ESOC; Johannes Schoenmaekers, ESA / ESOC

This is the second part of the presentation of SOURCE, a new MATLAB-oriented interplanetary global optimization tool with very short execution times. In the first half of the paper a quasi-local optimization algorithm is discussed. It is based on the same branch and pruning algorithm as the global optimization stage. In the second half the results of the application of the tool to two ESA missions are presented: JUICE and Solar Orbiter. The objective here is to validate whether the new tool can reproduce known trajectories for these missions, possibly find new options, while reducing the execution time.

10:25 AAS 13-303 Extremal Control and Guidance Solutions for Orbital Transfer with Intermediate Thrust

Dilmurat Azimov, University of Hawaii at Manoa

The variational problem of an extremal transfer of a spacecraft between elliptical orbits via one or more intermediate-thrust arcs with constant specific impulse in a central Newtonian field is considered. New analytical solutions for the transfers between two coplanar elliptical orbits via the Lawden's one and two intermediate thrust (IT) arcs are obtained. The results have been compared to the transfers with impulsive thrusts. The analytical solutions for the transfer problems obtained in this paper are utilized in the derivation of the guidance laws for motion with IT arc.

10:45 AAS 13-304 Sequential Convex Programming For Impulsive Transfer Optimization In Multibody Systems

Eric Trumbauer, University of California, Irvine; Benjamin Villac, University of California, Irvine

This paper describes the development of a rapid local optimizer for minimum fuel impulsive transfers in multibody and higher order gravity systems. This iterative process involves solving approximate convex problems and using differential correction to restore continuity. State transition matrices of arcs in the nonlinear system are used to derive the linear equality constraints and cost function of the convex approximation. Dynamic trust regions and other constraints are also shown to be convex. The exact solution of the resulting subproblem is found using existing convex solvers. Performance is compared to existing methods and is seen to be fast and robust.

11:05 AAS 13-297 Orbit Clustering Based on Transfer Cost

Eric Gustafson, NASA / Caltech JPL; Juan Arrieta, NASA / Caltech JPL; Anastassios Petropoulos, NASA / Caltech JPL

We propose using cluster analysis to perform quick screening for combinatorial global optimization problems. The key missing component currently preventing cluster analysis from use in this context is the lack of a useable metric function that defines the cost to transfer between two orbits. We study several proposed metrics and clustering algorithms, including k-means and the expectation maximization algorithm. We also show that proven heuristic methods such as the Q-law can be modified to work with cluster analysis.

SESSION 12: SPECIAL SESSION: MARS SCIENCE LABORATORY (MSL) -- II

Chair: Dr. Gerhard Kruizinga, Jet Propulsion Laboratory

8:00 AAS 13-422 Entry System Design and Performance Summary for the Mars Science Laboratory Mission

Allen Chen, NASA / Caltech JPL

While the Sky Crane portion of Mars Science Laboratory's Entry, Descent, and Landing system draws well-deserved attention as the iconic image of the landing, the entry segment is at least an equally harrowing part of the journey where a multitude of opportunities for failure exist. Over 99% of the spacecraft's kinetic energy is dissipated during entry; all before the use of the supersonic parachute or the descent engines. This paper provides an overview of the entry segment design and summarizes Curiosity's as flown entry performance on the night of August 5th.

8:20 AAS 13-307 Mars Science Laboratory Entry, Descent, and Landing Trajectory and Atmosphere Reconstruction

Chris Karlgaard, Analytical Mechanics Associates, Inc.; Mark Schoenenberger, NASA Langley Research Center; Prasad Kutty, NASA Langley Research Center; Jeremy Shidner, Analytical Mechanics Associates, Inc.

On August 5th 2012, The Mars Science Laboratory (MSL) entry vehicle successfully entered Mars' atmosphere and landed the Curiosity rover on its surface. Onboard instrumentation was used to reconstruct the entry trajectory and measure information about the atmosphere encountered. The instrumentation includes IMU accelerations and angular rates; surface pressure measurements from the Mars Entry Atmospheric Data System experiment; radar altimeter data; and the vehicle aerodynamic database. These data sources are blended using a Kalman filter. This paper provides an overview of the approach and the details of the results of the reconstruction.

8:40 AAS 13-308 Inertial Navigation Entry, Descent, and Landing Reconstruction using Monte Carlo Techniques

Rafael Lugo, North Carolina State University

A new method for performing entry, descent, and landing trajectory reconstruction is presented as an extension of the standard inertial navigation approach. The method, Inertial Navigation Statistical Trajectory and Atmosphere Reconstruction (INSTAR), provides statistical uncertainties for the reconstructed trajectory parameters by incorporating Monte Carlo dispersion techniques. It also permits the inclusion of redundant data sources using them to refine the dispersed trajectories down to those that satisfy the redundant observations. The advantage of inertial navigation over statistical techniques, the independence from aerodynamic and atmospheric models, is thus maintained. INSTAR is demonstrated on flight data from the Mars Science Laboratory mission.

9:00 AAS 13-306 Preliminary Trajectory Reconstruction Results of the Mars Science Laboratory Entry Vehicle

Mark Schoenenberger, NASA Langley Research Center

On August 5th 2012, the Mars Science Laboratory entry vehicle entered Mars' atmosphere, flying a guided entry until parachute deploy. The Curiosity rover completed the entry sequence and landed safely in Gale crater. This paper compares the aerodynamics of the entry capsule extracted from onboard flight data, including Inertial Measurement Unit (IMU) accelerometer and rate gyro information, and heatshield surface pressure measurements. From the onboard data, static aerodynamic force and moment coefficients have been extracted. These data are compared to preflight predictions. The comparisons show the MSL aerodynamic characteristics have been identified to uncertainties smaller than used for preflight simulations.

9:20 AAS 13-309 Preliminary Statistical Trajectory, Atmosphere, and Aerodynamic Reconstruction of the MSL Entry, Descent, and Landing

Soumyo Dutta, Georgia Institute of Technology; Robert Braun, Georgia Institute of Technology

On August 6, 2012, the Mars Science Laboratory landed the largest payload on Mars using the largest aeroshell and supersonic parachute and an innovative Sky Crane. The aeroshell was instrumented with pressure transducers that allowed for the reconstruction of the vehicle's pressure distribution and freestream atmospheric conditions through hypersonic and supersonic flight regime. This paper shows preliminary results of the vehicle's trajectory, atmosphere, and aerodynamic coefficient reconstruction using statistical estimation methods, like extended and unscented Kalman filters, and data from the on-board inertial measurement unit, terminal descent radar altimeter, and the pressure sensors.

9:40 Break

10:05 AAS 13-310 The Mars Science Laboratory (MSL) Entry, Descent, and Landing Instrumentation (MEDLI) Hardware

Michelle Munk, NASA Langley Research Center

The Mars Science Laboratory (MSL) Entry, Descent and Landing Instrumentation (MEDLI) hardware was a first-of-its-kind sensor system that gathered engineering data from the MSL heatshield during Mars entry on August 6, 2012. MEDLI measured pressure and temperature, each at seven discrete locations determined by aerodynamicists and aerothermodynamicists. We will present a pictorial history, description of the MEDLI hardware, and its requirements, to provide context for the MEDLI performance and MSL reconstruction papers contained in the session.

10:25 AAS 13-311 A Reconstruction of Aerothermal Environment and Thermal Protection System Response of the Mars Science Laboratory Entry Vehicle

Deepak Bose, NASA Ames Research Center; Todd White, ERC, Inc.; Jose Santos, Jacobs Technology, Inc.; Milad Mahzari, Georgia Institute of Technology; Karl Edquist, NASA Langley Research Center

This paper will present a reconstruction of aerothermal environment and thermal protection system response of the Mars Science Laboratory (MSL) entry vehicle. The heat shield of the MSL entry vehicle was instrumented with thermocouples, ablation sensors, and pressure transducers that acquired engineering data during the guided hypersonic entry. The instrumentation suite is called the MSL Entry, Descent, and Landing Instrumentation (MEDLI). Using inverse parameter estimation and uncertainty analysis of TPS response models, best estimates of time-varying aeroheating and TPS response will be presented. A validation of predictive models and its impact on design margins will also be presented.

10:45 AAS 13-312 Telecom Performance and Mission Design during the Entry, Descent, and Landing of the Mars Science Laboratory

Brian Schratz, NASA / Caltech JPL; Allen Chen, NASA / Caltech JPL; Fernando Abilleira, NASA / Caltech JPL; Jeremy Shidner, Analytical Mechanics Associates, Inc.

This paper discusses the MSL UHF and X-band telecommunications configuration during EDL , and the mission design and configuration of the supporting Mars orbiters and Earth tracking stations. Actual link performance will be compared to predictions including signal strength, Doppler, plasma attenuation, and the geometries between MSL, and its relay and DTE partners. Predictions were generated using link models developed at JPL and incorporated into NASA Langley's Monte Carlo simulations of EDL. Extensive coordination efforts and testing occurred to ensure that all the relay and Earth stations were ready to capture this historic and critical event.

11:05 AAS 13-313 Mars Science Laboratory Post-Landing Location Estimation Using POST2 Trajectory Simulation

Jody Davis, NASA Langley Research Center; Jeremy Shidner, Analytical Mechanics Associates, Inc.; David Way, NASA Langley Research Center

The MSL Curiosity rover landed safely on Mars August 5th, 2012 at 10:32 PDT, ERT. Immediately following touchdown confirmation, best estimates of position were calculated to assist in determining official MSL locations during EDL. POST2 was the primary trajectory simulation tool used to predict MSL EDL performance. This paper presents the methods and results of pre/post-landing MSL location estimates and associated MRO HiRISE camera imagery. POST2 Monte Carlo data, MSL flight telemetry, MRO/ODY relay orbiter positions and HiRISE DEM's were utilized in generating these estimates. Predicted versus actual rover and balance mass locations are compared.

SESSION 13: ORBITAL DYNAMICS AND SPACE ENVIRONMENT -- I

Chair: John Seago, Analytical Graphics, Inc.

13:30 AAS 13-465 The Equations of Relative Motion in the Orbital Reference Frame
Stefano Casotto, Universita' di Padova

The full, exact equations of relative motion about a given orbit for two non-interacting spacecraft are derived. The novelty of the method resides in the use of the general expression for the angular velocity of the RTN reference frame with respect to an inertial frame. It is shown that appropriate approximations reduce these equations to the well-known Tschauner-Hempel or to the Hill-Clohessy-Wiltshire equations of relative motion.

13:50 AAS 13-316 Evolution of Angular Velocity for Space Debris as a Result of YORP
Antonella Albuja, University of Colorado at Boulder; Daniel Scheeres, University of Colorado; Jay McMahon, University of Colorado

The Yarkovsky- O'Keefe-Raszvieskii-Paddack (YORP) effect has been well studied for asteroids. This paper analyzes the effects of YORP on the angular velocity of objects in Earth orbit. A semi-analytic solution to find the averaged Fourier coefficients defining the total moment on a body as a result of YORP is derived. This solution is used to explore the rate of change of a space debris like body's angular velocity. Solutions of the analytical theory are compared with numerical integrations.

14:10 AAS 13-317 Coupled Orbit-Attitude Motion of High Area-to-Mass Ratio (HAMR) Objects Including Self-Shadowing
Carolin Früh, Air Force Research Laboratory; Moriba Jah, Air Force Research Laboratory

The current paper shows the effect of self-shadowing on the coupled attitude-orbit dynamics of objects with high area-to-mass ratios (HAMR) in simulating standard multi-layer insulation materials (MLI) as bent and tilted single rigid sheets. The coupled orbit-attitude perturbations of solar radiation pressure, thermal re-radiation of the object itself, Earth magnetic and Earth gravity field are taken into account. Light curves of the simulated objects as observed from a ground based optical sensor are extracted. The results are compared to the attitude-orbit dynamics and light curves, when neglecting self-shadowing effects.

14:30 AAS 13-318 Refining High Area-to-Mass Ratio (HAMR) Object Macro Models Using Past Orbit Estimates and a 6-DOF Orbit and Attitude Propagator
Robert Robertson, Virginia Polytechnic Institute and State University; Troy Henderson, Virginia Polytechnic Institute and State University

Inactive high area-to-mass ratio (HAMR) objects are an increasingly common hazard to active satellites, especially in the GEO orbit regime. HAMR objects are particularly susceptible to the influence of solar radiation pressure (SRP). SRP forces are highly dependent on the physical properties of the object, which are approximated using an object's macro model. This paper will present a method for refining macro models of HAMR objects using past orbit estimates and a 6-DOF propagator. These refined macro models can improve our ability to accurately predict future trajectories of HAMR objects.

14:50 AAS 13-488 DROMO propagator revisited

Hodei Urrutxua, Technical University of Madrid (UPM); Manuel Sanjurjo-Rivo, Universidad Carlos III; Jesus Pelaez, Technical University of Madrid (UPM)

In this paper we carried out a different deduction of the DROMO propagator, underlining its close relation with the Hansen ideal frame concept, and also the similarities and the differences with the theory carried out by Deprit in the paper "Ideal elements for perturbed keplerian motions" (Journal of Research of the National Bureau of Standards. Sec. B: Math. Sci., 79B, No. 1-2:1--15, 1975 Paper 79B1\&2--416). Simultaneously we introduce some improvements in the formulation that leads to a more synthetic propagator.

15:10 Break

15:35 Withdrawn

15:55 AAS 13-486 The Mean-Solar-Time Origin of Universal Time and UTC

John H. Seago, Analytical Graphics, Inc.; P. Seidelmann, University of Virginia

Universal Time is the measure of Earth rotation that serves as the astronomical basis of civil timekeeping. Since the end of the 19th century, the rate of Universal Time has been maintained to resemble Newcomb’s mean solar time at Greenwich. Here, the concept of a fictitious mean sun is revived and compared with modern ephemerides and UT1. Results suggest that Universal Time is ahead of Newcomb’s mean sun by an amount which is much less than the allowable difference between UTC and UT1. Thus, UT1 and UTC remain practically synonymous with mean solar time at the prime meridian.

16:15 AAS 13-490 Exploring the Impact of a Three-Body Interaction Added to the Gravitational Potential Function in the Restricted Three-Body Problem

Natasha Bosanac, Purdue University; Kathleen Howell, Purdue University; Ephraim Fischbach, Purdue University

Many binary star systems possess a significantly smaller companion, such as an exoplanet, in orbit about the binary. The dynamical model for the motion of the exoplanet is derived based on the circular restricted three-body problem, but extended to incorporate a three-body interaction added to the gravitational potential function. This additional contribution is assumed to depend inversely on the product of the distances between the three bodies. Frequency analysis is used to explore the influence of this three-body interaction on periodic and quasi-periodic orbits in the exterior region for a large mass ratio binary.

16:35 AAS 13-323 Preliminary Simulation for Light Curves of Rocket Body in LEO

Hideaki Hinagawa, Kyushu University; Toshiya Hanada, Kyushu University

Space debris has become an inevitable problem for the future space exploration, and spacecraft is suggested to capture and remove space debris. To fulfill this mission, you have to know target's attitude motion when installing a mitigation-related device. To support, we developed a simulator of orbit, attitude, and light curve to see how an object behaves. This paper presents preliminary research on a rocket body in LEO, and succeeded in estimating a rocket body shape's axes ratio, pole axis, rotation period using Fast Fourier Transform and Amplitude Method. We are planning the real observation in the near

16:55 AAS 13-315 Spacecraft explosion event characterization using correlated observations

Masahiko Uetsuhara, Kyushu University; Toshiya Hanada, Kyushu University; Toshifumi Yanagisawa, Japan Aerospace Exploration Agency; Yukihito Kitazawa, IHI Corporation

This paper aims to characterize a spacecraft explosion event using correlated observations. Outcomes of the characterization measure will enable us to make current space situational awareness accurate, and to predict realistic future space situations. An event to be characterized in this paper is a breakup of the Titan 3C Transtage (1968-081E) exploded in the geostationary region. Characteristics to be evaluated include delta-velocity given to each fragment though the event, and a size distribution of the breakup fragments. This paper also discusses how effective the evaluated characteristics will contribute to re-visiting observation plans for the breakup fragments.

SESSION 14: SPACECRAFT GUIDANCE, NAVIGATION, AND CONTROL -- I

Chair: Dr. Yanping Guo, Applied Physics Laboratory

13:30 AAS 13-325 The Deep Space Atomic Clock: Ushering in a New Paradigm for Radio Navigation and Science

Todd Ely, NASA / Caltech JPL; Jill Seubert, NASA / Caltech JPL; John Prestage, NASA / Caltech JPL; Robert Tjoelker, NASA / Caltech JPL

The Deep Space Atomic Clock (DSAC) project is developing a small, low-mass atomic clock based on mercury-ion trap technology and plans to demonstrate it in space by 2015. DSAC will provide an on-board spacecraft frequency reference that can be used to form precision 1-Way radiometric tracking data. With an Allan Deviation (A.D.) at 1 day of better than 2.E-14, DSAC will have a long term accuracy and stability that is equivalent to the existing Deep Space Network. The benefits of this for deep space radio navigation and science will be presented.

13:50 AAS 13-326 Flight Testing of Trajectories Computed by G-FOLD: Fuel Optimal Large Divert Guidance Algorithm for Planetary Landing

Behcet Acikmese, The University of Texas at Austin

This paper describes the first terrestrial flight testing of a planetary pinpoint landing guidance algorithm called G- FOLD, Guidance algorithm for Fuel Optimal Large Diverts. The algorithm will enable access to currently unreachable but scientifically valuable science targets, such as for Mars sample return mission, and is a component for enabling delivery of large payloads necessary for human class planetary missions.

14:10 AAS 13-327 Deployment of Spacecraft Structures Using Shape Memory Alloys

Ryan Stanley, Virginia Polytechnic Institute and State University; Troy Henderson, Virginia Polytechnic Institute and State University

In this paper, the deployment of various spacecraft structural elements using shape memory alloys is analyzed. The considerable design challenge of unfolding a spacecraft's structural component from its stowed, launch configuration to its operational configuration in orbit is approached from a unique perspective by utilizing the memory property of shape memory alloys activated by the incident solar radiation in the space environment. This paper will examine the deployment of structural booms, solar cell panels, solar sails and other components by exploiting this phenomenon in conjunction with folding algorithms developed from computational origami programs and inspired by biological organisms.

14:30 AAS 13-471 Analytical Guidance for Spacecraft Relative Motion under Constant Thrust Using Relative Orbit Elements

Riccardo Bevilacqua, Rensselaer Polytechnic Institute; Thomas Lovell, Air Force Research Laboratory

This paper introduces novel analytical guidance solutions for spacecraft relative motion considering continuous, on-off thrust, and using Relative Orbit Elements. The relative state vector can be obtained at any given time, accommodating any thrust magnitude, as well as generic activation times and durations. Relative Orbit Elements geometrically interpret key aspects of the relative motion, including, for example, the relative ellipse size, and its center evolution in time. The analytical solutions are tested using a sample guidance thrust profile based on input-shaping. The use of Relative Orbit Elements shows substantial benefits and added simplicity with respect to Cartesian Coordinates.

14:50 AAS 13-328 Multiple Sliding Surface Guidance for Planetary Landing: Tuning and Optimization via Reinforcement Learning
Daniel Wibben, The University of Arizona; Brian Gaudet, University of Arizona; Roberto Furfaro, The University of Arizona; Jules Simo, University of Strathclyde

A novel non-linear guidance algorithm for planetary landing is proposed and analyzed. Based on Higher-Order Sliding Control Theory, the Multiple Sliding Surface Guidance algorithm has been specifically designed to take advantage of the ability to reach the sliding surface in a finite time. However, after initial analysis, it has been seen that the performance of MSSG is very sensitive to the choice in guidance gains and is generally sub-optimal. Reinforcement learning has been used to tune and investigate the behavior of the MSSG algorithm to find an optimal set of gains for both performance and fuel efficiency.

15:10 Break

15:35 AAS 13-329 Optimal Lunar Landing and Retargeting using a Hybrid Control Strategy
Daniel Wibben, The University of Arizona; Roberto Furfaro, The University of Arizona; Ricardo Sanfelice, The University of Arizona

A novel non-linear spacecraft guidance scheme utilizing a hybrid controller for pinpoint lunar landing and retargeting is presented. The hybrid system approach utilizes the fact that the logic and behavior of switching guidance laws is inherent in the definition of the system, thus autonomous retargeting is possible. The presented case utilizes a combination of a global controller to bring the lander to a predefined reference trajectory, and a local controller to bring it to the desired point on the lunar surface. The behavior and performance of the hybrid system is analyzed, with emphasis on the case of autonomous retargeting.

15:55 AAS 13-330 Navigating a Crewed Lunar Vehicle Using LiAISON
Jeff Parker, University of Colorado at Boulder; Jason Leonard, University of Colorado at Boulder; Rodney Anderson, NASA / Caltech JPL; Ryan McGranaghan, University of Colorado at Boulder; Kohei Fujimoto, University of Colorado at Boulder; George Born, University of Colorado at Boulder

This paper examines the benefits of navigating a crewed vehicle between the Earth and the Moon using both ground tracking and satellite-to-satellite tracking. Linked Autonomous Interplanetary Satellite Orbit Navigation (LiAISON) is a new technique that has been shown to dramatically improve the navigation of lunar satellites, libration orbiters, and Earth orbiting satellites using scalar intersatellite observations. In this paper, LiAISON is applied to the problem of navigating a crewed vehicle to the Moon. It has been found that LiAISON observations improve the navigation enough to reduce the number of active ground tracking stations from six to three.

16:15 AAS 13-331 Constrained Station Change in GEO Using A Legendre Pseudospectral Method

Seung Pil Kim, The Pennsylvania State University; Robert Melton, The Pennsylvania State University

Relocation of a GEO satellite in minimum time, with attention to collision avoidance, is considered. The collision avoidance term, incorporated as an integral form in the objective function, is included by specifying a maximum or minimum radius depending on whether the transfer is in the east or west-direction. Several east- and west-direction maneuvers are simulated; all the states are found to be within feasible ranges. Multiple revolutions and large longitude station change cases are also demonstrated using this method. The transfer time is found to be only weakly affected by the initial thrust acceleration for the multi-revolution

16:35 AAS 13-332 Optimal Trajectory Design for Aerobraking

Ling Jiang, Beihang University

Aerobraking is an efficient aeroassisted technique that has been used successfully in recent Mars missions. However, trajectory design process is complicated yet time consuming with multiple passes through the atmosphere. A simple but effective design method to make this process easier is proposed. Firstly, perturbed classic element of orbit analysis is used to optimize of periapsis selection. After choosing the appropriate initial periapsis, an elaborate computational aerodynamics-trajectory model is developed to simulate the trajectory. Simulation results show a significant reduction in the maximum control input and maximum heat rate. The method here can be used for reference to engineering

16:55 AAS 13-333 Research and Verification of Multi-frequency Same Beam VLBI Based on General TT&C Signal

Lue Chen, Beijing Aerospace Control Center; Ling Jiang, Beihang University; Geshi Tang, Beijing Aerospace Control Center; Songtao Han, Beijing Aerospace Control Center ; Mei Wang, Beijing Aerospace Control Center ; Huicui Liu, Beijing Aerospace Control Center

The method of multi-frequency same beam VLBI utilizing spacecraft general Tracking, Telemetry and Control (TT&C) signal is proposed in this paper. The mathematical calculation of the difference phase delay of multi-frequency same beam VLBI is analyzed, and a method of error model modification of difference phase delay is introduced. Utilizing the multi-frequency information of the general TT&C signals, the simulation results shows that, picoseconds level differential phase delay is obtained after delay error model modification. This could provide reliable measurement technology for the relative navigation of two spacecrafts in deep space mission.

SESSION 15: DYNAMICAL SYSTEMS THEORY

Chair: Dr. Kathleen Howell, Purdue University

13:30 AAS 13-334 Leveraging Resonant Orbit Manifolds to Design Transfers Between Libration Point Orbits in Multi-body Regimes

Mar Vaquero, Purdue University; Kathleen Howell, Purdue University

Resonant orbits are widely employed in mission design for planetary flybys (JEO) and, more recently, to support long-term stability (IBEX). Yet, resonant orbits have not been explored as transfer mechanisms between non-resonant orbits in multi-body systems. Given the increased interest in Libration Point Orbits (LPOs) for a large number of different purposes, transfers from LEO to the Earth-Moon LPOs that leverage conic arcs and invariant manifolds associated with resonant orbits and LPOs are investigated. Solutions are generated in the three-body model and transitioned to a full ephemeris model. Optimization techniques can further reduce propellant requirements.

13:50 AAS 13-493 Tour Design Using Resonant Orbit Heteroclinic Connections in Patched Circular Restricted Three-Body Problems

Rodney Anderson, NASA / Caltech JPL

It is increasingly desirable to incorporate multi-body effects in tour design early in the process to make use of these effects and potentially discover new solutions. Flybys have previously been designed using the heteroclinic connections of resonant orbits in the circular restricted three-body problem (CRTBP), but tour design often requires the consideration of additional moons, especially within the Jovian system. In this study, heteroclinic connections of resonant orbits are chained together within separate CRTBP models to perform multiple flybys that advance through desired resonances. Aspects of patching these trajectories together are explored, and a sample trajectory is computed.

14:10 AAS 13-336 Examining the Learning Rate in Iterative Learning Control Near the Start and the End of the Desired Trajectory

Fei Gao, Tsinghua University; Richard Longman, Columbia University

Iterative learning control (ILC) can be used in spacecraft applications to make feedback control systems performing repeated tracking maneuvers produce high precision tracking accuracy. ILC laws have been developed that in a few iterations for learning improve the tracking accuracy by a factor of 1000. This paper examines in detail the learning rate, and finds that the learning near the start of the trajectory and near the end can be slow. Methods a developed to address these issues, and also to produce a smart method to start the iterations with the real world so that learning is accomplished more quickly.

14:30 AAS 13-337 Linear State Representations for Discrete-Time Bilinear System Identification by Interaction Matrices

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

Bilinear systems can be viewed as a bridge between linear and nonlinear systems, providing a promising approach to handle the satellite attitude control problem. This paper provides a formal justification for the extension of interaction matrices to bilinear system theory and uses them to express the bilinear state as a linear function of past data and as another linear function of future data. Based on the intersection of the two resulting vector spaces of input-output data, an efficient discrete-time bilinear system identification algorithm is developed, needing data from only one experiment with no specific restriction on the input

14:50 AAS 13-469 Second Order Nonlinear Initial Value Solution for Relative Motion Using Volterra Theory

Brett Newman, Old Dominion University; Mary Stringer, Old Dominion University; Thomas Lovell, Air Force Research Laboratory; Ashraf Omran, CNH-Fiat Industrial

In this paper, application of Volterra multi-dimensional convolution theory is applied to the nonlinear J2 perturbed circular relative motion problem. Approximate analytic expressions for the time dependent deputy positions in terms of initial conditions, chief elements, and gravity parameters are obtained, although unperturbed results are emphasized here. The Clohessy-Wiltshire (CW) linear solution is found to be embedded within the broader nonlinear solution, and the additional nonlinear terms are used to examine characteristics of the associated motion. Further, accuracy of the nonlinear solution improves on that for the linear solution.

15:10 Break

15:35 AAS 13-470 Second Order Nonlinear Boundary Value Solution for Relative Motion Using Volterra Theory

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

Relative orbital dynamic models are used primarily for modeling the motion between a deputy and chief spacecraft. However, these models can be used to plan inertial maneuvers of a single spacecraft as well. Here, the well-known Lambert problem, which has no known closed-form solution for inertial dynamics, is investigated as a rendezvous problem, whereby a deputy is to rendezvous with a fictitious chief. A Lambert-like guidance scheme based upon the Hill-Clohessy-Wiltshire relative motion model is derived. The accuracy of this guidance scheme is then compared to the “true” Lambert solution.

15:55 AAS 13-339 Preliminary Design Considerations for Access and Operations in Earth-Moon L1/L2 Orbits

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

Within the context of manned spaceflight activities, Earth-Moon libration point orbits could support lunar surface operations and serve as staging areas for future missions to asteroids and potentially Mars. This investigation explores preliminary design considerations including Earth-Moon L1/L2 libration point orbit selection, transfers, and stationkeeping costs associated with maintaining a spacecraft in the vicinity of L1 or L2 for a specified duration. Existing tools in the areas of multi-body trajectory design, dynamical systems theory, and orbit maintenance are leveraged in this analysis to explore end-to-end concepts for manned missions to Earth-Moon libration points.

16:15 AAS 13-340 Optimal Impulsive Manifold-Based Transfers with Guidance to Earth-Moon L1 Halo Orbits

William Anthony, New Mexico State University; Annie Larsen, New Mexico State University; Eric Butcher, New Mexico State University

The optimization of a two-impulse transfer from LEO or GEO to a L1 halo orbit utilizing its stable invariant manifold is considered. The first burn is to depart LEO/GEO while the second burn injects the spacecraft onto the stable manifold. A genetic algorithm and primer vector theory are utilized in the trajectory optimization. An LQR-based guidance algorithm is employed to mitigate manifold injection thrust errors and remain on the stable manifold. Monte Carlo analyses are employed to obtain distributions of miss distance and guidance delta-v for given Gaussian distributions of burn error magnitude and direction.

16:35 AAS 13-341 Abort Options for Human Missions to Earth-Moon Halo Orbits

Mark Jesick, Analytical Mechanics Associates, Inc.

One possible destination for future human space exploration is a halo orbit in the Earth-moon system. A mission to a halo orbit around the translunar libration point (L2), for example, would provide experience in spaceflight further from the Earth than ever before, and a properly chosen L2 halo remains in view of Earth, allowing constant communication with ground control. Because of these and other advantages of utilizing halo orbits, and because off-nominal planning is essential for all human spaceflight, this study analyzes abort trajectories for human halo missions, with an emphasis on the use of free returns.

16:55 AAS 13-338 Short and Long Term Closed Orbit Design in Sun-Earth Elliptic-Restricted 3-Body Problem

Yoshihide Sugimoto, The Graduate University for Advanced Studies; Yasuhiro Kawakatsu, JAXA / ISAS; Stefano Campagnola, JAXA / ISAS; Takanao Saiki, JAXA / ISAS

In CR3BP, well designed Halo orbits can orbit more than two rotations without any orbit correction maneuver since the dynamical system assumes circular orbits for two dominant bodies. However, under the actual condition, the dominant bodies are co-orbiting in elliptic orbits and it is essential for the real missions to include those disturbing effects into a plane dynamical model of CR3BP.The objectives of this research are, therefore, to design reference closed-orbit in the ER3BP (Elliptic Restricted Three-Body Problem), which enables to consider the effect from the eccentricity, for short term and also long term.

SESSION 16: SPECIAL SESSION: DAWN

Chair: Dr. Shyam Bhaskaran, Jet Propulsion Laboratory

13:30 AAS 13-342 Ion Propulsion: An Enabling Technology for the Dawn Mission
Charles Garner, NASA / Caltech JPL; Marc Rayman, NASA / Caltech JPL; John Brophy, NASA / Caltech JPL; Steve Mikes, NASA / Caltech JPL; Gregory Whiffen, NASA / Caltech JPL

The Dawn mission, part of NASA's Discovery program, is enabled using an on-board ion propulsion system (IPS) developed at JPL that will provide 11 km/s of delta-V to the spacecraft using less than 400 kg of xenon propellant. IPS is used for primary propulsion for cruise to Vesta and Ceres, and for orbit maneuvers. IPS operations have been almost-trouble-free, delivering 7 km/s of delta-V while using 260 kg of xenon for cruise to Vesta and orbit maneuvers.

13:50 AAS 13-343 Thrust Direction Optimization: Satisfying Dawn's Attitude Agility Constraints
Gregory Whiffen, NASA / Caltech JPL

NASA's Dawn mission is exploring the giant asteroid Vesta and the dwarf planet Ceres. The Dawn spacecraft has complex, difficult to quantify, and severe limitations on its attitude agility. The low-thrust transfers between science orbits at Vesta required complex time varying thrust directions due to Vesta's strong and complex gravity. Thrust design objectives (like minimum propellant or minimum transfer time) often result in thrust direction evolutions that cannot be accommodated by the attitude control system. Several new optimal control objectives, called thrust direction optimization were developed and used to successfully navigate Dawn through all transfers at Vesta.

14:10 AAS 13-344 Dawn Maneuver Design Performance at Vesta
Daniel Parcher, NASA / Caltech JPL; Matthew Abrahamson, NASA / Caltech JPL; Alessandro Ardito, ARPSOFT s.r.l.; Dongusk Han, NASA / Caltech JPL; Robert Haw, NASA / Caltech JPL; Brian Kennedy, NASA / Caltech JPL; Nickolaos Mastrodemos, NASA / Caltech JPL; Sumita Nandi, NASA / Caltech JPL; Ryan Park, NASA / Caltech JPL; Brian Rush, NASA / Caltech JPL; Brett Smith, NASA / Caltech JPL; John Smith, NASA / Caltech JPL; Andrew Vaughan, NASA / Caltech JPL; Gregory Whiffen, NASA / Caltech JPL

The Dawn spacecraft orbited the asteroid Vesta from July 16, 2011 to September 5, 2012, successfully accomplishing the four planned science orbits and two planned rotational characterization orbits. The lowest-altitude science orbit lasted four months, with 20 planned orbit maintenance maneuvers. Navigation results from Vesta demonstrate that the navigation plan was sufficient to achieve orbit delivery accuracy requirements. This paper compares the flown Dawn trajectory against the planned trajectory and expected maneuver dispersions. Understanding the effectiveness of the maneuver design plan at Vesta is a key component of planning for Ceres operations, the next destination for the Dawn mission.

14:30 AAS 13-346 Dawn Orbit Determination Team: Trajectory Modeling and Reconstruction Processes at Vesta

Matthew Abrahamson, NASA / Caltech JPL; Alessandro Ardito, ARPSOFT s.r.l.; Dongusk Han, NASA / Caltech JPL; Robert Haw, NASA / Caltech JPL; Brian Kennedy, NASA / Caltech JPL; Nickolaos Mastrodemos, NASA / Caltech JPL; Sumita Nandi, NASA / Caltech JPL; Ryan Park, NASA / Caltech JPL; Brian Rush, NASA / Caltech JPL; Andrew Vaughan, NASA / Caltech JPL

The Dawn spacecraft spent over a year in orbit around Vesta from July 2011 through August 2012. In order to maintain the designated science reference orbits and enable the transfers between those orbits, precise and timely orbit determination was required. Challenges included low-thrust ion propulsion modeling, estimation of relatively unknown Vesta gravity and rotation models, tracking data limitations, incorporation of real-time telemetry into dynamics model updates, and rapid maneuver design cycles during transfers. This paper discusses the detailed dynamics models, filter configuration, and data processing implemented to deliver a rapid orbit determination capability to the Dawn project.

14:50 AAS 13-345 Dawn Orbit Determination Team: Trajectory and Gravity Prediction Performance during Vesta Science phases.

Brian Kennedy, NASA / Caltech JPL; Matthew Abrahamson, NASA / Caltech JPL; Alessandro Ardito, ARPSOFT s.r.l.; Dongusk Han, NASA / Caltech JPL; Robert Haw, NASA / Caltech JPL; Nickolaos Mastrodemos, NASA / Caltech JPL; Sumita Nandi, NASA / Caltech JPL; Ryan Park, NASA / Caltech JPL; Brian Rush, NASA / Caltech JPL; Andrew Vaughan, NASA / Caltech JPL

The Dawn spacecraft was launched on September 27th of 2007 to consecutively rendezvous with and observe the two largest bodies in the asteroid belt, Vesta and Ceres. It has already completed over a year’s worth of direct observations of Vesta and is currently on a cruise trajectory to Ceres. This data collection required careful planning and execution from all spacecraft teams. Dawn’s Orbit Determination (OD) team was tasked with accurately predicting the trajectory of the Dawn spacecraft during the Vesta science phases. This paper will describe the OD team contributions to executing those phases.

15:10 Break

15:35 AAS 13-347 Dawn Orbit Determination Team: Modeling and Fitting of Optical Data at Vesta

Brian Kennedy, NASA / Caltech JPL; Matthew Abrahamson, NASA / Caltech JPL; Alessandro Ardito, ARPSOFT s.r.l.; Robert Haw, NASA / Caltech JPL; Nickolaos Mastrodemos, NASA / Caltech JPL; Sumita Nandi, NASA / Caltech JPL; Ryan Park, NASA / Caltech JPL; Brian Rush, NASA / Caltech JPL; Andrew Vaughan, NASA / Caltech JPL

The Dawn spacecraft has recently spent over a year collecting direct science observations of Vesta. While at Vesta, Dawn's Orbit Determination (OD) team was tasked with determination of the Vesta rotational rate, pole orientation and ephemeris, among other Vesta parameters. This paper will describe the initial determination of the Vesta ephemeris and frame using both radiometric and optical data, and the also describe the final results using data from later in the Vesta mission, along with modeling and process refinements.

15:55 AAS 13-348 Recovering the Gravity Field of Vesta from Dawn

Sami Asmar, NASA / Caltech JPL; Alex Konopliv, NASA / Caltech JPL; Ryan Park, NASA / Caltech JPL; Carol Raymond, NASA / Caltech JPL

The Dawn mission to Vesta has completed a global solution of gravity measurements of degree and order 20. When correlated with a shape model derived from imaging, these data can constrain the interior structure from the core to the crust. Utilizes precision spacecraft Doppler tracking and landmark tracking from framing camera images to measure the gravity field, the solution also yields the spin-pole location and rotation. The second-degree harmonics together with assumptions on obliquity or hydrostatic equilibrium determine the moments of inertia and constrain the core size and density. J2 parameter shows inconsistency with a homogenous density body.

16:15 Withdrawn

16:35 AAS 13-350 Spiraling Away from Vesta: Design of the Transfer from the Low to High Altitude Dawn Mapping Orbits

John Smith, NASA / Caltech JPL; Daniel Parcher, NASA / Caltech JPL; Gregory Whiffen, NASA / Caltech JPL

Dawn has successfully completed its orbital mission at Vesta and is currently en route to an orbital rendezvous with Ceres in 2015. The longest duration and most complex portion of the Vesta departure trajectory was the transfer from the low to high altitude science orbit. This paper describes the design of this low-thrust trajectory optimized assuming a minimum-propellant mass objective. The transfer utilized solar-electric ion propulsion applied over 139 spacecraft revolutions about Vesta. Science drivers, operational constraints, and robustness to statistical uncertainties are addressed. The 45-day transfer trajectory was successfully implemented in early 2012.

SESSION 17: SPACE SITUATIONAL AWARENESS AND CONJUNCTION ANALYSIS -- I

Chair: Dr. Daniel Scheeres, University of Colorado

8:00 AAS 13-351 Collision Probability for Resident Space Objects using Gaussian Mixture Models

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

Computation of space object collision probability plays a large role in the spacecraft community. The number of active satellites and debris is increasing day by day, which leads to a very realistic chance of a runoff. In general, the methods in practice for computing collision probability require that the uncertainty distributions be represented with a linearized position covariance; otherwise Monte Carlo simulations are required, which are very computationally intensive. Our goal is to improve the accuracy of the covariance propagation phase by using Gaussian Mixture Models, and to thus better approximate the non-linear probability distribution resulting near the encounter.

8:20 AAS 13-352 Determining a Probability-based Distance Threshold for Conjunction Screening

Salvatore Alfano, Center for Space Standards and Innovation

Various economizing filters are used to identify orbiting pairs that cannot come close enough over a prescribed time period to be considered hazardous. Such pairings can then be eliminated from further computation to quicken the overall processing time. When conjunction probability is to be used as a metric, a minimum distance threshold can be determined from the minimum acceptable probability threshold. This work develops an analytical approximation that relates maximum probability to a miss distance threshold, thereby ensuring that the screening distance is adequate for probability-based conjunction assessment.

8:40 AAS 13-353 Insertion Error and Conjunction Analysis for Single-Launch, Large Scale Space System

Andrew Rogers, Virginia Polytechnic Institute and State University; Matthew Schmitt, Virginia Polytechnic Institute and State University; Troy Henderson, Virginia Polytechnic Institute and State University; Scott Bailey, Virginia Polytechnic Institute and State University; Chad Fish, Virginia Polytechnic Institute and State University

The deployment of large-scale, multi-satellite space systems from a single launch vehicle offers an attractive platform for scientific observations. By deploying the satellites in a string of pearls configuration initially, with a small spread in semi-major axis and inclination, the natural orbit dynamics cause the orbits to spread, leading to global coverage (from the scientific measurement standpoint). This paper investigates the effect of orbit insertion error on the constellation's long term configuration and provides an initial conjunction analysis for the un-controlled constellation.

9:00 Withdrawn

9:20 AAS 13-355 Trajectory Error and Covariance Realism for Launch COLA Operations
Matthew Hejduk, a.i. solutions

The closing of satellite launch windows to mitigate collision hazards has been questioned due to concerns about the accuracies of the predicted launch trajectories and accompanying covariances. The present analysis examined thirty-seven launch events, comparing the predicted trajectories to the associated launch telemetry in order to evaluate trajectory error and covariance realism. The analysis found that these trajectories are more error-infused than satellite ephemerides but that the associated covariances are realistic error statements. Given that these covariances are appropriate to the trajectories they describe, these products, if used correctly, can form an adequate basis for launch window closure.

9:40 Break

10:05 AAS 13-357 On-Board Estimation of Collision Probability for Cluster Flight
Michael Phillips, Emergent Space Technologies

Being able to detect and respond to potential collisions is a significant concern for implementing satellite cluster flight. The accuracy and speed at which collision probability can be estimated is a key factor in determining the minimum allowable closest approach distance between any two modules, and thus the total size of a cluster. A method is presented which takes into account both the state and state uncertainty to estimate collision probability. Additionally this method generates a range of values in which the true probability of collision will fall. The accuracy of this method verified through Monte Carlo simulation.

10:25 AAS 13-359 Autonomy Architecture for a Raven-Class Telescope with Space Situational Awareness Applications
Ryan D. Coder, Georgia Institute of Technology; Marcus Holzinger, Georgia Institute of Technology

This paper investigates the autonomy architecture design of a Raven-class telescope as applied to the tracking and high level characterization problem in Space Situational Awareness (SSA). Various levels of autonomy are defined and existing systems and capabilities are discussed. Telescope interactions with distributed sensor networks such as the Space Surveillance Network (SSN) are reviewed, and several relationships between autonomy and scheduling of telescopes are addressed. An autonomy architecture design for a Raven-class telescope is presented and future extensions are proposed.

10:45 AAS 13-360 A Geometric Analysis to Protect Manned Assets from Newly Launched Objects – COLA Gap Analysis

Mark E. Hametz, a.i. solutions

A safety risk was identified for the International Space Station (ISS) by The Aerospace Corporation, where the ISS would be unable to react to a conjunction with a newly launched object following the end of the launch COLA process. NASA/JSC has requested that all US launches take additional steps to protect the ISS during this "COLA gap" period. This paper details the results of a geometric-based COLA gap analysis method developed by the NASA Launch Services Program used for three NASA missions to determine if launch window cutouts are required to mitigate this risk.

SESSION 18: ATTITUDE DETERMINATION, DYNAMICS, AND CONTROL -- III

Chair: Dr. Don Mackison, University of Colorado

8:00 **AAS 13-361** **Greedy Tasking for Spacecraft Attitude Resource Sharing**
Shawn Johnson, University of Florida; Norman Fitz-Coy, University of Florida

This paper investigates greedy strategies for spacecraft attitude resource sharing in fractionated spacecraft architectures. One spacecraft has the capability to measure its inertial attitude and its relative attitude with respect the other spacecraft. All other spacecraft in the network require inertial attitude knowledge, but lack sensing feedback. This sensor tasking is shown to lack separation in estimation and control, which motivates the application of greedy tasking. Shannon entropy and covariance matrix norms are used as metrics for greedy tasking and are compared with a baseline Round-robin tasking. Simulations demonstrate the method's improvement in network-level attitude pointing accuracy.

8:20 **AAS 13-362** **q-Method Extended Kalman Filter**
Renato Zanetti, Draper Laboratory; Thomas Ainscough, Draper Laboratory; John Christian, NASA Johnson Space Center; Pol Spanos, Rice University

A new algorithm is proposed that smoothly integrates non-linear estimation of the attitude quaternion using Davenport's q-method and estimation of non-attitude states through an extended Kalman filter. The new method is compared to a similar existing algorithm showing its similarities and differences. The validity of the proposed approach is confirmed through numerical simulations.

8:40 **AAS 13-363** **Attitude Reconstruction Analysis of the Reentry Breakup Recorder**
Russell Patera, The Aerospace Corporation

The REBR (reentry breakup recorder) is a small self contained space vehicle whose purpose is to obtained data to help define a space vehicle's reentry environment. The first REBR mission flew on JAXA's HTV2 space vehicle and recorded data during atmosphere reentry on March 30, 2011. REBR used the Iridum network to transmit data during its descent through the lower atmosphere. This paper focuses on the methods used to reconstruct REBR's attitude through the highly dynamic breakup environment using REBR's low sample rate data.

9:00 **AAS 13-364** **Online Attitude Determination of a Passively Magnetically Stabilized Spacecraft**
Roland Burton, Stanford University; Stephen Rock, Stanford University

An online attitude determination filter is introduced that is capable of estimating the attitude of a passively magnetically stabilized spacecraft to within about five degrees accuracy while using only limited sensing. This filter enables nano satellites to perform onboard attitude determination even when no dedicated attitude sensors are installed, instead relying only on the electrical currents from body mounted solar panels. The online attitude filter is applied in post processing to orbital data from NASA Ames Research Center's O/OREOS and the University of Michigan's RAX-1 spacecraft.

9:20 AAS 13-365 Development of the Illinisat-2 Attitude Determination and Control System Testing Suite

Alexander Ghosh, University of Illinois at Urbana-Champaign; Erik Kroeker, University of Illinois at Urbana-Champaign; Patrick Haddox, University of Illinois at Urbana-Champaign; Victoria Coverstone, University of Illinois at Urbana-Champaign

This work discusses the development of a magnetic-based attitude determination and control system for the Illinisat-2, and the ground support equipment needed to validate the system. Its attitude determination is performed using magnetometers and coarse sun sensors applying Kalman filtering method, while the attitude control is performed with magnetic torquers. To perform the flight testing of this system, a Helmholtz cage was developed. This work will discuss the lessons learned of developing the system, and of the testing apparatus, as well as outline the method for calibration of the system and the next steps in its development.

9:40 Break

10:05 AAS 13-366 Estimation of Spacecraft Angular Acceleration Using Linear Accelerometers

Vivek Nagabhushan, University of Florida; Norman Fitz-Coy, University of Florida; Shawn Johnson, University of Florida

Several challenges in the attitude determination and control of a spacecraft like mass property and misalignment may benefit from the measurement of spacecraft angular acceleration. Differentiation of angular velocity measurements from a gyroscope has undesirable effects like noise amplification. This paper will describe methods to estimate spacecraft angular acceleration using linear accelerometer and gyroscope measurements. Two configurations, that use uni-axial, and tri-axial accelerometers, respectively are presented and compared in this paper. The effect accelerometer bias and noise on the angular acceleration estimate are evaluated. An EKF to identify the effective bias in the angular acceleration estimate is developed.

10:25 AAS 13-367 Closed-form Optimal Maneuver Control Solutions for Under-actuated Spacecraft

Donghoon Kim, Texas A&M University

All spacecraft are designed to be maneuvered to achieve pointing objectives. This is accomplished by designing a three-axis control system which can achieve arbitrary maneuvers, where the objective is to reorient the spacecraft and suppress the residual angular velocity at the end of the maneuver. If one of the three-axis control actuators fails then new control laws are required. This paper explores optimal sequential Euler angle rotation strategies with only two control torque inputs. A careful reformulation of the problem necessary conditions in terms of two switch-times yields a closed-form solution that has been validated numerically.

10:45 AAS 13-368 Attitude Tracking and Trajectory Planning for Underactuated Spacecraft

Dongxia Wang, Beihang University; Yinghong Jia, Beihang University; Lei Jin, Beihang University; Shijie Xu, Beihang University

This paper provides some new results for the problem of attitude tracking control and on-line feasible trajectory generation for a symmetric rigid spacecraft with two controls. Firstly, we deduce the necessary and sufficient condition of feasible trajectory according to the models characteristics. Secondly, we design three types of nonlinear control law according to the different attitude tracking task. Thirdly, we use the notion of differential flatness and propose a simple way for designing the trajectory in the flat output space. Both the theoretical and numerical results illustrate the validity of the control strategy in this paper.

11:05 AAS 13-369 Attitude Optimization of a Spinning Solar Sail via Spin Rate Control to Accelerate in Tangential Direction

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

The spin-axis direction of a spinning solar sail rotates around an equilibrium point near the Sun direction, and it leads to a complexity in the attitude control. The objective of this research is to derive an optimal spin rate control law for a spinning solar sail to accelerate in the tangential direction of its orbit. Using the calculus of variations, analytical and numerical solutions showing a bang-bang control of the spin rate are obtained. The control method determined in this study enables a spinning solar sail to accelerate continuously and explore the outer solar system and beyond.

11:25 AAS 13-370 Attitude Stabilization of a Spacecraft Underactuated by Two Parallel Control Moment Gyros

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

Three-axis attitude stabilization of a spacecraft by two parallel arranged control moment gyros (CMGs) is investigated. The backstepping method is first used to design a novel saturated controller for the kinematics and then a stabilization controller for the complete system. Then, the direct-inverse steering logic for two CMGs is modified into a new form, by taking the attitude error into account, to get the command gimbal rates. Finally, a steady state controller is proposed forming a switched control logic in onjunction with previous stabilization controller. Numerical simulation results validate the effectiveness of the proposed control law.

SESSION 19: ORBITAL DYNAMICS AND SPACE ENVIRONMENT -- II

Chair: Dr. Paul Cefola, University at Buffalo (SUNY)

8:00 AAS 13-371 Numerical Analysis of Thermal Radiation Perturbations for a Mercury Orbiter

Benny Rievers, ZARM (Center of Applied Space Technology and Microgravity), University of Bremen; Takahiro Kato, German Aerospace Center (DLR); Jozef van der Ha, Consultant; Claus Lämmerzahl, ZARM (Center of Applied Space Technology and Microgravity), University of Bremen

We present a numerical approach for the precise determination of the solar and thermal effects acting on a Mercury Orbiter. The spacecraft as well as the planet are represented by a set of sub-surfaces allowing for the inclusion of geometrical details. The method uses a generic MATLAB/simulink-based software tool including individual models for the solar radiation pressure, the re-emitted thermal radiation pressure, the planetary albedo and the infrared radiation pressure. The performance of the model is demonstrated on the basis of a Mercury Orbiter where the orbit and spacecraft configuration are taken from NASA's Messenger.

8:20 AAS 13-372 Novel Orbits of Mercury and Venus Enabled using Low-Thrust Propulsion

Pamela Anderson, University of Strathclyde; Malcolm Macdonald, University of Strathclyde; Chen-wan Yen, NASA / Caltech JPL

Natural Sun-synchronous orbits do not exist at Mercury and Venus as the reciprocal of flattening of these planets is so low the natural perturbations are of no use for generating Sun-synchronous orbits. This work proposes the use of continuous low-thrust propulsion to generate Sun-synchronous orbits at Mercury and Venus where they are otherwise not possible; therefore, increasing the opportunities for observation and allowing simplification of the spacecraft thermal environment. Continuous acceleration is also considered to alter the natural critical inclinations of a variety of orbits to increase the opportunities for remote sensing of the inner planets.

8:40 AAS 13-373 EOP and Space Weather Data for Flight Operations

David Vallado, Center for Space Standards and Innovation; T.S. Kelso, Center for Space Standards and Innovation

Earth Orientation Parameter and Space Weather data are critical data elements for numerical propagation and space operations. Since CSSI first began assembling consolidated files of EOP and space weather data, we have tracked the performance of these data to better understand what operational users can expect. We present detailed analysis and results over the last few years to assess the best sources for this data, and recommend options for processing when no data exists. Corrections to space weather data are shown where anomalies exist. Finally, we investigate the implications of space weather prediction accuracy and its effect on satellite lifetime.

9:00 AAS 13-374 Refining Space Object Radiation Pressure Modeling with Bidirectional Reflectance Distribution Functions

Charles Wetterer, Pacific Defense Solutions, LLC; Richard Linares, University at Buffalo, State University of New York; John Crassidis, University at Buffalo, State University of New York; Thomas Kelecy, Boeing LTS; Marek Ziebart, University College London; Moriba Jah, Air Force Research Laboratory; Paul Cefola, University at Buffalo, State University of New York

High fidelity orbit propagation requires detailed knowledge of the solar radiation pressure (SRP) on a space object. In turn, the SRP is dependent not only on the space object's shape and attitude, but also on the absorption and reflectance properties of each surface on the object. These properties are described by a surface bidirectional reflectance distribution function (BRDF). This paper demonstrates that for space debris whose interactions with electro-magnetic radiation are described accurately with a BRDF, then hitherto unknown torques account for rotational characteristics affecting both tracking signatures and the ability to predict the orbital evolution.

9:20 AAS 13-375 Essential Thrust Fourier Coefficient Set of Averaged Gauss' Equations for Orbital Mechanics

Hyun Chul Ko, University of Colorado at Boulder; Daniel Scheeres, University of Colorado

By applying an averaging method to Gauss's variation equations, the perturbing accelerations acting on a spacecraft can be presented as a function of 14 Thrust Fourier Coefficients (TFCs). Time rate changes of mean orbital elements related to these TFCs are analyzed and the representation of these thrust coefficients as a function of change in orbit states is studied. We find both minimum coefficient solutions as well as minimum norm solutions of TFCs. The minimum set of 6 TFCs provides the finite basis representation of arbitrary orbital maneuvers that allow us to dynamically interpolate between states across an unknown maneuver.

9:40 Break

10:05 AAS 13-321 Fast Interpolation of High Fidelity Gravity Fields

Nitin Arora, Georgia Institute of Technology / NASA / Caltech JPL; Ryan Russell, The University of Texas at Austin

An update is provided on the development of a new interpolated gravity model that efficiently trades memory for speed. The model utilizes the weighting function interpolation method originally proposed by Junkins et.al, and a new adaptive selection of local polynomials. The acceleration and higher order derivatives are smooth and are calculated naturally as the gradient of the fitted geopotential. The new polynomial selection algorithm reduces the memory requirements by upto 40% over the prototype model. As an example, fitting the GGM02C field requires 1.4 Gb of memory while achieving over 300x speedup over the Pines spherical harmonics implementation.

10:25 AAS 13-376 An Algorithm for Trajectory Propagation and Uncertainty Mapping on GPU

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

This paper introduces an efficient parallel numerical integrator for use on graphics processing units (GPUs) to propagate large sets of trajectories. The method is based on modifying Picard iterations to fit the structure of GPUs. This enables the efficient computation of orbital properties on sections of initial conditions of a dynamical system. This is applied to the problem of state uncertainty propagation, where the use of an unscented transformation further allows to optimize the grid of initial conditions to propagate. Thereby, it reduces the overall computational load for such problems.

10:45 AAS 13-377 Trajectory Evolution Under Laser Photonic Propulsion in The Two-Body Problem

Fu-Yuen Hsiao, Tamkang University

The photonic laser propulsion (PLP) system can produce continuous and constant thrust. This paper reviews its basics and then studies its application in the two-body interplanetary trajectory. This study also derives the equations of motion (EOM) for a spacecraft for the two-body problem, and variation of orbit elements. This study introduces the normalized Gauss' Equations to evaluate the evolution of orbit elements with parameters of mother ship. The evolution of orbit elements also confirms the constraint on the smallest thrust as proposed in the previous study. Numerical simulations are also provided for potential applications to interplanetary travel.

11:05 AAS 13-378 A Semi-Analytical Approach to Study Resonances Effects on the Orbital Motion of Artificial Satellites

Rodolpho Moraes, UNIFESP; Sandro da Silva Fernandes, ITA; Jarbas Sampaio, UNESP/FEG; Jorge Formiga, FATEC

A semi-analytical approach is proposed to study resonances effects on the orbital motion of artificial satel-lites. Applying successive Mathieu transformations, the order of dynamical system is reduced and the final system is solved by numerical integration. Here simulations are presented showing the variations of the orbital elements of artificial satellites orbiting in the neighbourhood of the 2:1 and of the 15:1 resonance condition. Through the resonance overlap criterion the possible regular and irregular motions are investigated by the time behaviour of orbital elements. The largest Lyapunov exponent is used as tool to verify chaotic motions.

11:25 AAS 13-491 Accurate and fast orbit propagation with a new complete set of elements

Giulio Baù, University of Pisa; Claudio Bombardelli, Technical University of Madrid (UPM)

We present a new complete set of eight elements to propagate the perturbed two-body problem, which is obtained by applying the following improvements to a very efficient propagator published by Peláez et al. in 2007, and known as dromo: the method generalizes dromo to account for disturbing potentials and it introduces a time element as a dependent variable in place of the time. Our scheme shows the best performance when compared with dromo and two efficient elements methods derived from the Kustaanheimo-Stiefel and Sperling-Burdet regularizations for the J2 perturbation of Earth and J2 + Moon's perturbations.

SESSION 20: INTERPLANETARY MISSION STUDIES

Chair: Dr. Jon Sims, Jet Propulsion Laboratory

8:00 Withdrawn

8:20 AAS 13-382 MESSENGER's Maneuvers to Reduce Orbital Period during the Extended Mission: Ensuring Maximum Use of the Bi-Propellant Propulsion System

Sarah Flanigan, The Johns Hopkins University Applied Physics Laboratory

Two orbit-correction maneuvers (OCMs) were required during MESSENGER's extended mission to reduce the orbital period from 11.6 to 8 hours. The OCMs were designed as a pair to maximize use of the bi-propellant propulsion system. The first maneuver was designed to be flexible to a range of oxidizer remaining in the system. A special autonomy scheme was necessary to respond to oxidizer depletion and continue the maneuver without interruption using only monopropellant thrusters. The second maneuver executed four days later and was designed on the basis of the performance of the first maneuver.

8:40 AAS 13-383 MESSENGER Navigation Operations During The Mercury Orbital Mission Phase

Brian Page, KinetX Aerospace, Inc.; Christopher Bryan, KinetX Aerospace, Inc.; Kenneth Williams, KinetX Aerospace, Inc.; Anthony Taylor, KinetX Aerospace, Inc.; Dale Stanbridge, KinetX Aerospace, Inc.; Peter Wolff, KinetX Aerospace, Inc.; Bobby Williams, KinetX SNAFD

The MESSENGER spacecraft was launched in August 2004 and began orbiting Mercury in March 2011 for a nominal one-year scientific investigation. A mission extension was initiated in March 2012. In order to optimize the scope and return of the onboard scientific instruments and the stability of the spacecraft orbit about the planet, the orbital period was reduced from 12 to 8 hours in April 2012. This paper describes MESSENGER's Mercury orbital navigation operations and trajectory estimation performance for the mission period from Mercury orbit insertion through the nominal mission to the first 9 months of the extended mission.

9:00 AAS 13-384 Transfer Trajectory Design for the Mars Atmosphere and Volatile EvolutioN (MAVEN) Mission

David Folta, NASA Goddard Space Flight Center

The Mars Atmosphere and Volatile EvolutioN (MAVEN) mission will determine the history of the loss of volatiles from the Martian atmosphere from a highly inclined elliptical orbit. MAVEN will launch Cape Canaveral Air Force Station on an Atlas-V 401 during an extended 36-day launch period opening November 18, 2013. The MAVEN Navigation and Mission Design team performed a Monte Carlo analysis of the Type-II transfer to

characterize; dispersions of the arrival B-Plane, trajectory correction maneuvers (TCMs), and the probability of Mars impact. This paper presents analysis of critical events, maneuvers and DV budgets, and planetary protection.

9:20 AAS 13-494 Jovian Tour Design for Orbiter and Lander Missions to Europa

Stefano Campagnola, JAXA / ISAS; Brent Buffington, NASA / Caltech JPL; Anastassios Petropoulos, NASA / Caltech JPL

Europa is one of the most interesting targets for solar system exploration, as its ocean of liquid water could harbor life. Following the recommendation of the Planetary Decadal Survey, NASA commissioned a study for a flyby mission, an orbiter mission, and a lander mission. This paper presents the lander and orbiter moon tours. The total DV and radiation dose is reduced by exploiting multi-body dynamics and avoiding phasing loops in the Ganymede-to-Europa transfer. Some trajectories are presented in detail, including the baseline lander tour 12L01, and an orbiter option with Tisserand-leveraging maneuvers and a gravitational capture.

9:40 Break

10:05 AAS 13-385 Hybrid Propulsion Transfers for Mars Science Missions

Giorgio Mingotti, University of Strathclyde; Francesco Topputo, Politecnico di Milano; Mauro Massari, Politecnico di Milano

Special Earth-Mars transfers that exploit both chemical and solar electric propulsion are investigated in this work. A dedicated launch strategy via Soyuz is considered. Firstly, a high-thrust, low-Isp impulse is used to place the spacecraft onto an Earth-escape trajectory, possibly performing a lunar swingby. Then, an heliocentric rendez-vous with Mars is achieved via low-thrust, high-Isp propulsion, followed by a ballistic capture leading to a final, low-altitude orbit around Mars. Hybrid propulsion transfers outperform chemical transfers (Hohmann) in terms of propellant consumption. Furthermore, a few considerations at system level are also proposed.

10:25 AAS 13-386 An Orbit Design of AKATSUKI to Avoid Long Eclipse on its Orbit around Venus

Yasuhiro Kawakatsu, JAXA / ISAS

AKATSUKI, the Japanese Venus explorer, once failed to inject itself into the orbit around Venus in 2010, but now it is on the way to re-encounter Venus in 2015. However, due to a malfunction of the propulsion system, AKATSUKI can be only injected into the orbit much higher than that originally planned. It causes a couple of issues to be considered in its orbit design, one of which is the long eclipse on the orbit around Venus. Introduced in this paper is an orbit design strategy to avoid the long eclipse under this situation.

10:45 AAS 13-387 Observations planning optimization for BepiColombo's Mercury rotation experiment

Alessandra Palli, University of Bologna; Rachele Meriggiola, University of Rome; Luciano Iess, University of Rome; Paolo Tortora, University of Bologna

The identification of an observation planning ensuring the fulfillment of the scientific objectives is fundamental in the frame of Mercury's rotation experiment to be carried out by ESA's BepiColombo mission. The observables are represented by image pairs of the same landmark on Mercury's surface, captured at two different epochs via the on-board high resolution camera. An end-to-end software simulator was implemented, including the optimization module, to reproduce the expected experiment performance in real operations. The accuracy returned by the rotational parameters estimation module represents the figure of merit of each solution and drives the

11:05 AAS 13-388 The Trajectory Control Strategies of Akatsuki for Venus Orbit Reinsertion

Chikako Hirose, Japan Aerospace Exploration Agency

The Japanese Venus explorer "Akatsuki (PLANET-C)", which now rotates about the Sun, will approach to Venus again in 2015. For the Venus orbit re-insertion, several trajectory strategies were devised. In this paper, we introduce the difficulties we faced in redesigning the trajectory of Akatsuki after the failure of the first Venus Orbit Insertion (VOI) in 2010 and report some newly devised trajectory control strategies including Gravity Brake Method, which will make the most of the solar perturbations to conduct the Venus orbit insertion for the second time.

SESSION 21: RENDEZVOUS AND FORMATION FLYING

Chair: Dr. Ossama Abdelkhalik, Michigan Technological University

13:30 AAS 13-389 Optimal Formation Keeping near a General Keplerian Orbit under Nonlinear Perturbations

Kwangwon Lee, Yonsei University; Chandeok Park, Yonsei University; Sang-Young Park, Yonsei University; Daniel Scheeres, University of Colorado

This study presents a new semi-analytic approach to optimal spacecraft formation keeping by employing generating functions which appear in the theory of Hamiltonian systems. An appropriate generating function allows us to assign the costate as an explicit function of its associated states, and to consider any desired tracking trajectories by simple algebraic substitutions. This analytic nature is highly favorable, as it is often necessary to analyze many different boundary conditions and operational time spans for a variety of desired tracking trajectories. Numerical results demonstrate that the accommodation of higher-order nonlinearities results in more accurate tracking property.

13:50 AAS 13-390 Orbit Trajectory Design for the Boeing Commercial Crew Transportation System

Tom Mulder, Boeing

Under a Space Act Agreement with NASA, Boeing is developing a transportation system that delivers crew and cargo to the International Space Station and future Bigelow Space Complex. The launch vehicle and Boeing spacecraft will be capable of both automated (no human interaction) and autonomous (no ground assistance) flight from lift-off to docking and undocking to landing. Orbit and entry trajectory design is derived from techniques proven on Apollo-Skylab, Space Shuttle, and Orbital Express missions; mixed with new algorithms Boeing developed internally and for other programs. This paper describes orbit trajectory design for the CST-100 mission.

14:10 AAS 13-391 Minimum Time Rendezvous using Differential Drag

Matthew Harris, The University of Texas at Austin; David Hull, The University of Texas at Austin; Behcet Acikmese, The University of Texas at Austin

This paper presents a numerical scheme to solve the minimum time rendezvous problem of two spacecraft using differential drag. In light of the linear time invariant dynamics, existence and uniqueness of the minimum time control problem is guaranteed. The nonlinear programming problem is converted to a sequence of linear programming problems with guaranteed convergence to the global minimum. The linear programs appear as part of a line search for the final time on a bounded interval. Conservative lower and upper bounds for the final time are derived, and comparisons with other methods regarding computation time and flight time are made.

14:30 AAS 13-392 Optimal maintenance of relative circular inertial motion for nulling interferometry applications

Stefano Casotto, Universita' di Padova; Nicola Baresi, Universita' di Padova

A Linear Quadratic Tracker and a Linear Quadratic Regulator have been developed to study the formation keeping of two satellites performing circular relative motion on an inertial plane about a J2-perturbed elliptic orbit. A numerical model of relative motion is adopted, rather than the Hill-Clohessy-Wiltshire model, and applied to an Earth-bound analog of the back-up configuration of the L2-positioned Darwin mission. The optimal control profile is found by solving the DRE within either the LQT- or the LQR-based approach. A parametric study shows that the more realistic dynamical model leads to appreciable advantages.

14:50 AAS 13-393 Application of Relative Satellite Motion Dynamics to Lambert's Problem

Lee Jasper, University of Colorado; William Anthony, New Mexico State University; Thomas Lovell, Air Force Research Laboratory; Brett Newman, Old Dominion University

In this paper, the well-known Lambert problem, which has no known closed-form solution for inertial dynamics, is investigated as a rendezvous problem, whereby a deputy is to rendezvous with a fictitious chief. A Lambert-like guid-ance scheme based on the Hill's-Clohessy-Wiltshire model, a well-known linear solution for relative motion, is derived. A similar scheme based on a recent closed-form relative motion solution with second-order accuracy is also present-ed. The accuracy of both guidance schemes is then compared to the "true" Lambert solution for various orbital scenarios.

15:10 Break

15:35 AAS 13-395 Impulsive Hovering Formation Based on Relative Orbit Elements

Jianfeng Yin, Beihang University; Guo Zhong, Beihang University

A new set of relative orbit elements (ROE) is defined to describe the geometric characteristics of the hovering formation. An impulsive feedback control strategy based on ROE is proposed to put a satellite into a hovering pattern relative to the reference satellite. The formation can be controlled from any configuration to the hovering formation using the proposed control method. The error correction of the control laws is developed. The impulsive fuel cost of the non-Keplerian relative motion is studied compared to the continuous thrust control method. Several numerical simulations are presented to demonstrate the proposed hovering formation model.

15:55 AAS 13-396 Lyapunov-Based Guidance Schemes for In-Plane Rendezvous Using Levi-Civita Coordinates

Sonia Hernandez, The University of Texas at Austin; Maruthi Akella, The University of Texas at Austin

We present closed-loop guidance schemes using Lyapunov stability theory for rendezvous, by adopting the Levi-Civita transformation of the planar two-body problem. These coordinates are advantageous because the solution to the unperturbed differential equations is that of a linear harmonic oscillator, so the analytical solution is explicitly characterized. The control scheme progresses through thrust-coast regimes covering two phases: first, a matching of the target's semi-major axis, and second, a matching of position and velocity of the target. The control algorithm is robust, computationally fast, and can be used for both low- and high- thrust problems.

16:15 AAS 13-397 Formation Flying near the Libration Points by Impulse Control
Mai Bando, Kyushu University; Akira Ichikawa, Nanzan University

In this paper halo orbits near a collinear libration point are considered, and the maintenance problem by impulsive feedback is considered. For this purpose the equations of motion are expressed by the rotating framework whose origin is the libration point. This makes the dynamics semilinear, and the linear control theory can be employed. For the follower's orbit periodic perturbations of the halo orbit are used. To maintain such an orbit, the output regulation thoery for linear systems is used. Stabilizing feedback controls are designed via the algebraic Riccati equations of the linear quadratic regulator (LQR) for discrete-time system.

16:35 AAS 13-474 Study of Elliptical Relative Motion Control Based on Relative Orbit Elements
Jianfeng Yin, Beihang University; Chao Han, Beihang University

A new impulsive feedback control law is developed for the elliptical relative motion based on relative orbit elements (ROE). The control of the in-plane and out-of-plane relative motions can be completely decoupled using the new method, which are suitable for both elliptical and circular reference orbits. The ROE-based control method needs four thrusts to achieve the elliptical relative motion control. Two different impulsive in-plane control methods are proposed. Different typical orbit maneuvers, including formation establishment, reconfiguration, long-distance maneuver and formation keeping are simulated to demonstrate the performance of the proposed ROE-based control laws.

SESSION 22: FLIGHT DYNAMICS OPERATIONS AND SPACECRAFT AUTONOMY

Chair: David Dunham, KinetX, Inc.

13:30 AAS 13-398 Verification of the Orekit Java Implementation of the Draper Semi-analytical Satellite Theory

Paul Cefola, University at Buffalo, State University of New York; Barry Bentley, University at Cambridge; Luc Maisonobe, CS Communications & Systems; Pascal Parraud, CS Communications & Systems; Romain Di-Costanzo, CS Communications & Systems; Zachary Folcik, Arlington, MA

The verification of the java Orekit implementation of the Draper Semi-analytical Satellite Theory (DSST) is discussed. The Orekit library for space flight dynamics has been published under the open-source Apache license V2. The DSST is unique due to the included force models. However, the DSST has not been readily accessible to the wider Astrodynamics research community. Implementation in Orekit program is a comprehensive task because it involves migrating the DSST to the object-oriented java language and to a consistent decomposition strategy. The resolution of anomalies discovered during the verification process is an important product of this project.

13:50 AAS 13-399 CubeSat Collision Risk Analysis at Orbital Injection

Mauro Pontani, University of Rome "La Sapienza"; Chantal Cappelletti, GAUSS s.r.l.

The CubeSat project is aimed at increasing accessibility to space, due to the limited costs and development times for such nanosatellites. Usually Cubesats are released in clusters and, in the absence of any maneuver capability, collision risk analysis is necessary. This research includes a worst-case analysis, with reference to two distinct operational orbits and two distinct release systems, after formulating the problem as a parameter optimization problem. The results attained in this research lead to identifying some desirable characteristics of CubeSats release systems, such as the correct timing for successive releases, or the optimal position of the nanosatellite dispenser.

14:10 AAS 13-400 Effects of the Local Plasma Environment on the Dynamics of Electrodynamic Tether Systems

John Janeski, Virginia Polytechnic Institute and State University; Christopher Hall, University of New Mexico; Wayne Scales, Virginia Polytechnic Institute and State University

Electrodynamic tether (EDT) systems consist of a long tether connecting two satellites that develops a current for generating power or thrust via the system's electromagnetic interaction with the space environment. A complete system model for an EDT is developed that combines a high-fidelity tether dynamics model and a model for the tether current governed by the local plasma properties. Variations in the tether system dynamics due to the tether current model are investigated and compared to experimental data from the Plasma

Motor Generator mission. The International Reference Ionosphere model generates the plasma parameters for the current collection model.

14:30 AAS 13-401 Planning and Execution of a Specialized Maneuver for the ARTEMIS Mission: Achieving Three Goals with One Sequence

Jeffrey Marchese, UC Berkeley, Space Sciences Laboratory; Daniel Cosgrove, UC Berkeley, Space Sciences Laboratory; Sabine Frey, UC Berkeley, Space Sciences Laboratory; Manfred Bester, UC Berkeley, Space Sciences Laboratory

After Lunar orbit insertion (LOI) the ARTEMIS probes, designated P1 and P2, were in sub-optimal states with regard to attitude and spin-rate. We describe herein our project to design and apply a maneuver sequence performed on P2 to simultaneously alter the spin-rate, the attitude and the semi-major axis (SMA). The implementation of the maneuver sequence resulted in the correction of the requisite parameters with significant fuel savings over executing equivalent single-purposed maneuvers.

14:50 AAS 13-498 A Scheme for Simplified Trajectory Design in Aero-Gravity Assist Using Singular Orbits

Naoko Ogawa, Japan Aerospace Exploration Agency; Kazuhisa Fujita, Japan Aerospace Exploration Agency; Jun'ichiro Kawaguchi, Japan Aerospace Exploration Agency

This paper describes a novel strategy for simplified trajectory design in aero-gravity assist missions using one-rev singular orbits and iterative algorithms. One of difficulties in aero-gravity assist compared to usual swing-bys is that the extent of deceleration and the periapsis altitude are coupled and dependent to each other. Thus we utilize one-revolution singular orbits. One-rev orbits have a notable feature that there is a degree of freedom for orbit design, which allows us to choose several coupled parameters independently in aero-gravity assists. Detailed iterative algorithms and an example trajectory are shown.

15:10 Break

15:35 AAS 13-443 Optical Navigation Capabilities for Deep Space Missions

Coralie Jackman, KinetX, Inc.; Philip Dumont, KinetX, Inc.

KinetX, Inc., a private corporation, is currently providing navigation for three NASA deep space missions: MESSENGER, New Horizons, and OSIRIS-REx. Two of these, New Horizons to the Pluto system, and OSIRIS-REx to the asteroid 1999RQ36, rely heavily on optical navigation (OpNav) to insure mission success. KinetX developed OpNav software uses spacecraft imaging to determine the spacecraft trajectory and targets' ephemerides. This paper describes the KinetX approach to optical navigation, simulating spacecraft images for testing, processing real data, and generating products for orbit determination. Also included are imaging simulations for New Horizons and OSIRIS-REx and real data results.

15:55 AAS 13-406 Long-term Attitude and Orbit Prediction of Solar Sailing IKAROS While Being Lost in Space

Yuya Mimasu, Japan Aerospace Exploration Agency; Sho Taniguchi, Fujitsu Limited; Hiroshi Takeuchi, Japan Aerospace Exploration Agency; Yoji Shirasawa, Japan Aerospace Exploration Agency; Osamu Mori, Japan Aerospace Exploration Agency; Ryu Funase, Japan Aerospace Exploration Agency; Takanao Saiki, JAXA / ISAS; Yuichi Tsuda, Japan Aerospace Exploration Agency

The world's first solar sail IKAROS (Interplanetary Kite-craft Accelerated by Radiation Of the Sun) which is operated by Japan Aerospace Exploration Agency (JAXA) lost communication with the ground station due to the power shortage on December 24, 2011. In order to acquire IKAROS again after the power comes back, we immediately initiated to predict the attitude and orbit for the spacecraft. As the result of the effort for the prediction, finally we acquire IKAROS after 9 months. This paper presents that the attitude and orbit prediction technique, while IKAROS was lost in space.

16:15 AAS 13-407 In-Flight Aerodynamic and Mass Properties Identification Design for Mars Aerobraking

Ling Jiang, Beihang University

Aerobraking is a revolutionary technique that has been used successfully in recent Mars missions. But consideration of significant risk and cost has led to the development of autonomous aerobraking design. This paper proposes a novel method of estimating varying aerodynamic and mass properties in-flight to improve the onboard capacity for corridor controller design. The identification approach is divided into two steps: executing mass properties identification at the apoapsis walk-in and adjustment maneuvers first, and then implementing aerodynamic property estimation during atmospheric passes. Simulation results show that the proposed approach is simple and effective.

Session 23: Small-body Missions

Chair: Dr. Ryan Park, Jet Propulsion Laboratory

13:30 AAS 13-408 Classification of Distant Earth-Return Trajectories for Near-Earth Asteroid Mission Applications

Nicholas Bradley, The University of Texas at Austin; Cesar Ocampo, The University of Texas at Austin

A classification is presented that categorizes free-return trajectories in the Earth-Sun rotating frame that begin and end near the Earth with no intermediate velocity adjustments. Candidate trajectories and trajectory families are searched to determine possible orbits to rendezvous with near-Earth asteroids. Determination of trajectory families is accomplished via a numerical search technique, which uses a constrained zero-cost optimization algorithm. Hundreds of candidate trajectories are found, satisfying constraints at Earth and escape energy conditions. The trajectories are classified as periodic and non-periodic, and further subdivided as Earth-leading, Earth-trailing, in-plane, and out-of-plane.

13:50 AAS 13-409 Trajectories to Nab a NEA (Near-Earth Asteroid)

Damon Landau, NASA / Caltech JPL; John Dankanich, AeroDank, Inc.; Nathan Strange, NASA / Caltech JPL; Julie Bellerose, Carnegie Mellon University SV / NASA ARC; Pedro Llanos, University of Southern California; Marco Tantardini, The Planetary Society

In 2010 and 2011 NASA and KISS sponsored studies to investigate the feasibility of identifying, capturing, and returning an entire (albeit small) NEA to the vicinity of Earth, and concluded that a 40kW solar electric propulsion system launched on an Atlas551 provided sufficient propulsion to control an asteroids trajectory. Once secured by the spacecraft, a NEA with a naturally close encounter with Earth is nudged over a few years to target a lunar gravity assist, capturing the object into Earth orbit. With further use of solar perturbations, up to 3,600,000kg of NEA could enter in high-lunar orbit.

14:10 AAS 13-411 Design, Dynamics and Stability of the OSIRIS-REx Sun-Terminator Orbits

Daniel Scheeres, University of Colorado; Brian Sutter, Lockheed-Martin

OSIRIS-REx is a NASA asteroid sample return mission that launches in 2016 and visits asteroid 1999 RQ36. To support its main goal of surface sampling, the spacecraft must orbit in close proximity to the asteroid to estimate accurate models of the asteroid's shape, gravity field and spin state. To do this it is essential that the spacecraft reside in an orbit that is relatively close to the asteroid and which is stable enough to not require trajectory control maneuvers for periods up to a few weeks. This paper with discuss the dynamics, design and implementation of these orbits.

14:30 AAS 13-412 Electric Propulsion Alternatives for the OSIRIS-REx Mission

Kamesh Sankaran, Whitworth University; Christopher Grochowski, Whitworth University; Jonathan Hoff, Whitworth University

This study evaluated the ability of eight existing ion and Hall thrusters to meet some of the key requirements of the OSIRIS-REx mission to the asteroid 1999RQ36, and return with a sample of the asteroid to Earth. The thrusters were chosen based on demonstrated performance and lifetime characteristics at power levels higher than 5 kW, and were evaluated for this mission at their measured performance levels. The resulting values of trip time and wet mass at LEO for the evaluated thrusters are compared with the existing plan of the OSIRIS-REx mission.

14:50 AAS 13-413 Terminal Guidance Navigation for an Asteroid Deflection Spacecraft

Shyam Bhaskaran, NASA / Caltech JPL; Brian Kennedy, NASA / Caltech JPL

Kinetic deflection with a spacecraft is a viable technique for mitigating the threat of an Earth impacting asteroid. The technique to do this was demonstrated with the Deep Impact mission, using an onboard autonomous navigation system to perform the terminal guidance to impact. In this paper, we expand on the use of this system for the various mission parameters that a deflection mission might encounter, such as the approach phase angle and velocity, and size and shape of the asteroid. Monte Carlo simulations were performed to assess the ability of the system to perform the task under the various conditions.

15:10 Break

15:35 AAS 13-414 Trajectory Exploration Within Binary Systems Comprised of Small Irregular Bodies

Loic Chappaz, Purdue University; Kathleen Howell, Purdue University

In an initial investigation into the behavior of a spacecraft near a pair of irregular bodies, consider the full two body problem with an ellipsoidal primary and a second spherical primary. Two primary configurations are addressed: "synchronous" and "non-synchronous" configurations. The synchronous configuration represents a system that is analogous to the Circular Restricted Three Body Problem (CR3BP). Thus, concepts and tools similar to those applied in the CR3BP are available to design periodic trajectories for a third body in synchronous systems. In non-synchronous systems, the search for periodic orbits for a third body is more complex.

15:55 AAS 13-415 Close Proximity Operations using Stereoscopic Imaging

Jacob Darling, Missouri University of Science and Technology; Keith LeGrand, Missouri University of Science and Technology; Henry Pernicka, Missouri University of Science and Technology; Thomas Lovell, Air Force Research Laboratory; Bharat Mahajan, Missouri University of Science and Technology

The relative guidance, navigation, and control of a pair of spacecraft using real-time data from a stereoscopic imaging sensor are investigated. Relative Orbital Elements are used to model the separation between the spacecraft to ensure the secondary spacecraft stays within the usable field of view of the stereoscopic imager. An Unscented Kalman Filter is implemented to estimate the inertial states of both spacecraft given GPS and stereoscopic imaging measurements aboard the primary spacecraft along with an SDRE controller to maintain a desired trajectory about the secondary spacecraft.

16:15 AAS 13-416 Alternative Hybrid Propulsion Transfers for Marco Polo NEOs Sample Return Mission

Mauro Massari, Politecnico di Milano; Francesco Topputo, Politecnico di Milano; Giorgio Mingotti, University of Strathclyde

In this paper the new concept of hybrid propulsion transfers is applied to the trajectory design for the ESA MarcoPolo mission, a NEO sample return mission. The concept of hybrid propulsion transfers combine the features of low-energy transfer, which implies impulsive maneuver accomplished using chemical propulsion, and low-thrust transfer. The optimization is performed with a direct transcription procedure. The problem is formulated as a nonlinear programming problem and solved for a finite set of variables, maximizing the final spacecraft mass. The designed hybrid propulsion transfers have been in-depth compared with the baseline trajectories obtained for MarcoPolo mission.

16:35 AAS 13-417 A simulation study of gravity and ephemeris estimation of asteroid 1999JU3 using spacecraft radiometric tracking, optical, and altimeter measurements

Hitoshi Ikeda, Japan Aerospace Exploration Agency; Yuichi Tsuda, Japan Aerospace Exploration Agency; Yuya Mimasu, Japan Aerospace Exploration Agency; Makoto Yoshikawa, Japan Aerospace Exploration Agency

The Japanese asteroid explorer Hayabusa-2 will be launched to return samples from asteroid 1999JU3. The physical parameters of the target body are very important not only for its scientific investigation but also for the spacecraft navigation. In particular, the gravity is essential to perform a stable touch down sequence to collect samples from the asteroid's surface. We performed a simulation study of gravity estimation using earth-based radiometric tracking measurements (2way RARR) and spacecraft-based measurements (optical camera and laser altimeter) with global parameter estimation technique. We will also present a method for ephemeris improvement of 1999JU3.

SESSION 24: SPECIAL SESSION: MARS SCIENCE LABORATORY (MSL) -- III

Chair: Dr. Eric Gustafson, Jet Propulsion Laboratory

13:30 AAS 13-424 Powered Flight Design and Reconstructed Performance Summary for the Mars Science Laboratory Mission
Steven Sell, NASA / Caltech JPL

The Powered Flight segment of Mars Science Laboratory's Entry, Descent, and Landing system extends from backshell separation through landing. Although this segment removes less than 0.1% of the kinetic energy dissipated during EDL, any segment that ends in touchdown on the surface of Mars is particularly critical. This paper provides an overview of the powered flight design, key features, and event timeline. It also summarizes Curiosity's as flown performance on the night of August 5th as reconstructed by the flight team.

13:50 AAS 13-425 Approach and Entry, Descent, and Landing Operations for the Mars Science Laboratory Mission
Allen Chen, NASA / Caltech JPL

On August 5th, 2012, at 10:31 PM PDT, the Mars Science Laboratory (MSL) rover Curiosity landed safely within Gale Crater. Her successful landing depended not only upon the flawless execution of the numerous critical activities during the seven minute entry, descent, and landing (EDL), but also upon the operational preparations and decisions made by the flight team during approach, the final weeks, days, and hours prior to landing. This paper summarizes the operations plans made in preparation for EDL and the as flown decisions and actions executed that balanced the operational and EDL risks.

14:10 AAS 13-426 The Mars Science Laboratory Entry, Descent, and Landing Flight Software
Kim Gostelow, NASA / Caltech JPL

This paper describes the design, development, and testing of the EDL program from the perspective of the software engineer. We briefly cover the overall MSL flight software organization, and then the organization of EDL itself. We discuss the timeline, the structure of the GNC code (but not the algorithms as they are covered elsewhere in this conference) and the command and telemetry interfaces. Finally, we cover testing and the influence that testability had on the EDL flight software design.

14:30 AAS 13-458 Design and Development of the MSL Descent Stage Propulsion System
Jeffrey Weiss, NASA / Caltech JPL

On August 5, 2012, The Mars Science Laboratory mission successfully landed the largest interplanetary rover ever built, Curiosity, on the surface of Mars. The Entry, Descent, and Landing (EDL) phase of this mission was by far the most complex landing ever attempted on a planetary body. The Descent Stage Propulsion System (DSPS) played an integral and critical role during Curiosity's EDL. The purpose of this paper is to present an overview of the design and development of the MSL DSPS. Driving requirements, system design, component selection, new developments, and key challenges will be discussed.

14:50 AAS 13-457 Lessons Learned from the Development of the MSL Descent Stage Propulsion System

Carl Guernsey, NASA / Caltech JPL; Jeffrey Weiss, NASA / Caltech JPL

Development of the MSL descent stage propulsion system required a number of new propulsion hardware developments incorporating technologies not normally found in spacecraft propulsion subsystems. These requirements were driven by the relatively high (25,000 N) thrust level and the requirement for precise throttling of the main engine. This paper presents lessons learned in the course of these developments, including surprises and anomalies discovered at the subsystem level as well as the component level.

15:10 Break

15:35 AAS 13-461 Fabrication, Assembly & Test of the Mars Science Laboratory (MSL) Descent Stage Propulsion System.

Morgan Parker, NASA / Caltech JPL; Raymond Baker, NASA / Caltech JPL; Art Casillas, NASA / Caltech JPL; Dellon Strommen, NASA / Caltech JPL; Rebekah Tanimoto, NASA / Caltech JPL

The MSL Descent Stage Propulsion System (DSPS) guided the rover Curiosity through the Martian atmosphere and and landed Curiosity safely on the surface of Mars. The DSPS is the most challenging and complex propulsion system ever built at JPL. This paper will examine challenges and solutions encountered during the fabrication, assembly, and test of the DSPS, including the distributed and cramped nature of the configuration, 7 different tubing sizes ranging from 0.25" up to 1.25" O.D, 46 unique weld schedules and over 300 tubing welds, shorting of structural loads through the larger tubing, and numerous other challenges.

15:55 AAS 13-464 Verification and Validation of the MSL/Curiosity Rover Entry Descent and Landing System

Richard Kornfeld, NASA / Caltech JPL; Ravi Prakash, NASA / Caltech JPL; Allen Chen, NASA / Caltech JPL; Ann Devereaux, NASA / Caltech JPL; Martin Greco, NASA / Caltech JPL; Corey Harmon, NASA / Caltech JPL; Devin Kipp, NASA / Caltech JPL; Alejandro San Martin, NASA / Caltech JPL; Steven Sell, NASA / Caltech JPL; Adam Steltzner, NASA / Caltech JPL

On August 5/6, 2012, the Curiosity rover successfully touched down on the Martian surface setting off the most ambitious surface exploration of this planetary body. Preceding this significant step were years of design, development and testing of the Curiosity Entry, Descent and Landing (EDL) system to prepare for the most complex landing endeavor ever attempted at Mars. This paper discusses the approach and implementation of the overall EDL verification and validation (V&V) program. The lessons learned and conclusions described herein can serve as a pathfinder for the EDL system testing approach and implementation of future Mars landed missions.

16:15 AAS 13-463 Managing Complexity in the MSL/Curiosity Entry, Descent, and Landing Flight Software and Avionics Verification and Validation Campaign

Aaron Stehura, NASA / Caltech JPL; Matthew Rozek, NASA / Caltech JPL

The complexity of the Mars Science Laboratory (MSL) mission presented the Entry, Descent, and Landing systems engineering team with many challenges in its Verification and Validation (V&V) campaign. This paper describes some of the logistical hurdles related to managing a complex set of requirements, test venues, test objectives, and analysis products faced by the authors as they implemented a specific portion of V&V to test the interaction of flight software with the MSL avionics. Application-specific solutions to these problems are presented herein, which can be generalized to other space missions and to similar formidable systems engineering problems.

SESSION 25: SPACE SITUATIONAL AWARENESS AND CONJUNCTION ANALYSIS -- II

Chair: Dr. Ryan Russell, University of Texas at Austin

8:00 AAS 13-429 Application of a Laser Rangefinder for Space Object Imaging and Shape Reconstruction

Michael Nayak, Space Development & Test Directorate, US Air Force; Bogdan Udrea, Embry-Riddle Aeronautical University

This paper investigates the application of a laser rangefinder (LRF) for generation of a point cloud of a Resident Space Object (RSO), with sufficient resolution to provide comparable registration and shape reconstruction to an imaging LIDAR, for an SSA mission scenario. We examine a method that employs a combination of relative motion between the chaser and RSO & chaser attitude motion to perform 3D RSO imaging. These techniques are applied to reconstructing asteroid 1999-RQ36, of interest to NASA's OSIRIS-REx mission, and RSOs shaped as generic geostationary telecommunications satellites, and validated with inclusion of stochastic & pulse-dilation error models.

8:20 AAS 13-430 Sensitivity Analysis of the Lightcurve Measurement Model for Use in Attitude and Shape Estimation of Resident Space Objects

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

This paper will focus on a recently used light curve measurement model that was based on developments in the computer graphics area and the information contained therein to evaluate the model's effectiveness in characterizing the attitude, angular velocty and shape parameters of an RSO. This evaluation will be performed using synthetic measurements generated for representative object attitude maneuvers. Numerical sensitivities (observation matrix) will be computed and a detailed study will be conducted to study the information present in this measurement.

8:40 AAS 13-433 Comparing the Reid Cost to the Mahalanobis Distance for Uncorrelated Track Association

Cornelius Chow, Pacific Defense Solutions, LLC.; Keric Hill, Pacific Defense Solutions, LLC.; Joshua Horwood, Numerica Corporation; Chris Sabol, Air Force Maui Optical and Supercomputing

A central problem faced by the space surveillance community is the problem of track-to-track association. Under Gaussian assumptions a track state can be characterized by its first two moments (mean and covariance). As such, the Mahalanobis distance is commonly used to parametrize the correlation of data sets. However, naive summations of information yield large association hypervolumes that increase the likelihood of false alarms. The Reid cost instead scales the product of the probability densities of both tracks by a third fused estimate. Simulations of 1000 space objects show tremendous improvement in resolving associations when using Reid's function.

9:00 AAS 13-435 Operating Characteristic Approach to Effective Satellite Conjunction Filtering

Salvatore Alfano, Center for Space Standards and Innovation; David Finkleman, Center for Space Standards and Innovation

This paper extends concepts of signal detection theory to predicting the performance of conjunction screening techniques. Conjunction filter parameters are determined based on tradeoffs between Type I and Type II errors, admitting infeasible conjunctions and missing valid conjunction estimates. We take the most trustworthy and precise orbits of the satellite catalog to be ground truth. All filters use simplified models of orbit dynamics. The orbit path filter suffers significant Type I errors even with extremely large “pads”. Path filters achieve very low Type II error rates with pad sizes of 50 km or greater.

9:20 AAS 13-431 An AEGIS-FISST Sensor Management Approach for Joint Detection and Tracking in SSA

Islam Hussein, University of New Mexico; Richard Erwin, Air Force Research Laboratory; Moriba Jah, Air Force Research Laboratory

In this paper our goal is to develop information-based metrics for sensor allocation. However, conventional information-based approaches to the sensor allocation problem are mostly dedicated to the problem of sensor allocation for multi-object tracking (without detection). Thus, we develop a Finite Set Statistical (FISST) approach to sensor allocation for joint search, detection and tracking. Moreover, we seek to obtain closed-form sensor allocation metrics using the AEGIS-FISST framework which we have recently developed.

9:40 Break

10:05 AAS 13-432 An AEGIS-FISST Algorithm for Joint Detection, Classification and Tracking

Islam Hussein, University of New Mexico; Carolin Früh, Air Force Research Laboratory; Richard Erwin, Air Force Research Laboratory; Moriba Jah, Air Force Research Laboratory

The goal of this paper is to use finite set statistics to solve the joint detection, classification and tracking problem in space situational awareness. The resulting FISST filter will be termed Multi-Target, Multi-Class (MTMC) FISST filter and extends the existing multi-target FISST filter used for joint detection and tracking (without classification). We will directly approximate the FISST equations using the Gaussian mixtures AEGIS, which is an estimation approach for non-linear continuous dynamical systems. While the general theory will be introduced, we will demonstrate it on a simple SSA single-object detection, classification and tracking problem.

10:25 AAS 13-434 Orbit Determination Of An Uncooperative RSO Using A Stereo Vision-Based Sensor

Bharat Mahajan, Missouri University of Science and Technology; Henry Pernicka, Missouri University of Science and Technology; Jacob Darling, Missouri University of Science and Technology

This study focuses on the capability of an inspector spacecraft to determine the orbit and ballistic coefficient of a resident space object using an onboard passive stereo vision-based relative navigation sensor. The inspector spacecraft absolute position (from GPS) is used in addition to the vision-based sensor data by onboard filters to estimate the RSO orbit. An LQG controller enables the inspector to continuously track the object by using stereo images from the sensor. The accuracy degradation in the orbit determination process due to the vision sensor measurement errors are analyzed using consider covariance analsyis.

10:45 AAS 13-436 Optimal Impulsive Collision Avoidance

Claudio Bombardelli, Technical University of Madrid (UPM)

Closed-form analytical expressions are provided to accurately estimate the minimum distance between two orbiting bodies following a generic impulsive collision avoidance maneuver. The expressions, which are valid for generic elliptical orbits, are validated with a full numerical model and employed to derive optimal maneuver direction and orbit location in order to maximize the close approach distance between the colliding bodies. While long warning time maneuvers appear to be optimal when the impulse is virtually tangent to the orbit the case of short warning time presents less intuitive results.

SESSION 26: ATTITUDE DETERMINATION, DYNAMICS, AND CONTROL -- IV

Chair: Dr. Maruthi R. Akella, The University of Texas at Austin

8:00 AAS 13-475 An Accurate and Efficient Gaussian Fit Centroiding Algorithm for Star Trackers

Tjorven Delabie, KU Leuven; Joris De Schutter, KU Leuven; Bart Vandenbussche, KU Leuven

This paper presents a novel centroiding algorithm for star trackers. The proposed algorithm fits an elliptical Gaussian function to the measured pixel data and derives explicit expressions to determine the centroids of the stars. The algorithm proved in tests to yield accuracy comparable to that of the most accurate existing algorithms, while being significantly less computationally intensive. This reduction in computational cost allows to improve performance by acquiring the attitude estimates at a higher rate. It is also a valuable contribution to the expanding field of small satellites, where it could enable low-cost platforms to have highly accurate attitude.

8:20 AAS 13-485 Attitude and Orbit Propagations of High Area-to-Mass Ratio (HAMR) Objects Using a Semi-Coupled Approach

Carolin Früh, Air Force Research Laboratory; Moriba Jah, Air Force Research Laboratory

In this paper a new approach is presented to propagate the attitude and orbital motion of objects with high area-to-mass ratios (HAMR) in near geostationary orbit in a semi-coupled approach. To ease the computational burden and allow real time applications, orbit and attitude motion are not propagated as fully coupled system, but only initialized as fully coupled and then decoupled and propagated independently, using the values derived in the initialization step as a priori values. Entropy serves as a double metric and the system is triggered to re-coupled again.

8:40 AAS 13-476 Attitude Determination for the Van Allen Probes

Adam Fosbury, The Johns Hopkins University Applied Physics Laboratory; Gabe D. Rogers, The Johns Hopkins University Applied Physics Laboratory; John H. Wirzburger, The Johns Hopkins University Applied Physics Laboratory; Madeline N. Kirk, The Johns Hopkins University Applied Physics Laboratory; J. Courtney Ray, The Johns Hopkins University Applied Physics Laboratory

This paper describes the ground-based attitude estimation system used by the Van Allen Probes. This system consists of three algorithms with varying levels of fidelity and complexity. Attitude estimation results from each algorithm are presented along with descriptions of, and solutions to, challenges encountered during the commissioning period. Results have had better than expected accuracy, surpassing the spacecraft's requirements.

9:00 AAS 13-478 Sigma Point Transformation for Gaussian Mixture Distributions Applied to Attitude Estimation

Richard Linares, University at Buffalo, State University of New York; John Crassidis, University at Buffalo, State University of New York

This paper describes the development of an approximate method for propagating uncertainty through stochastic dynamical systems using a quadrature rule integration based method. The development of quadrature rules for Gaussian mixture distributions is discussed. A numerical solution to this problem is considered that uses a Gram-Schmidt process. The new approach is applied to the attitude estimation problem where a quadrature expansion is considered on SO(3). The proposed method outperforms the unscented kalman filter for attitude estimation while providing an expansion that maintains the attitude parameterizations on SO(3).

9:20 AAS 13-210 Cubesat Attitude Control Systems with Magnetic Torquers and Flywheel

Junquan Li, York University; Mark Post, York University; Regina Lee, York University

The accuracy of nanosatellite attitude control using pure magnetic actuators only is low and on the order less than 5 degrees. The main reason is that the magnetic torque is only orthogonal to the instantaneous direction of the Earth's magnetic field. In this paper, the pure magnetic control and hybird magnetic control numerical simulations are presented for nadir pointing and limb pointing. The results show that precise attitude tracking can be reached using hybrid magnetic control. The attitude control accuracy of hybrid nonlinear sliding mode control method is less that 0.5 degree.

9:40 Break

10:05 AAS 13-481 Nanosatellite Sun Sensor Attitude Determination using Low-Cost Hardware

Mark Post, York University; Junquan Li, York University; Regina Lee, York University

This paper outlines the development of two coarse sun sensor methodologies that are compact and efficient enough for a CubeSat-class nanosatellite: direct measurement of the solar angle using a photodiode array sensor, and estimation of the solar angle using current measurements from an array of solar cells. An overview of the technology and hardware designs used is provided in the context of a university nanosatellite development program. Testing results from the sun sensors on a laboratory attitude control system are used to validate and compare the performance of the two methodologies for nanosatellite attitude control.

10:25 AAS 13-479 Optimization of Directional Sensor Orientation with Application to Photodiodes for Spacecraft Attitude Determination

John Springmann, University of Michigan; James Cutler, University of Michigan

We present a method to optimize the orientation of body-mounted directional sensors and instruments. The optimization formulation consists of using the attitude sphere to create directions over which to optimize, and deriving an objective function that uses these directions along with their weights. The optimization method demonstrated by application to photodiodes for spacecraft attitude determination, in which the orientation of the photodiodes are optimized to provide the most accurate sun vector estimates with the given hardware. This technique maximizes subsystem performance and provides a design method to replace traditional, iterative design approaches to sensor placement.

10:45 AAS 13-482 Sensor Calibration for the MICROSCOPE Satellite Mission

Hanns Selig, ZARM (Center of Applied Space Technology and Microgravity), University of Bremen

The French drag free satellite mission MICROSCOPE (launch in 2017) will perform a test of the universality of free fall (Equivalence Principle - EP) to a new level of accuracy. The payload consists of two sensors, each controlling the free fall of a pair of test masses. The EP test strongly depends on the rejection of disturbances arising from the coupling and misalignments of the instrument vectorial outputs. Therefore the performance of the mission depends on the success of the calibration operations which are planned during the satellite life in orbit, as well as on ground at the ZARM drop tower.

SESSION 27: SPACECRAFT GUIDANCE, NAVIGATION, AND CONTROL -- II

Chair: Dr. Marcus Holzinger, Georgia Institute of Technology

8:00 AAS 13-438 Precision Landing at Mars Using Discrete-event Drag Modulation

Zachary Putnam, Georgia Institute of Technology; Robert Braun, Georgia Institute of Technology

An entry, descent, and landing system concept for achieving Mars Science Laboratory class accuracy for a Mars Exploration Rover class payload at Mars is presented. The concept uses a single drag-area jettison event to control its trajectory during entry. A three-degree-of-freedom trajectory simulation is used in conjunction with Monte Carlo techniques to assess the performance of the entry, descent, and landing system concept. Results indicate a terminal accuracy competitive with pre-flight Mars Science Laboratory estimates and a significant reduction in peak heat rate and integrated heat load relative to the Mars Exploration Rover entry system.

8:20 AAS 13-439 Decentralized Guidance of Swarms of Spacecraft Using a Model Predictive Control Implementation of Sequential Convex Programming

Daniel Morgan, University of Illinois at Urbana-Champaign; Soon-Jo Chung, University of Illinois at Urbana-Champaign; Fred Y. Hadaegh, NASA / Caltech JPL

This paper presents a decentralized, model predictive control algorithm for the reconfiguration of swarms of spacecraft composed of hundreds to thousands of agents with limited capabilities. In our prior work, sequential convex programming has been used to determine collision-free, fuel-efficient trajectories for the reconfiguration of spacecraft swarms. This paper uses a model predictive control implementation of the sequential convex programming algorithm in real-time. By updating the optimal trajectories during the reconfiguration, the model predictive control algorithm becomes decentralized and more robust to errors in sensing and actuation.

8:40 AAS 13-440 Spacecraft Maneuvering via Atmospheric Differential Drag Using an Adaptive Lyapunov Controller

David Perez, Rensselaer Polytechnic Institute; Riccardo Bevilacqua, Rensselaer Polytechnic Institute

An adaptive Lyapunov Controller originally proposed by the authors in previous work for a rendezvous maneuver using differential drag is here generalized allowing for the tracking of reference trajectories or dynamics. The control algorithm is tested using Systems Tool Kit simulations for a Re-phase, a Fly-around, and a rendezvous maneuvers. The interest in autonomous propellant-less maneuvering comes from the desire of reducing costs for performing formation maneuvering. Successful autonomous propellant-less maneuvering of LEO S/C can be achieved using Differential Drag.

9:00 AAS 13-441 Model Diagnostics and Dynamic Emulation: Enhancing the Understanding and Impact of Complex Models in Satellite Constellation Design

Ryan McKennon-Kelly, The Aerospace Corporation; Patrick Reed, The Pennsylvania State University; David Spencer, The Pennsylvania State University; Matthew Ferringer, The Aerospace Corporation

This paper proposes and demonstrates sensitivity-informed model diagnostics as applied to constellation design (CD). Model diagnostics provide guidance on how computationally intensive simulations can be simplified; yielding substantial computational savings while minimally impacting fidelity. Current methods average performance for various locations over a year; preventing nuanced evaluation of systems, and preventing the tailoring of the design for specific applications. We discovered the most important inputs, times, and locations for analysis; highlighting key dynamics typically occluded by averaging. We guided creation of simplified models we call "dynamic emulators", with significant potential for improving the computational tractability of intensive design optimization.

9:20 AAS 13-442 Simulation and Analysis of a Phobos-anchored Tether

Andrew Klesh, NASA / Caltech JPL; Eric Gustafson, NASA / Caltech JPL

We investigate the dynamics and feasibility of a light-weight tether anchored to Phobos near Stickney crater. The tether is initially deployed along the Mars-Phobos line with its tip sitting beyond the Mars-Phobos L1 point. Such a tether could potentially provide a stable, low-gravity anchor point for human or robotic missions, or serve as an elevator for Phobos resources. Unfortunately trajectories near the L1 point are unstable, and there are proportionally large disturbance forces. We model the tether and simulate the evolution of its position to determine the feasibility and potential control needs of implementation.

9:40 Break

10:05 AAS 13-444 Spacecraft Navigation Using Celestial Gamma-ray Sources

Chuck Hisamoto, ASTER Labs, Inc.; Suneel Sheikh, ASTER Labs, Inc.; Zaven Arzoumanian, Independent Contractor

Techniques for determining spacecraft position using celestial gamma-ray sources are presented. These bright, high-energy events provide well-defined characteristics conducive to accurate time-alignment among spacecraft detectors. Utilizing assemblages of photons from distant gamma-ray bursts, relative positions between two spacecraft can be accurately computed along the direction to the source based upon the difference in arrival time of the burst at each spacecraft's location. Burst profile correlation methods used to time-align the high energy signals are provided. Navigation algorithm simulations using future observation capabilities demonstrate position uncertainties comparable to the NASA Deep Space Network.

10:25 AAS 13-487 Potential Effects of a Realistic Solar Sail and Comparison to an Ideal Sail

Jules Simo, University of Strathclyde; Colin McInnes, Advanced Space Concepts Laboratory, University of Strathclyde

In this paper, novel families of highly non-Keplerian orbits for spacecraft utilising solar sail at linear order are investigated in the Earth-Moon circular restricted three-body problem. Firstly, it is assumed implicitly that the solar sail is a perfect reflector. The orbits were accomplished by using an optimal choice of the sail pitch angle, which maximize the out-of-plane distance. Thereafter, the resulting effects of the non-ideal flat sail model have been computed and compared with an ideal solar sail. The main effect of the non-perfect sail is to reduce the out-of-plane displacement.

10:45 AAS 13-445 Station-Keeping Strategies for Satellite Constellation

Hongzheng Cui, Beijing Aerospace Control Center; Geshi Tang, Beijing Aerospace Control Center; Jianfeng Yin, Beihang University; Hao Huang, Beihang University; Chao Han, Beihang University

This paper firstly introduces the concepts on control box and control reference for absolute and relative station-keeping, how to determine the control reference, and the uniform control flow for different station-keeping strategies. And then, studies the different station-keeping control-laws for Walker constellation, including different orbital regions. The demonstration experiments concerning different station-keeping strategies are carried out with initial orbit element errors and control tolerance based on Constellation Station Keeping Kit (CSKK), which is recently designed and developed recently at BACC for satellte constellation operation demonstration.

SESSION 28: MISSION/MANEUVER DESIGN

Chair: Dr. Rodney Anderson, Jet Propulsion Laboratory

8:00 AAS 13-447 Modeling and Simulation of the MICROSCOPE mission
Meike List, ZARM (Center of Applied Space Technology and Microgravity), University of Bremen

The French MICROSCOPE mission is designed to test the weak Equivalence Principle with an accuracy of 1E-15. The experiment will be carried out on board of a small satellite, developed and produced within the CNES Myriad series. The desired accuracy of the measurement will be provided with the help of two high-precision capacitive diff erential accelerometers. The ZARM is involved in the mission data evaluation process. In this context a comprehensive simulation of the real system is being set up. The simulation tool HPS as well as an overview about different modelling aspects will be presented.

8:20 AAS 13-449 Orbital Transfer Techniques for Round-Trip Mars Missions
Damon Landau, NASA / Caltech JPL

The human exploration of Phobos and Deimos presents a highly constrained orbital transfer problem, as the equatorial plane is generally not accessible from the arrival/departure interplanetary trajectories with energetically optimal maneuvers. The proposed strategy shifts the arrival/departure maneuvers away from periapsis so that the apsides of the parking orbit lie in the plane of the target orbit, permitting efficient plane change maneuvers at apoapsis of an elliptical parking orbit. This technique is approximately five times as efficient as shifting the apsides in orbit, providing significant propellant savings to transfer between the arrival, target, and departure orbits at Mars.

8:40 AAS 13-451 Optimal Mixed Impulsive/Continuous Thrust Trajectories to the Interior Earth-Moon L1 Lagrange Point
Daero Lee, New Mexico State University; Eric Butcher, New Mexico State University; Amit Sanyal, New Mexico State University

Optimal transfer trajectories are designed for a spacecraft using mixed impulsive and continuous thrust propulsion to depart low-Earth orbit and enter a specified planar Lyapunov orbit at the interior Earth-Moon L1 Lagrange point in the framework of the planar Circular Restricted Three Body Problem. The flight time and impulsive/continuous thrust weighting factor are specified in advance. The continuous dynamic optimization problem is reformulated as a discrete optimization through direct transcription and collocation, which then is solved using nonlinear programming software. The design results of various types of transfer trajectories are analyzed through the parametric study.

9:00 AAS 13-452 The Plans for Getting OCO-2 into Orbit
Mark Vincent, Raytheon; Mark Garcia, NASA / Caltech JPL

A detailed comparison will be made between the planned method for inserting the Orbiting Carbon Observatory 2 (OCO-2) into the A-train and the one that would have been used had OCO-1 successfully achieved its Injection Orbit. Ma-jor differences arise from the fact that OCO-1 was launched on a Taurus XL with a target 65 km below the A-Train while OCO-2 will be launched on a Delta II with a likely target only 15 km below the A-Train. Comparisons will include the designs to handle nominal, off-nominal, and contingency cases.

9:20 AAS 13-466 Lyapunov-Floquet Transformation of Satellite Relative Motion in Elliptic Orbits

Ryan Sherrill, Auburn University; Andrew Sinclair, 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. A Lyapunov-Floquet transformation has been determined which relates the linearized equations of relative motion to the Hill-Clohessy-Wiltshire equations through a periodic coordinate transformation. This transformation allows the Hill-Clohessy-Wiltshire equations to describe the relative motion for any elliptic orbit.

9:40 Break

10:05 AAS 13-467 Calibration of Linearized Solutions for Satellite Relative Motion

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

The motion of a deputy satellite relative to a chief satellite can be described with either Cartesian coordinates or orbital-element differences. For close proximity, both descriptions can be linearized. An underappreciated fact is that the linearized descriptions are equivalent: the linearized transformation between the two solves the linearized dynamics. This suggests a calibrated initial condition for linearized Cartesian propagation that is related to the orbital-element differences by the linearized transformation. This calibration greatly increases the domain of validity of the linearized approximation, and provides far greater accuracy in matching the nonlinear solution over a larger range of separations.

10:25 AAS 13-454 Mission Design for NASA's Van Allen Probes Mission

Fazle Siddique, The Johns Hopkins University Applied Physics Laboratory; Gene Heyler, The Johns Hopkins University Applied Physics Laboratory

The Van Allen Probes mission, part of NASA's Living With a Star Program, successfully launched on August 30th, 2012 from Cape Canaveral. The two year mission consists of two spin stabilized spacecraft in highly eccentric Earth orbits that cause one spacecraft to lap the other approximately four times per year and provide insight into the dynamics of

Earth's radiation belts. The observatories were designed, built, and operated by the Johns Hopkins University Applied Physics Laboratory. This paper describes the spacecraft and instruments, the trajectory design, the launch windows and targeting, the post-separation correction and notional decommissioning plans.

10:45 AAS 13-455 Ongoing Mission Analysis for the Solar TErrestrial RElations Observatory (STEREO)

Christopher Scott, The Johns Hopkins University Applied Physics Laboratory; Martin Ozimek, The Johns Hopkins University Applied Physics Laboratory

The state of mission analysis for the ongoing Solar Terrestrial Relations Observatory is presented. Recent developments include the construction of a 20-year predictive ephemeris that compares modeling sensitivity. Additionally, a detrending analysis was undertaken on the coefficient of solar reflectivity. Finally, hypothetical mission extension options are studied given the remaining fuel on each of the spacecraft, including small-body flybys and Earth-moon system capture. All small-bodies that pass nearby both STEREO satellites are considered for flyby targeting, and capture trajectories are validated with stability mapping. High-fidelity end-to-end mission design scenarios are then presented.

11:05 AAS 13-456 Orbital Accessibility Problem for Spacecraft with a Single Impulse

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

Orbital accessibility problem for spacecraft under a single impulsive maneuver was investigated. The theory of orbital boundary value problem was adopted to attain a geometrical description of the accessibility condition, which was further converted to an algebraic proposition. Three typical applications have been suggested: to solve orbital accessibility problem when both the impulse magnitude and the destination are specified, to search the minimum impulse required when only the destination is given, and to calculate the reachable domain when only the impulse magnitude is given. Numerical examples validated the proposition and demonstrated its three typical applications.

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18	Kauai Salon 2	AAS 13-363	Patera	Attitude Reconstruction Analysis of the …
19	Kauai Salon 3	AAS 13-373	Vallado, Kelso	EOP and Space Weather Data for Flight Operations
20	Puna Room C&D	AAS 13-383	Page, et al.	MESSENGER Navigation Operations During …
		9:00		
18	Kauai Salon 2	AAS 13-364	Burton, Rock	Online Attitude Determination of a Passively …
19	Kauai Salon 3	AAS 13-374	Wetterer, et al.	Refining Space Object Radiation Pressure …
20	Puna Room C&D	AAS 13-384	Folta	Transfer Trajectory Design for the Mars …
		9:20		
17	Kauai Salon 1	AAS 13-355	Hejduk	Trajectory Error and Covariance Realism for …
18	Kauai Salon 2	AAS 13-365	Ghosh, et al.	Development of the Illinisat-2 Attitude …
19	Kauai Salon 3	AAS 13-375	Ko, Scheeres	Essential Thrust Fourier Coefficient Set …
20	Puna Room C&D	AAS 13-494	Campagnola, et al.	Jovian Tour Design for Orbiter and Lander …
		BREAK: 9:40 - 10:05		
		10:05		
17	Kauai Salon 1	AAS 13-357	Phillips	On-Board Estimation of Collision Probability …
18	Kauai Salon 2	AAS 13-366	Nagabhushan, et al.	Estimation of Spacecraft Angular Acceleration …
19	Kauai Salon 3	AAS 13-321	Arora, Russell	Fast Interpolation of High Fidelity Gravity Fields
20	Puna Room C&D	AAS 13-385	Mingotti, et al.	Hybrid Propulsion Transfers for Mars Science …
		10:25		
17	Kauai Salon 1	AAS 13-359	Coder, Holzinger	Autonomy Architecture for a Raven-Class …
18	Kauai Salon 2	AAS 13-367	Kim	Closed-form Optimal Maneuver Control …
19	Kauai Salon 3	AAS 13-376	Nakhjiri, Villac	An Algorithm for Trajectory Propagation …
20	Puna Room C&D	AAS 13-386	Kawakatsu	An Orbit Design of AKATSUKI to Avoid …
		10:45		
17	Kauai Salon 1	AAS 13-360	Hametz	A Geometric Analysis to Protect Manned …
18	Kauai Salon 2	AAS 13-368	Wang, et al.	Attitude Tracking and Trajectory Planning …
19	Kauai Salon 3	AAS 13-377	Hsiao	Trajectory Evolution Under Laser Photonic …
20	Puna Room C&D	AAS 13-387	Palli, et al.	Observations planning optimization for …
		11:05		
18	Kauai Salon 2	AAS 13-369	Ono, et al.	Attitude Optimization of a Spinning Solar Sail …
19	Kauai Salon 3	AAS 13-378	Moraes, et al.	A Semi-Analytical Approach to Study …
20	Puna Room C&D	AAS 13-388	Hirose	The Trajectory Control Strategies of Akatsuki …
		11:25		
18	Kauai Salon 2	AAS 13-370	Gui, et al.	Attitude Stabilization of a Spacecraft …
19	Kauai Salon 3	AAS 13-491	Baù, Bombardelli	Accurate and fast orbit propagation with…

Wednesday, February 13, 2013 (PM)

Session	Room	Doc. #	Author(s)	Title
		13:30		
21	Kauai Salon 1	AAS 13-389	Lee, et al.	Optimal Formation Keeping near a General…
22	Kauai Salon 2	AAS 13-398	Cefola, et al.	Verification of the Orekit Java Implementation …
23	Kauai Salon 3	AAS 13-408	Bradley, Ocampo	Classification of Distant Earth-Return …
24	Puna Room C&D	AAS 13-424	Sell	Powered Flight Design and Reconstructed …
		13:50		
21	Kauai Salon 1	AAS 13-390	Mulder	Orbit Trajectory Design for the Boeing …
22	Kauai Salon 2	AAS 13-399	Pontani, Cappelletti	CubeSat Collision Risk Analysis at Orbit Injection
23	Kauai Salon 3	AAS 13-409	Landau, et al.	Trajectories to Nab a NEA (Near-Earth Asteroid)
24	Puna Room C&D	AAS 13-425	Chen	Approach and Entry, Descent, and Landing …
		14:10		
21	Kauai Salon 1	AAS 13-391	Harris, et al.	Minimum Time Rendezvous using Differential Drag
22	Kauai Salon 2	AAS 13-400	Janeski, et al.	Effects of the Local Plasma Environment …
23	Kauai Salon 3	AAS 13-411	Scheeres, Sutter	Design, Dynamics and Stability of the …
24	Puna Room C&D	AAS 13-426	Gostelow	The Mars Science Laboratory Entry, Descent, …
		14:30		
21	Kauai Salon 1	AAS 13-392	Casotto, Baresi	Optimal maintenance of relative circular…
22	Kauai Salon 2	AAS 13-401	Marchese, et al.	Planning and Execution of a Specialized …
23	Kauai Salon 3	AAS 13-412	Sankaran, et al.	Electric Propulsion Alternatives for the…
24	Puna Room C&D	AAS 13-458	Weiss	Design and Development of the MSL Descent …
		14:50		
21	Kauai Salon 1	AAS 13-393	Jasper, et al.	Application of Relative Satellite Motion …
22	Kauai Salon 2	AAS 13-498	Ogawa, et al.	A Scheme for Simplified Trajectory Design …
23	Kauai Salon 3	AAS 13-413	Bhaskaran, Kennedy	Terminal Guidance Navigation for an Asteroid …
24	Puna Room C&D	AAS 13-457	Guernsey, Weiss	Lessons Learned from the Development of …
		BREAK: 15:10 - 15:35		
		15:35		
21	Kauai Salon 1	AAS 13-395	Yin, Zhong	Impulsive Hovering Formation Based on Relative …
22	Kauai Salon 2	AAS 13-443	Jackman, Dumont	Optical Navigation Capabilities for Deep Space …
23	Kauai Salon 3	AAS 13-414	Chappaz, Howell	Trajectory Exploration Within Binary Systems …
24	Puna Room C&D	AAS 13-461	Parker, et al.	Fabrication, Assembly & Test of the Mars…
		15:55		
21	Kauai Salon 1	AAS 13-396	Hernandez, Akella	Lyapunov-Based Guidance Schemes for In-Plane …
22	Kauai Salon 2	AAS 13-406	Mimasu, et al.	Long-term Attitude and Orbit Prediction of Solar …
23	Kauai Salon 3	AAS 13-415	Darling, et al.	Close Proximity Operations using Stereoscopic …
24	Puna Room C&D	AAS 13-464	Kornfeld, et al.	Verification and Validation of the MSL/Curiosity …
		16:15		
21	Kauai Salon 1	AAS 13-397	Bando, Ichikawa	Formation Flying near the Libration Points …
22	Kauai Salon 2	AAS 13-407	Jiang	In-Flight Aerodynamic and Mass Properties …
23	Kauai Salon 3	AAS 13-416	Massari, et al.	Alternative Hybrid Propulsion Transfers …
24	Puna Room C&D	AAS 13-463	Stehura, Rozek	Managing Complexity in the MSL/Curiosity …
		16:15		
21	Kauai Salon 1	AAS 13-474	Yin, Han	Study of Elliptical Relative Motion Conttrol …
23	Kauai Salon 3	AAS 13-417	Ikeda, et al.	A simulation study of gravity and ephemeris …

Thursday, February 14, 2013 (AM)

Session	Room	Doc. #	Author(s)	Title
		8:00		
25	Kauai Salon 1	AAS 13-429	Nayak, Udrea	Application of a Laser Rangefinder for Space …
26	Kauai Salon 2	AAS 13-475	Delabie, et al.	An Accurate and Efficient Gaussian Fit …
27	Kauai Salon 3	AAS 13-438	Putnam, Braun	Precision Landing at Mars Using Discrete …
28	Puna Room C&D	AAS 13-447	List	Modeling and Simulation of the MICROSCOPE …
		8:20		
25	Kauai Salon 1	AAS 13-430	Henderson, Subbarao	Sensitivity Analysis of the Lightcurve …
26	Kauai Salon 2	AAS 13-485	Früh, Jah	Attitude and Orbit Propagations of High …
27	Kauai Salon 3	AAS 13-439	Morgan, et al.	Decentralized Guidance of Swarms of Spacecraft …
28	Puna Room C&D	AAS 13-449	Landau	Orbital Transfer Techniques for Round-Trip …
		8:40		
25	Kauai Salon 1	AAS 13-433	Chow, et al.	Comparing the Reid Cost to the Mahalanobis …
26	Kauai Salon 2	AAS 13-476	Fosbury, et al.	Attitude Determination for the Van Alen Probes
27	Kauai Salon 3	AAS 13-440	Perez, Bevilacqua	Spacecraft Maneuvering via Atmospheric …
28	Puna Room C&D	AAS 13-451	Lee, et al.	Optimal Mixed Impulsive/Continuous Thrust …
		9:00		
25	Kauai Salon 1	AAS 13-435	Alfano, Finkleman	Operating Characteristic Approach to Effective …
26	Kauai Salon 2	AAS 13-478	Linares, Crassidis	Sigma Point Transformation for Gaussian …
27	Kauai Salon 3	AAS 13-441	McKennon-Kelly, et al.	Model Diagnostics and Dynamic Emulation: …
28	Puna Room C&D	AAS 13-452	Vincent, Garcia	The Plans for Getting OCO-2 into Orbit
		9:20		
25	Kauai Salon 1	AAS 13-431	Hussein, et al.	An AEGIS-FISST Sensor Management Approach .
26	Kauai Salon 2	AAS 13-210	Li, et al.	Cubesat Attitude Control Systems with Magnetic …
27	Kauai Salon 3	AAS 13-442	Klesh, Gustafson	Simulation and Analysis of a Phobos-anchored …
28	Puna Room C&D	AAS 13-466	Sherrill, et al.	Lyapunov-Floquet Transformation of Satellite …
		BREAK: 9:40 - 10:05		
		10:05		
25	Kauai Salon 1	AAS 13-432	Hussein, et al.	An AEGIS-FISST Algorithm for Joint Detection, …
26	Kauai Salon 2	AAS 13-481	Post, et al.	Nanosatellite Sun Sensor Attitude Determination …
27	Kauai Salon 3	AAS 13-444	Hisamoto, et al.	Spacecraft Navigation Using Celestial Gamma-ray ..
28	Puna Room C&D	AAS 13-467	Sinclair, et al.	Calibration of Linearized Solutions for Satellite …
		10:25		
25	Kauai Salon 1	AAS 13-434	Mahajan, et al.	Orbit Determination Of An Uncooperative RSO …
26	Kauai Salon 2	AAS 13-479	Springmann, Cutler	Optimization of Directional Sensor Orientation …
27	Kauai Salon 3	AAS 13-487	Simo, McInnes	Potential Effects of a Realistic Solar Sail …
28	Puna Room C&D	AAS 13-454	Siddique, Heyler	Mission Design for NASA's Van Allen Probes …
		10:45		
25	Kauai Salon 1	AAS 13-436	Bombardelli	Optimal Impulsive Collision Avoidance
26	Kauai Salon 2	AAS 13-482	Selig	Sensor Calibration for the MICROSCOPE …
27	Kauai Salon 3	AAS 13-445	Cui, et al.	Station-Keeping Strategies for Satellite Constellation
28	Puna Room C&D	AAS 13-455	Scott, Ozimek	Ongoing Mission Analysis for the Solar …
		11:05		
27	Kauai Salon 3	AAS 13-446	Zhou, et al.	Global Damping Configuration of Large Space …
28	Puna Room C&D	AAS 13-456	Changxuan, et al.	Orbital Accessibility Problem for Spacecraft …

RECORD OF MEETING EXPENSES

23rd AAS/AIAA Space Flight Mechanics Meeting
Kauai Marriott Resort Hotel, Lihue, Hawaii
11 February - 14 February 2013

Name: ______________________________ Organization: ______________________________

Category	Early Registration (through 15 Jan 2013)	Regular Registration
Full - AAS or AIAA Member	$530	$580
Full - Non-member	$630	$645
Retired*	$120	$170
Student*	$120	$170
Special Event Guest Ticket	$75	$75
Special Event Child Ticket (6-12 yrs)	$40	$40

Registration Fee: ____________________

Conference Proceedings (Hard Cover)[1]
___ @ $290 (domestic) ____________________
___ @ $380 (international) ____________________

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

Special Event Guest Ticket ___@ $75 ____________________
Special Event Child Ticket ___@ $40 ____________________

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