26th AAS/AIAA Space Flight Mechanics Meeting,

February 14-18

Napa, CA

Image courtesy: www.nasa.gov

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AIAA Technical Chair

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26TH AAS/AIAA SPACE FLIGHT MECHANICS MEETING

CONFERENCE INFORMATION

GENERAL INFORMATION

Welcome to the 26th Space Flight Mechanics Meeting, hosted by the American Astronautical Society (AAS) and co-hosted by the American Institute of Aeronautics and Astronautics (AIAA), February 14 – 18, 2016 (https://www.facebook.com/AAS-Space-Flight-Mechanics-Committee-1275373679142776/ on social media). This meeting is organized by the AAS Space Flight Mechanics Committee and the AIAA Astrodynamics Technical Committee, and held at the Embassy Suites Hotel, 1075 California Boulevard, Napa, CA 94559, (707)-253-9540, http://www.embassysuitesnapahotel.com/.

REGISTRATION

Registration Site (https://www.xcdsystem.com/aas/index.cfm)

In order to encourage early registration, we have implemented the following conference registration rate structure: **Register by December 31, 2015 and save $70!**

Category	Early Registration (through Dec 31, 2015)	Registration (beginning Jan 1, 2016)	Walk-up Registration (beginning Feb 1, 2016)
Full - AAS or AIAA Member	$525	$595	$695
Full - Non-member	$625	$695	$795
Retired or Student* - Member	$220	$290	$390
Retired or Student* - Non-member	$320	$390	$490

**does not include proceedings CD*

Refunds will be issued in full until January 31, 2016. A 10% fee will be assessed for all refunds issued after that date and until 8:00 am PST February 15, 2016. No refunds will be issued after 8:00 am PST February 15, 2016.

One ticket to the Markham Winery for wine tasting and dinner on Tuesday evening is included with every registration. Bus transportation is provided from the conference hotel to the winery and back. Please be sure to bring a valid photo ID in order to be served. Guest tickets for the tasting/dinner may be purchased for $100. More information about the wine tasting and dinner is included below.

All registrants and guests are invited to the welcome reception on Sunday evening for food and drinks.

A conference registration and check-in table will be located in the Fountain Court of the Embassy Suites Hotel and will be staffed according to the following schedule:

- Sunday February 14: 3pm – 6pm
- Monday February 15: 7:30am – 2pm
- Tuesday February 16: 8am – 2pm
- Wednesday February 17: 8am – 2pm
- Thursday February 18: 8am – 10 am

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

SCHEDULE OF EVENTS

Technical sessions begin on Monday, 15 February, at 8 am. The last technical sessions end at 12:20 pm on Thursday, 18 February. Presentations are limited to 15 minutes with an additional 5 minutes for questions and answers. Each session has a 20-minute morning or afternoon break. Authors are required to be in their session room 30 minutes prior to the start of their sessions. No speakers' breakfast will be served.

Day	Start	End	Function	Room
Sunday 14 February	3pm	6pm	Registration	Fountain Court
	6pm	9pm	Early Bird Reception (Food and Hosted Bar)	Fountain Court
Monday 15 February	7:30am	2pm	Registration	Fountain Court
	8am	12pm	Session 1: Attitude Determination	Pinot Noir BC
	8am	12pm	Session 2: Trajectory Optimization 1	Cabernet
	8am	12pm	Session 3: Spacecraft Dynamics	Sauvignon
	8am	12pm	Session 4: Spacecraft Autonomy	Chardonnay AB
	10am	10:20am	Morning Break	Fountain Court
	Noon	1:30pm	Joint Technical Committee Lunch	Chardonnay C
	1:30pm	4:50pm	Session 5: Mission Design 1	Pinot Noir BC
	1:30pm	4:50pm	Session 6: Guidance and Control 1	Cabernet
	1:30pm	4:50pm	Session 7: Estimation	Sauvignon
	1:30pm	4:50pm	Session 8: Dynamics and Perturbations 1	Chardonnay AB
	3:10pm	3:30pm	Afternoon Break	Fountain Court
	5pm	6pm	Dirk Brouwer Award Plenary and Breakwell Student Travel Award Presentation	Chardonnay ABC
	6pm	7pm	Cocktail Reception	Fountain Court

Day	Start	End	Function	Room
Tuesday 16 February	8am	2pm	Registration	Fountain Court
	8am	12pm	Session 9: Attitude Dynamics and Control 1	Pinot Noir BC
	8am	12:20pm	Session 10: Orbital Debris and Space Environment	Cabernet
	8am	12pm	Session 11: Mission Design 2	Sauvignon
	8am	12:20pm	Session 12: Satellite Constellations	Chardonnay AB
	10am	10:20am	Morning Break	Fountain Court
	Noon	1:30pm	AIAA Technical Committee Lunch	Chardonnay C
	1:30pm	4:50pm	Session 13: Attitude Dynamics and Control 2	Pinot Noir BC
	1:30pm	4:50pm	Session 14: Dynamics Models	Cabernet
	1:30pm	4:50pm	Session 15: Orbit Determination	Sauvignon
	1:30pm	4:50pm	Session 16: Asteroid & Earth Orbiting Missions 1	Chardonnay AB
	3:10pm	3:30pm	Afternoon Break	Fountain Court
	6pm	9pm	Offsite Event: Markham Winery Tasting and Dinner **Buses depart the Embassy Suites at 5:30pm**	Markham Winery
Wednesday 17 February	8am	2pm	Registration	Fountain Court
	8am	12pm	Session 17: Space Situational Awareness 1	Pinot Noir BC
	8am	12:20pm	Session 18: Asteroid & Earth Orbiting Missions 2	Cabernet
	8am	12pm	Session 19: Guidance and Control 2	Sauvignon
	8am	12pm	Session 20: Trajectory Optimization 2	Chardonnay AB
	10am	10:20am	Morning Break	Fountain Court
	Noon	1:30pm	AAS Technical Committee Lunch	Chardonnay C
	1:30pm	5:50pm	Session 21: Dynamics and Perturbations 2	Pinot Noir BC

Day	Start	End	Function	Room
Wednesday 17 February	1:30pm	5:30pm	Session 22: Mission Design 3	Cabernet
	1:30pm	5:30pm	Session 23: Spacecraft Relative Motion	Sauvignon
	1:30pm	5:10pm	Session 24 - Special Session: Results from GTOC8	Chardonnay AB
	3:30pm	3:50pm	Afternoon Break	Fountain Court
	5:30pm	6:30pm	Conference Administration Subcommittee	Cabernet
	5:30pm	6:30pm	Technical Administration Subcommittee	Pinot Noir BC
	5:30pm	6:30pm	Website Administration Subcommittee	Sauvignon
Thursday 18 February	8am	10am	Registration	Fountain Court
	8am	11:40am	Session 25: Spacecraft Rendezvous	Pinot Noir BC
	8am	12:00pm	Session 26: Trajectory Optimization 3	Cabernet
	8am	12:20pm	Session 27: Space Situational Awareness 2	Sauvignon
	8am	12:20pm	Session 28: Navigation	Chardonnay AB
	10am	10:20am	Morning Break	Fountain Court

A map of the Embassy Suites Hotel and the relevant meeting rooms appears on the next page.


Sauvignon
Fireplace
Cabernet
Chardonnay C
Chardonnay B
Chardonnay A
CHARDONNAY BALLROOM
Fountain Court
Pinot Noir C
Pinot Noir B
Pinot Noir A
PINOT NOIR BALLROOM
119-ICE / SODA
251-ICE / SODA
351-ICE / SODA
ELEVATORS
OUTDOOR POOL
MILL POND GARDEN
ATRIUM
Grille 29
Lounge
Rest-rooms
Fountain Court
Chardonnay
Cabernet Sauvignon
Pinot
INDOOR POOL & SPA
Suites 357-366 above Indoor Pool
ELEVATORS
LOBBY
SUNDECK Entrance to Meeting Rooms and Grille 29 Restaurant & Lounge
173-ICE / SODA
273-ICE / SODA
373-ICE / SODA / SNACK

Special Events

Early Bird Reception

Sunday, 14 February 6:00 – 9:00 pm

Location: Fountain Court

Buffet Menu

Grilled Vegetable Antipasto Salad

Tossed Green Salad with Balsamic Vinagrette

BBQ Bourbon Pork Baby Back Ribs

Roasted Pacific Salmon with Lime Herb Beurre Blanc

Oven Roasted Red Potatoes

Steamed Mix of Vegetables

Two Layer Chocolate Cake with Strawberry Coulis

Crème Brule

Dirk Brouwer Award Plenary and Breakwell Travel Award Presentation:

Monday, 15 February 5:00 – 6:00 pm (Ceremony and Lecture)

6:00 – 7:00 pm (Awards Reception)

Location: Chardonnay ABC (Ceremony and Lecture)

Fountain Court (Awards Reception)

Flower Constellations and k-vector Applications

In the first part the Flower Constellations theory evolution is summarized. The initial motivation, the original theory, the 2-D and 3-D Lattice versions, and the Necklace problem will be presented. Various examples and animations for potential current and futuristic applications will be shown.

In the second part, the k-vector range searching technique is summarized with particular emphasis on the most recent applications. Inverting nonlinear functions, probability-based range searching in n-dimensions, iso-surface identification, intensive random sampling generation, and gene sequence identification will be shown.

DIRK BROUWER AWARD HONOREE

Daniele Mortari is Professor of Aerospace Engineering at Texas A&M University, working in the fields of attitude and position estimation, satellite constellation design, and sensor data processing. In addition, he has taught at the School of Aerospace Engineering of Rome's University, and at Electronic Engineering of Perugia's University. He received his dottore degree in Nuclear Engineering from University of Rome "La Sapienza," in 1981. He is IEEE and AAS Fellow, AIAA Associate Fellow, Honorary Member of IEEE-AESS Space System Technical Panel, and former IEEE Distinguish Speaker. He has published more than 275 papers and has been widely recognized for his work, including receiving Best Paper Award from AAS/AIAA, two NASA's Group Achievement Awards, 2003 Spacecraft Technology Center Award, 2007 IEEE Judith A. Resnik Award, and 2016 AAS Dirk Brouwer Award.

MARKHAM WINERY TASTING AND DINNER

Tuesday, 16 February	5:30 pm (Buses Depart Embassy Suites Hotel for Markham Winery)
	6:00 – 7:00 pm (Wine Tasting)
	7:00 – 9:00 pm (Buffet Dinner)
Location	Markham Winery

Markham Vineyards is one of the oldest continuously operated wineries in the Napa Valley and is located approximately 25-30 minutes from the Embassy Suites Hotel. Upon arrival at the Markham Winery, guests are free to roam the Tasting Room, Art Gallery, and Patio while being served Sauvignon Blanc and Cabernet from the bar. Guests will then be invited into the Barrel Room for a buffet dinner paired with Chardonnay & Merlot. Non-alcoholic beverages (sodas, water) will also be available. Please be sure to bring a valid photo ID in order to be served!

All conference registrations will receive an event ticket, which includes bus transportation to and from the Markham Winery from the Embassy Suites Hotel. Conference attendees are encouraged to utilize the provided bus transportation; please keep in mind if choosing to seek alternate transportation arrangements that the winery will not be open for our group until 6pm. Buses will depart the Embassy Suites Hotel at 530 pm, and at least one bus will depart the Markham Winery to begin returning to the Embassy Suites hotel between 8 and 830 pm. All remaining buses will depart the Markham Winery at 9 pm.

Guest tickets are available for $100 each on the conference registration site.

Conference attendees should indicate any dietary restrictions on their completed registrations prior to February 1, 2016 so that the caterer can be informed.

Buffet Menu

Angus New York Strip, Roasted, Garlic Herb Crust, Au Jus
Roasted Game Hens, Herb Crusted, Lemon-Tarragon Gremolata
Simply Roasted Potatoes
Pan Roasted “Piggy Sprouts” Brussel Sprouts
Hearts of Romaine Salad
Chocolate Hazelnut Tart, Bittersweet Chocolate Sauce, Whipped Cream

CONFERENCE LOCATION

EMBASSY SUITES NAPA VALLEY

1075 California Boulevard
Napa, CA, 94559
www.embassysuitesnapahotel.com
(707) 253-9540 (voice)
(707) 253-9202 (fax)

The Mediterranean luxury of the Embassy Suites Napa Valley welcomes you to experience the magic of our celebrated destination. We are minutes away from world famous wineries and renowned restaurants, and just a short walk to our vibrant down town Napa.

Awake to our complimentary, full cooked-to-order breakfast. Enjoy your morning coffee or end your day with a toast from our evening Manager's Reception – overlooking our Millpond and resident swans.

A room block with the Government Per Diem Rate ($149/night) will be held through **January 22, 2016**. Reservations requested after this date will be accepted based upon availability and subject to the hotel's prevailing rate. We encourage all conference attendees to make your hotel reservation early!

Attendees may register at the personal group web page listed below or they may call the reservations department at 1-800-EMBASSY. Please be sure to mention the group code AAS or the group name "American Astronautical Society" when making reservations in order to receive the group rate of $149 (or prevailing government per diem). Group arrival is 2/14/2016 and Group Departure is 2/18/2016. A limited number of rooms are available at the group rate 3 days pre/post group arrival and departure.

For any pre or post group dates questions, please contact Marianne Hollman at 707-320-9511 or Marianne.Hollman@hilton.com.

Group Reservation Page:

http://embassysuites.hilton.com/en/es/groups/personalized/N/NAPVLES-AAS-20160214/index.jhtml?WT.mc_id=POG

Cancellations must be made 72 hours in advance of intended arrival.

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

ARRIVAL INFORMATION

Check-In and Checkout

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

Parking

Self-parking is complimentary.

HOTEL SERVICES AND AMENITIES

- 24-hour Front Desk
- Concierge Service (located at the front desk)
- Complimentary Cooked-to-Order Breakfast served daily for all registered hotel guests
- Complimentary Evening Beverage reception daily from 5:30pm-7:30pm
- Room Service
- Business Center with complimentary printing and faxing
- Complimentary newspapers in Lobby & Atrium
- Wireless high-speed Internet access in all guest suites and public areas
- Fitness Room by Precor
- Spa Services - In-room massage and spa services available upon request
- Heated indoor swimming pool
- Whirlpool, sauna and sun deck
- Guest Laundry facilities on-site
- Luggage Storage
- On-site ATM (Automated Teller Machine)
- Wine storage upon request

TRANSPORTATION INFO

Napa Valley is served by five airports. San Francisco International Airport (SFO), Oakland International Airport (OAK) and Sacramento International Airport (SMF) are each approximately 60 miles away (85 km) and can be reached in approximately 1.5 hours driving time. Santa Rosa Airport (STS) is about 35 miles away. Napa County operates a private, general aviation airport for which charter flights are available but no scheduled commercial flights. All airports host a variety of rental car agencies.

San Francisco and Oakland both have shuttle buses that run a fixed route schedule from the airport to the City of Napa. The bus will be branded with the name Evans or California Wine Tours. To access a schedule, contact Evans Transportation, 707-255-1559, or California Wine Tours, 800-294-6386. If you would like direct service to your hotel, Evans can arrange for that from their Napa terminal. It's best, however, to give them notice in advance of your trip. In most cases there will be an extra fee for this service.

There are several limousine companies listed here that can pick you up at the airport as well as take you on wine tours so you can relax and enjoy the experience of tasting some of America's legendary wines. Contact them about setting up a package that would include all of your driving needs for your trip.

DIRECTIONS FROM AIRPORTS

FROM SAN FRANCISCO across the Golden Gate Bridge

Highway 101 North to Highway 37 East. At the Infineon Raceway junction turn left onto Highway 121 North. Continue on 121 North to Highway 29 North. Turn left onto Highway 29 North. Exit at First Street. Turn right at the stop sign. Turn left at first stop light onto California Blvd. The hotel is on the left at 1075 California Blvd.

FROM SAN FRANCISCO / OAKLAND across the San Francisco/Oakland Bay Bridge

Highway 80 East to Highway 37 West, passing Six Flags Theme Park. Highway 37 to Highway 29 North and exit at First Street. Turn right at the stop sign. Turn left at the first stop light onto California Blvd. The hotel is on the left at 1075 California Blvd.

FROM SACRAMENTO / LAKE TAHOE

Highway 80 West to Highway 12 West. Turn right at second light onto Highway 29 North. Stay left at fork in the highway toward Calistoga and exit at First Street. Turn right at the stop sign. Turn left at the first stop light onto California Blvd. The hotel is on the left at 1075 California Blvd.

NAPA GROUND TRANSPORTATION

Public bus transportation is available within the City of Napa and between the main towns in the Napa Valley. The VINE is the fixed-route bus system in the County of Napa. All buses are wheelchair accessible. The VINE local buses in the City of Napa can take you to downtown Napa, recreation areas such as the Napa County Fairgrounds, shopping areas such as Bel Aire Plaza, Napa Premium Outlets, and South Napa Marketplace. Regional Routes 11 and 29 can take you to the Ferry. The Route 29 also goes to the El Cerrito Del Norte BART station. The Regional Route 25 connects Napa with the City of Sonoma in Sonoma County and Route 21 can take you to the Suisun City Train Depot.

Please visit http://www.ridethevine.com/ or call 707-251-2800 for schedules and maps.

AREA ATTRACTIONS

The Embassy Suites Napa Valley hotel is at the heart of the local area's attractions. Nearby, you'll be able to explore the quaint village charm of nearby historic downtown Napa, stroll along the Napa River Walk or shop at the premium outlet/specialty stores. Sample wines at over 250 wineries in Napa Valley. Taste from among thousands of boutique, hard-to-find wines at the ten tasting rooms and wine bars in downtown Napa. Take a hot air balloon ride for spectacular views of the valley. Play golf among the vineyards, go horseback riding in the rolling hills or schedule a wine tasting tour package with one of the local limousine companies.

Get on your bike and ride (0.0 mi. from hotel)

Napa Downtown is the perfect place to take a leisurely spin on a bike. Maps of various routes throughout Napa Valley are available for more challenging rides.
http://www.visitnapavalley.com/napa_valley_bike_map.htm

Enjoy some Live Music (1.0 mi. from hotel)

The Uptown Theatre Napa is downtown's ultimate destination for live entertainment, and within walking distance from the conference hotel. Nestled in the famed West End district, this stunningly restored art deco masterpiece from 1937 showcases only the finest acts in music and comedy. A historic landmark, the Uptown offers a phenomenal, intimate live show experience with world class sound and site lines. Distance from the last row to the stage is only 98 feet making every seat truly a great seat! See the Uptown Theatre Napa for more information: http://www.uptowntheatrenapa.com/

Take a walk to historic downtown Napa (1.5 mi. from hotel)

Do Something Delicious in Napa, California! Downtown Napa is the ultimate culinary destination with more than 70 restaurants all within walking distance. Let your inner foodie out to play and treat yourself to something delicious. Visit DoNapa.com for a full listing of restaurants, wine tasting rooms, bars and things to do in Napa. With a dozen wine tasting rooms within walking distance of each other, Downtown Napa is also a wine-lover's paradise.

Visit Oxbow Public Market (2.5 mi from hotel)

Oxbow Public Market, located in the Oxbow District of Napa, has become the local gathering place for great food and wine in downtown Napa and throughout the Napa Valley. The 40,000 square foot marketplace, which includes a scenic outdoor deck with seating along the Napa River, features a diverse tenant mixture of local food vendors, artisan cafes and an organic produce outlet for local farms. Oxbow Public Market and its artisans and purveyors passionately support the concept of sustainable agriculture and local harvest promoting a healthy environment, and social and economic equity within our community. Merchants start opening at 7:30 am and many stay open until 9:30 pm. All tenants are expected to be open at least between 9 am and 7 pm. The restaurants are open later. It is recommended you check hours with individual merchants.

Take a ride on the Napa Valley Wine Train (2.5 mi from hotel)

The Napa Valley Wine Train is one of the most distinctive Napa restaurants, offering an authentic, memorable experience that echoes the glory days of train travel, with fine dining service, multiple course meals, Napa Valley scenery and ultimate relaxation aboard exquisitely restored vintage rail cars. This top dining establishment is housed in a museum quality, antique train that runs on 25 miles of track in the heart of the Napa Valley. The train itself has two engines, three kitchens on board and a collection of early 20th century Pullman rail cars faithfully restored with Honduran mahogany paneling, brass accents, etched glass partitions and plush armchairs that evoke the spirit of luxury rail travel in the early 1900s. Prices start at $124, reservations required.

Visit a nearby winery (4-6 mi. from hotel)

Accessible with only a short drive from the conference hotel, you can visit world-class wineries and enjoy panoramic views of Napa and the San Francisco Bay.

- Artesa http://www.artesawinery.com/

  Known for some of the best views in the entire valley, this highly-recommended local favorite is only 6 miles from the conference hotel. Tours 11:00AM-2:00 pm daily, Tastings 10:00 AM-5:00 pm daily. Last pour 4:30 pm. Tour groups are limited to 8 people.

- Hendry Ranch http://www.hendrywines.com/

World-class wine tasting and known for detailed, highly-educational tours. Only 4 miles from the conference hotel. Tastings at 11:00 am ($30), with morning and afternoon tours ($50-$75). All tours and tastings require reservations: Tasting and tour groups are limited to 8 people.

Explore the di Rosa Art Preserve (5.0 mi. from hotel)

Considered the most significant holding of Bay Area art in the world, di Rosa houses approximately 2,000 works of art by 800 artists. The collection includes significant works by Mark di Suvero, Robert Arneson, Roy De Forest, Enrique Chagoya, Manuel Neri, Joan Brown, William T. Wiley, Robert Hudson, Richard Shaw, Bruce Nauman, Deborah Butterfield, John Buck, David Best, Larry Sultan, Raymond Saunders, Bruce Conner, Allan Rath, Nathan Oliveira, Mildred Howard, Paul Kos, Squeak Carnwath, Viola Frey, Stephen de Staebler, and many others. Open Wednesday-Sunday, 10:00 am- 4:00 pm. The Gatehouse Gallery has a suggested donation of $5, and tours are $12-$15.

Check out a wine cave (7 mi. from hotel)

The Jarvis Estate winemaking facility is entirely contained within 45,000 square feet of cave tunneled into the scenic Vaca Mountains, four miles east of downtown Napa. It is not only a visual masterpiece, but a technical masterpiece as well. Due to the invariant temperature and high humidity level of caves, wineries have typically used caves for the barrel aging of wines. Jarvis Estate was the first in this country to tunnel a cave so large that it could hold the entire winemaking operation. With the help of chief geotechnic consultant Gregg Korbin and the largest computer at University of California Berkeley, William Jarvis was able to successfully plan and design the large chambers of our underground winery. As the cave extends further into the mountain, the chambers become larger. Pushing the state of the art, the last chamber could comfortably contain two full basketball courts.

Cost: $80/person, reservations required. Please wear appropriate footwear for walking throughout the cave.

Get in 18 holes or more (7 mi. from hotel)

There are many golf courses in Napa Valley. Nearby you will find the Chardonnay Golf Club as well as the Eagle Vines Golf Club.

Take the to the skies on a hot air balloon (8 mi. from hotel)

See the valley up high from a hot air balloon. Enjoy a calm and peaceful float there across the valley with a bird's eye view. Popular local choices include Balloons above the Valley and Napa Valley Balloons. ~$215 per person. Reservations required.

Visit the Napa Valley Museum (9 mi. from hotel)

Just across the St. Helena Highway from the culinary mecca of Yountville, you'll find this gem of a museum on the grounds of the California Veteran's Home. Napa Valley Museum offers a welcome break from whirlwind wine-tasting, and visiting its permanent collection of art and artifacts is an experience that truly brings the Valley into focus. From the 1950s Napa City Limits sign (Population, then: 13, 155. Now: 77, 000+.), to paintings and photos of the pioneers of wine, the museum's collection chronicles the history of the region, its people and geology, along with the wine industry that put Napa Valley on the map. Open Sunday-Tuesday, 10:00 am – 4:00 pm. Cost: $10/person.

Taste wine at a Castle (40 mi. from hotel)

Castello di Amorosa is a castle and a winery located near Calistoga, CA. First opening its doors to the public in April 2007, the castle is the pet project of 4th generation vintner, Dario Sattui, who also owns and operates the V. Sattui Winery named after his great-grandfather who originally established a winery in San Francisco in 1885 after emigrating from Italy to California . The castle interiors, which include 107 rooms on 8 levels above and below ground, cover approximately 121,000 square feet. Key details and building techniques are architecturally faithful to the 12th and 13th century time period. Among many other features it has: a moat; a drawbridge; defensive towers; an interior courtyard; a torture chamber; a chapel/church; a knights' chamber; and a 72 by 30 feet (9.1 m) great hall with a 22-foot (6.7 m)-high coffered ceiling. The torture chamber has an authentic 300-year-old iron maiden which Sattui states he bought for $13,000 in Pienza, Italy, a replica rack, prison chambers and other torture devices. The masonry, ironwork and woodwork was fashioned by hand using old world crafting techniques. Building materials included 8,000 tons of locally quarried stone, in addition to paving stones, terra cotta roofing tiles and some 850,000 bricks imported from Europe. Open daily, 9:30 am-5:00 pm. Tours begin at $40.00, reservations are highly recommended. 707-967-6272

Did we mention wine tasting?

The world-renowned Napa Valley is home to over 250 wineries that offer public tastings. A great place to begin your search for a winery that suits your tastes can be found on http://www.napavalley.com/drink/.

ADDITIONAL INFORMATION

SPEAKER ORIENTATION

Authors should have submitted a brief (approximately 50 words or 3 sentences) speaker's bio with their abstract submission. Author presentations (preferably in PDF format) will be submitted through a web-based system and are due by **Thursday February 11th, 2016, 23:59:59 Eastern Time**. Authors are required to be in their session room 30 minutes prior to the start of their sessions. No speakers' breakfast will be served.

Authors are reminded that the deadline to upload pre-prints to the https://www.xcdsystem.com/aas/ website is before **February 3, 2016, 23:59:59 Eastern Time**.

VOLUNTEERS

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

PRESENTATIONS

Each presentation is limited to 15 minutes. An additional five minutes is allotted between presentations for audience participation and transition. Session chairs shall maintain the posted schedule to allow attendees the option of joining a parallel session. Each room is equipped with a 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.

Each author is also acknowledges that he or she is releasing technical information to the general public and that respective papers and presentations have been cleared for public release. If any author of a paper is a US person (citizen or permanent resident), he or she acknowledges that the release of these data and content of the paper and presentation conforms to ITAR and are not on the USML. The information contained in these documents is neither classified, SBU, FOUO, nor proprietary to any sponsoring organization.

PREPRINTED MANUSCRIPTS

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

CONFERENCE PROCEEDINGS

All full registrants will receive a CD of the proceedings mailed to them after the conference (extra copies are available for $60 during the conference). However, the hardbound volume of *Advances in the Astronautical Sciences* covering this conference will be available to attendees at a reduced pre-publication cost, if ordered at the registration desk. After the conference, the hardbound proceedings will more than double in price, although authors will still receive a special 50% discount off the post-conference rate even if they delay their order until after the conference. Cost of Proceedings:

- Conference Rate $290 domestic ($380 international)
- Post-Conference Rate $600 (approx.)
- Authors (post-conference) $300 (approx.)

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

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

howell@purdue.edu

Journal of Guidance, Control and Dynamics
Editor-in-Chief: Dr. Ping Lu, Iowa State University
Manuscripts can be submitted via: https://mc.manuscriptcentral.com/aiaa

Journal of Spacecraft and Rockets
Editor-in-Chief: Dr. Robert D. Braun, Georgia Institute of Technology
Manuscripts can be submitted via: https://mc.manuscriptcentral.com/aiaa

SATISFACTION SURVEY

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COMMITTEE MEETINGS

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

Conference Schedule

Feb 15, 2016 - Pinot Noir BC

01 Attitude Determination

Chair: Sergei Tanygin

8:00 **AAS 16-225** **OPTIMIZATION OF A 3D PRINTED CUBESAT BAFFLE USING RAY TRACING**

Tjorven Delabie, KU Leuven University

Optical payloads and star trackers are equipped with a baffle to reduce the impact of stray light from the Sun or Moon. As small satellites and CubeSats are moving toward Earth Observation missions, small-scale performant baffles will need to be developed. This paper presents a novel method to improve the inner vane structure of baffles. Thanks to 3D-printing, more complex structures can be built with ease. The novel designs, their analytical performance and the performance obtained in optical tests are presented. The increased performance leads to a compact baffle that increases the image quality of star trackers and optical payloads.

8:20 **AAS 16-287** **Star Centroid on the f-radius Sphere using von Mises-Fisher Probability Distribution**

Daniele Mortari, Texas A&M University; Marcio A. A. Fialho, INPE - Instituto Nacional de Pesquisas Espaciais; Steven A. Lockhart, NASA - Johnson Space Center

This paper proposes a method to perform star centroid for star trackers using small focal length or large CCD or CMOS imagers. The stars light on the imager on these trackers are affected by gnomonic distortion and classic approach to perform centroid are not accurate. By mapping the gray tones and areas of the pixels into a fictitious sphere of focal length radius and using the von Mises-Fisher probability distribution, a more accurate star centroid can be obtained and, consequently, a more accurate attitude estimation.

8:40 **AAS 16-321** **Ideas for multispectral cameras with stacked pixels for star tracking and optical navigation**

Marcio A. A. Fialho, INPE - Instituto Nacional de Pesquisas Espaciais; Daniele Mortari, Texas A&M University; Leonel Perondi

This paper presents a new concept for multispectral (color sensitive) cameras that is advantageous both to star trackers and optical navigation cameras. The concept is based on the use of an image sensor with stacked pixels, where each pixel layer works as a spectral filter for the layers below. The paper presents limitations of commonly used technologies for color discrimination and how they can be overcome with the use of an image sensor with stacked pixels.

9:00 **AAS 16-322** **The Brazilian autonomous star tracker development.**

Marcio A. A. Fialho, INPE - Instituto Nacional de Pesquisas Espaciais; Leonel Perondi; Daniele Mortari, Texas A&M University

This paper presents the development effort of a Brazilian autonomous star tracker, a brief history and design decisions taken in order to increase star tracker survivability and flexibility to space environment, operation errors and changing mission requirements. The design is flexible enough to allow the use of the same hardware for different purposes, like a navigation camera or as a horizon sensor. An overview of the test and calibration setup is also presented.

9:20 **AAS 16-392** **Attitude Determination for Satellite with Nutation Using Single Antenna GPS Receiver and MEMS Gyro**

Ying Yang, Qian Xuesen Lab; Pei CHEN; Yong Li, Qian Xuesen Lab; Qingrui Zhou, Qian Xuesen Lab

This paper proposes a new subsystem of attitude determination for satellites with nutation motion, which makes use of information from single antenna GPS receiver and MEMS gyro. The measurement model for satellite's nutation motion has been derived. The subsystem senses attitude by demodulation of periodic oscillations of the GPS carrier phase with the aid of the torque-free dynamic equation of motion. Numerical examples for spin-stabilized satellites with nutation motion are carried out to validate the algorithm. Key parameters which affect the attitude sensing accuracy are analyzed at last.

9:40 **AAS 16-413** **Distortion Correction of the ICESat Star Tracker Data**

Sungkoo Bae, The University of Texas at Austin; Natalie Wolfenbarger

Most spacecraft missions nowadays use star trackers for accurate attitude determination and control. Without proper correction of measurement distortion caused by imperfect lens and detector, it could be difficult to determine the attitude with arcsecond accuracy. This paper describes the distortion correction methods that can be used with star tracker data after launch. A global method was used for ICESat Precision Attitude Determination and further improved for ICESat-2 mission. It also describes how to evaluate the result of the distortion correction using the distortion map and the attitude solution.

10:00 **Morning Break**

10:20 **AAS 16-534** **Characterization of the Effective Output Magnetic Field of a Tri-Axial Square Helmholtz Cage**

Ankit Jain, University of Illinois at Urbana Champaign

The accuracy of the Attitude Determination and Controls System (ADCS) for CubeSat-class satellites is crucial to their desired space-flight functionality. For such satellites, with a magnetic-based attitude system (i.e. involving magnetometers and torque coils); a Tri-Axial Square Helmholtz Cage serves as an excellent ground-based simulation and testing platform to both verify and validate the desired pointing accuracy of the satellite. The correct design and calibration of such a system is critical to its ultimate success in validating the ADCS. A few approaches for the characterization of the effective output magnetic field, generated by the cage, are discussed in this paper.

10:40 **AAS 16-543** **SPACE BASED IR SENSOR MANAGEMENT FOR SITUATIONAL AWARENESS**

Ajay Verma, Knowledge Based Systems Inc; Maruthi Akella, The University of Texas at Austin; John Freeze, Knowledge Based Systems, Inc.

A LEO cluster of IR sensors are dynamically scheduled to observe various target sites on earth associated with range of events posing varying degree of threat levels. The overall threat uncertainty is minimized by determining a near optimal solution for fixed time horizon non-myopic scheduling while considering a) finite delay arising from sensor rotational dynamics, b) target visibility based on relative sensor-target geometry resulting from sensor orbital dynamics, and c) quality of observation governed by the state of environment.

11:00 AAS 16-348 Attitude Determination and Control of ITASAT CubeSat

Valdemir Carrara, Instituto Nacional de Pesquisas Espaciais

This work presents the design of the ADCS (Attitude Determination and Control Subsystem) for the ITASAT CubeSat. A Kalman filter will estimate the attitude quaternion and gyro bias, based on measurements of magnetometer, coarse sun sensors and MEMS gyroscope. Results indicate that the Kalman filter tracks the bias of the gyroscope, decreasing the noise level present in the angular sensors. Reaction wheels and magnetorquers provide torques for attitude control. However, magnetic torque limitation together with poor gyroscope resolution jeopardizes the attitude stabilization. Methods to estimate the angular velocity to improve pointing accuracy will be presented, together with the simulation results.

11:20 AAS 16-374 Discrete Adaptive Angular Velocity Estimation - An Experimental Analysis

Marcelino Mendes de Almeida, The University of Texas at Austin; Maruthi Akella, The University of Texas at Austin

This paper presents hardware experimental results for the execution of the DAAVE (Discrete Adaptive Angular Velocity Estimator), an angular velocity estimation algorithm. DAAVE takes angular position quaternions as inputs and calculates angular velocity without any knowledge or assumption on the system dynamics. In order to test the effectiveness of the algorithm, an experimental setup was prepared in the Autonomous GN&C research laboratory of The University of Texas at Austin. The experiment consists of feeding data obtained from a Vicon System into the DAAVE. The algorithm processes the data and the outcome is compared with high-accuracy angular velocity measurements.

11:40 AAS 16-397 Spacecraft Dynamics Should be Considered in Kalman Filter Based Attitude Estimation

Zhiqiang Zhou, NASA Langley Research Center; Yaguang Yang, Nuclear Regulatory Commission (NRC)

Kalman filter based spacecraft attitude estimation has been used in some high-profile missions and has been widely discussed in literature. While some models in spacecraft attitude estimation include spacecraft dynamics, most do not. To our best knowledge, there is no comparison on which model is a better choice. In this paper, we discuss the reasons why spacecraft dynamics should be considered in the Kalman filter based spacecraft attitude estimation problem. We also propose a reduced quaternion spacecraft dynamics model which admits additive noise. Geometry of the reduced quaternion model and the additive noise are discussed. This treatment is more elegant in mathematics and easier in computation. We

Feb 15, 2016 - Cabernet

02 Trajectory Optimization 1

Chair: Stefano Campagnola

8:00 **AAS 16-247** **Low-Thrust Trajectory Optimization of Multiple Spacecraft with Cooperative Maneuvers**

Gao Tang, Tsinghua University; Fanghua Jiang

The low-thrust fuel-optimal control for the cooperative maneuvers of multiple spacecraft is discussed in this paper. The first example is the time-optimal transfers of two spacecraft to the target orbits with the final constraint on their phases.
In the other example two spacecraft maneuver simultaneously to form a triangle with the third. Indirect methods are applied by building Multiple-Point Boundary Value Problem (MPBVP). Homotopic approaches, normalization of initial costate variables, and switching detection methods are applied.
The preliminary methods to solve these problems are presented in another paper. However, new methods are proposed in this paper.

8:20 **AAS 16-260** **DYNAMIC OPTIMIZATION FOR SATELLITE IMAGE COLLECTION**

Isaac M. Ross; Ronald Proulx, Naval Postgraduate School; Joseph Greenslade, Naval Postgraduate School; Mark Karpenko, Naval Postgraduate School

The satellite image collection planning problem can be framed as a constrained hybrid dynamic optimization problem: the variables are discrete, continuous, dynamic and constrained. Industry solves this problem hierarchically. First, the dynamics are eliminated and the reduced problem is solved using a combination of heuristics and graph-theoretic techniques. Next, the dynamics are re-inserted to test feasibility of the solved imaging sequence. It is well-established that even the simplified planning problem is NP-hard. In this paper, we suggest that avoiding the hierarchical approach may indeed be simpler. Numerical results demonstrate the viability and scalability of this new approach.

8:40 **AAS 16-317** **Introducing a degree of freedom in the family of generalized logarithmic spirals**

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

A control parameter and a normal component of the thrust are added to the family of generalized logarithmic spirals in order to introduce a degree of freedom in the solution. The integrals of motion are preserved and a fully analytic solution is still found, which contains the original solution as a particular case. The construction of periodic orbits, transfers between arbitrary orbits and introducing coast arcs reduce to solving one equation with one unknown. Examples of application to different mission design scenarios are presented. Transfers between circular orbits are found to improve the performance of the Hohmann transfer.

9:00 **AAS** **Three-dimensional generalized logarithmic spirals**

16-323 *Javier Roa, Technical University of Madrid; Jesus Pelaez, Technical University of Madrid (UPM)*

The family of generalized logarithmic spirals is extended to the three-dimensional case. We effectively decouple the out-of-plane dynamics and find the exact and fully analytic solution to the motion. We prove that any control law assumed for the transversal motion still preserves the integrals of motion related to the energy and the angular momentum. Closed form solutions to the trajectory, the thrust acceleration and the time of flight are available including the out-of-plane motion. The simplest approach is to consider the generalized logarithmic helices, but we also explore alternative control laws. Examples of applications to interplanetary mission design problems are presented.

9:20 AAS 16-427 AN ADAPTIVE APPROACH FOR MODIFFED CHEBYSHEV PICARD ITERATION

Ahmad Bani Younes, Khalifa University

The demand of having fast and efficient numerical propagators to solve engineering problems has become essential. The level of system complexity increases the cost of obtaining the solution. Many real world problems require developing efficient, precise and fast solutions. For example, efficient, high precision orbit propagation has gained renewed impetus due to the rapidly escalating demands for improved Space Situational Awareness (SSA) and the challenges posed by the Kessler Syndrome, which hypothesizes that every collision of two space objects drastically increases the probability of subsequent collisions. The recent development Junkins et al. of Modiffed Chebyshev Picard Iteration (MCPI) has shown efficient solution for many engineering problems that require precise

9:40 AAS 16-519 Feasibility Regions of Boundary Value Problems of Low-Thrust Trajectories

Chit Hong Yam, Japan Aerospace Exploration Agency; Stefano Campagnola, JAXA / ISAS; Yasuhiro Kawakatsu, JAXA / ISAS; Ming Tony Shing

Two types of boundary values problems of low-thrust trajectories are considered: the matching problem and the reachability problem. We perform experiments on three approaches to solve and to analyze such boundary value problems, particularly the feasible regions of the solutions. A linear approximation method is applied which can compute the attainable sets of solutions efficiently and accurately for short transfer arcs as compared with the nonlinear constraint satisfaction method. An optimization approach that can map out the feasible set of solutions for long transfer arcs is also examined. Our results can be applied to low-thrust transfer problems with multiple legs.

10:00 Morning Break

10:20 AAS 16-227 Broad Search for Direct Trajectories from Earth to Double-satellite-aided Capture at Jupiter with Deep Space Maneuvers

Alfred Lynam, West Virginia University

Double-satellite-aided capture involves gravity assists of two of Jupiter's Galilean moons while a spacecraft is capturing into Jupiter orbit. In this paper, both gravity assists occur before a Jupiter Orbit Insertion (JOI) maneuver that completes the capture. We also find direct interplanetary trajectories from Earth to Jupiter that include a deep space maneuver (DSM). In each double-satellite-aided capture ``window", we use an optimizer to find the solution that captures the most mass into Jupiter orbit. The best solutions that launch in either 2022 or 2023 were numerically integrated in GMAT to provide practical double-satellite-aided captures for the Europa Mission's launch windows.

10:40 AAS 16-367 Parallel Genetic Algorithms For Optimal Control

Christopher McGrath, Naval Postgraduate School; Ronald Proulx, Naval Postgraduate School; Mark Karpenko, Naval Postgraduate School

This paper investigates the application of parallel genetic algorithms in finding solutions to optimal control problems using a direct shooting method. An example lunar lander problem is solved with parallel island genetic algorithms to demonstrate the effectiveness of different encoding types, crossover operators, and constraint-handling techniques. The incorporation of parallel processing is shown to improve robustness and accuracy in all algorithms considered in this study.

11:00 AAS 16-440 Attractive Set of Optimal Feedback Control for the Hill Three-Body Problem

Mai Bando, Kyushu University; Daniel Scheeres, University of Colorado

This paper investigates the combination of optimal feedback control with the dynamical structure of the three-body problem. Specifically we solve for the attracting set of an equilibrium point under optimal control with quadratic cost. In particular we find that the largest dimensions of the set are found along the stable manifold and the least extent is along the left eigenvector of the unstable manifold. The problem is worked out in detail analytically and we develop several proofs regarding the structure of the attractive set for an optimal transfer to an equilibrium point.

11:20 AAS 16-272 Global Optimization of n-Maneuver, High-Thrust Trajectories Using Direct Multiple Shooting

Matthew Vavrina, a.i. solutions; Jacob Englander, NASA Goddard Space Flight Center

The performance of impulsive, gravity-assist trajectories often improves with the inclusion of one or more maneuvers during transfers. However, grid-based scans over the design space can become computationally intractable for even one deep-space maneuver, and few global search routines are capable of an arbitrary number of maneuvers. To address this difficulty a trajectory transcription allowing for any number of maneuvers is developed within a global optimization framework for constrained, multi-leg, gravity-assist trajectories. The formulation exploits a robust shooting scheme and analytic derivatives for efficiency. The approach is applied to several interplanetary problems, achieving notable performance without a user-supplied initial guess.

11:40 AAS 16-487 Solving Singular Arc Problems with Direct Collocation Methods

Joseph Eide; Anil Rao, University of Florida

An approach is developed using collocation methods for algorithmically solving a singular optimal control problem. The approach identifies the possibility of a singular arc without the need to derive higher-order optimality conditions. The state and control approximation obtained from the collocation method on an initial mesh is analyzed and used to reformulate the optimal control problem into a multiple-phase problem with additional endpoint conditions. The approach is applied to two singular optimal control problems where it is found that the singular control approximation is indistinguishable from the singular control obtained using higher-order singular arc optimality conditions.

Feb 15, 2016 - Sauvignon

03 Spacecraft Dynamics

Chair: Francesco Topputo

8:00 **AAS 16-299** **Transfers to a Sun-Earth Saddle Point: An Extended Mission Design Option for LISA Pathfinder**

Andrew Cox, Purdue University; Kathleen Howell, Purdue University

The LISA Pathfinder extended mission may begin immediately following the primary mission to a Sun-Earth L1 libration point orbit. One extended mission with scientific appeal is a spacecraft path that makes multiple passes within 100 km of a gravitational equilibrium point. To explore this option, two methodologies are investigated: patching arcs from the circular restricted three-body problem, and propagating trajectories in a higher-fidelity four-body model. Mission designs are then corrected in an ephemeris model to demonstrate feasibility. Finally, potential trajectories are detailed and compared to the mission design criteria.

8:20 **AAS 16-310** **Algebraic manipulators: new perspectives in analytical or semi-analytical solutions to Astrodynamics problems**

Juan Félix San-Juan, University of LA Rioja; Rosario Gomez; Roberto Armellin, Universidad de La Rioja

The evolution of the hardware and the capabilities of the general computer algebra system have supplied us with the possibility of
developing a environment called MathATESAT embedding in Mathematica, which is not linked to a Poisson series processor.
MathATESAT implemented all the necessary tools to carry out high accuracy analytical or semi-analytical theories in order to analyze the quantitative and qualitative
behaviour of a dynamic system. In this work, we extend MathATESAT's facilities implemented from an analytical theory of the artificial satellite problem, the analytical transition matrix and one turn transfer map.

8:40 **AAS 16-311** **Application of the hybrid methodology to SGP4**

Juan Félix San-Juan, University of LA Rioja; Iván Pérez, University of La Rioja; Montserrat SanMartin

A hybrid perturbation theory may combine any kind of integration method, numerical, analytical or semianalytical, with forecasting techniques based on Statistical Time Series models or Computational Intelligence methods. This combination allows for an increase in the accuracy of the theory for predicting the position and velocity of any artificial satellite or space debris object, as well as modeling higher-order terms and other external forces not considered in the numerical, analytical or semianalytical theories. The aim of this communication is to develop a family of Hybrid Orbit Propagators based on SGP4 and an additive Holt-Winters method as the forecasting technique for

9:00 **AAS 16-332** **Survey of Numerical Methods for Computing Quasi-periodic Invariant Tori in Astrodynamics**

Nicola Baresi, University of Colorado Boulder; Zubin Olikara, Institut d'Estudis Espacials de Catalunya; Daniel Scheeres, University of Colorado

Quasi-periodic invariant tori are of great interest in astrodynamics because of their capability to further expand the design space of satellite missions. This paper compares the performance of three different approaches found in the literature. The first method computes invariant tori of flows using central differences, whereas the other two strategies calculate invariant curves of maps via shooting algorithms (one using surfaces of section and the other one using a stroboscopic map). All the algorithms are used for studying quasi-periodic motion in the Hill Problem, although only the last method succeeds in correctly computing three-dimensional tori and their stability.

9:20 **AAS 16-484** **Dynamics of Asteroid 2006 RH120: Pre-Capture and Escape Phases**

Brian Anderson, University of Southern California; Martin W. Lo, Caltech Department of Computing + Mathematical Sciences

Asteroid 2006 RH120 was the first natural object captured by the Earth to be observed called a Minimoon. In this work, we show that the invariant manifolds of the orbits around the L1 and L2 Lagrange points play a significant role in the capture of the asteroid around Earth and its eventual escape from the Earth approximately 1 year later. We determined that the asteroid approached the Earth through the stable manifold of an L1 Northern Halo Orbit. After the Temporary Capture, the asteroid escaped the Earth through the unstable manifold of an L2 Southern Halo.

9:40 **AAS 16-378** **Medium-Energy, Retrograde, Ballistic Transfer to the Moon**

Kenta Oshima, Waseda University; Francesco Topputo, Politecnico di Milano; Stefano Campagnola, JAXA / ISAS; Tomohiro Yanao, Waseda University

This study analyzes a recently discovered new class of exterior transfer to the Moon. The investigated exterior transfer has four distinct features; dynamics of Lagrange points is not utilized near apogee, angular momentum is negative, Kepler energy is negative, and high three-body energy in the capture phase to the Moon. We demonstrate the importance of energetically forbidden region as the bouncing mechanism near apogee and a tube geometry of collisional, singular orbits for the capture process by qualitatively constructing the novel type of exterior transfer to the Moon using the patched three-body technique in the bicircular restricted four-body model.

10:00 **Morning Break**

10:20 **AAS 16-312** **MANEUVER AND VIBRATION SUPPRESSION OF FLEXIBLE MANIPULATORS FOR CAPTURING UNKNOWN OBJECTS USING VARIABLE-SPEED CONTROL MOMENT GYROS**

Shiyuan Jia; Yinghong Jia; Shijie Xu

In this paper, the variable-speed control moment gyros are adopted as actuators for vibration suppression of space flexible manipulator. The manipulator is constituted by four links, two of which are flexible bodies, whereas the other two are rigid are rigid ones. VSCMGs are mounted on the two flexible links for active vibration suppression. The dynamics of the multibody systems are derived with unknown object parameters. Adaptive sliding mode controller is designed for maneuver and vibration suppression of flexible manipulator when capturing unknown objects. Numerical simulations of a maneuver task demonstrate the validity of the proposed method.

10:40 AAS 16-334 Active Vibration Suppression in Flexible Spacecraft during Attitude Maneuver

Zhaohui Wang, Beihang University; Ming Xu, Beihang University; Shijie Xu; Shiyuan Jia; Guoqi Zhang, Beijing Institute of Aerospace Control Technology

This paper focus on solving the problem of the active vibration control for a group of flexible appendages that not allowed to be settled with actuators. To solve these problems the unreliability or impracticality of structural, an identification system is designed to modify the structure parameters using the vibrate displacement of flexible appendages measured by the optical sensors. Then a feedback filter is designed to complete the attitude maneuver and damping the vibration of the flexible appendages using the modified parameters. The absence of displacement velocity sensors is compensated for by the presence of appropriate dynamics in the controller.

11:00 AAS 16-379 DESIGN AND OPTIMIZATION OF TENSION DISTRIBUTION FOR SPACE DEPLOYABLE MESH REFLECTORS

Sichen Yuan, University of Southern California; Bingen Yang, University of Southern California

A new method is proposed to determine tension distribution of space deployable mesh reflectors. In this method, numerical optimization algorithms are used to minimize the band-width of tension distribution of a mesh reflector structure. The optimization process takes two major steps. First, the nodal coordinates of a mesh reflector are determined from a geometry design, which eventually yields the equilibrium equations of the reflector. Second, an optimization algorithm is implemented to obtain a good tension distribution among all possible solutions from the nonlinear equilibrium equations of the reflector. Numerical simulation shows that the proposed method is able to significantly narrow

11:20 AAS 16-499 Dynamics and Control of the Flexible Electrostatic Sail Deployment

JoAnna Fulton; Hanspeter Schaub, University of Colorado

The deployment dynamics of an electrostatic sail (E-sail) are modeled for hub-mounted control. Spacecraft hub control torque requirements for obtaining desired spin rate trajectories are investigated. The dynamics are treated as a planar deployment and feedback control is applied. The sail is modeled for two different deployment strategies and tether stowage configurations, a tether spool wound up on a cylindrical hub which deploys the tether end masses tangentially, and a radially deployed configuration where each tether is stowed on an individual hub and actuated by a spool motor. Additionally, deployment behavior is determined for several tangentially deployed E-sails with varying characteristics.

11:40 AAS 16-547 Mechanics of bounded inextensible membranes subjected to external forces

Bo Fu; Rida Farouki; Fidelis Eke

In this study the exact shape of a bounded developable surface subjected to external forces is presented. These kinds of surfaces are different from most classes of plates or membranes that have been studied in detail in the past. There is no elastic deformation (zero Gaussian curvature), and the surface has no torsional resistance. The shape of the surface is determined by the geometrical boundary conditions and is a result of an equilibrium between internal tension and external forces. Understanding the shape of such surfaces is crucial for attitude dynamics of space structures and spacecraft, such as a solar sail.

Feb 15, 2016 - Chardonnay AB

04 Spacecraft Autonomy

Chair: Michael Gabor

8:00 AAS 16-309 MAINTAIN A LIBRATION POINT ORBIT IN THE SUN-MERCURY ELLIPTIC RESTRICTED SYSTEM

Hao Peng, Beihang University; Yuxin Liao, Beihang University; Shijie Xu; Shiyuan Jia

A new periodic libration point orbit in the Sun-Mercury Elliptic Restricted Three-Body Problem (ERTBP) is used as a nominal trajectory, and it is successfully tracked using a receding horizon control strategy solved by a newly-developed indirect Radau pseudo-spectral method. We emphasis that the ERTBP is nonautonomous and periodically time-dependent, so it is usually more unstable than the circular situation. The capability of using special libration point orbit in the ERTBP to explore the Sun-Mercury system is expected to be further demonstrated through this on-board control strategy investigation.

8:20 AAS 16-221 LDSD POST2 MODELING ENHANCEMENTS IN SUPPORT OF SFDT-2 FLIGHT OPERATIONS

Joseph White, AMA, INC; Angela Bowes, NASA LaRC; Soumyo Dutta, NASA Langley Research Center; Mark Ivanov, Jet Propulsion Laboratory; Eric Queen

Program to Optimize Simulated Trajectories II (POST2) was utilized to develop trajectory simulations characterizing all flight phases from drop to splashdown for the Low-Density Supersonic Decelerator (LDSD) Project's first and second Supersonic Flight Dynamics Tests (SFDT-1 and SFDT-2) which took place June 28, 2014 and June 8, 2015. This paper describes the modeling improvements incorporated into the LDSD POST2 simulations since SFDT-1 and presents how these modeling updates affected the predicted SFDT-2 performance and sensitivity to the mission design. The POST2 simulation flight dynamics support during the SFDT-2 launch, operations, and recovery is also provided.

8:40 AAS 16-217 Supersonic Flight Dynamics Test 2: Trajectory, Atmosphere, and Aerodynamics Reconstruction

Chris Karlgaard, Analytical Mechanics Associates, Inc.; Clara O'Farrell; Ginn Jason; John Van Norman, Analytical Mechanics Associates

The Low Density Supersonic Decelerator (LDSD) project is a technology development program designed to advance aerodynamic decelerator technologies for landing high mass payloads on Mars. The Supersonic Flight Dynamics Tests (SFDT) are a series of flight tests within the LDSD campaign, performed to demonstrate these technologies at Mars relevant conditions. The second flight test was SFDT-2, completed on June 8, 2015 at the Pacific Missile Range Facility in Kauai, Hawaii. This paper describes the instrumentation, analysis techniques, and flight test data utilized to reconstruct the SFDT-2 vehicle trajectory, atmosphere, and aerodynamics. The reconstruction results are presented and explored.

9:00 AAS 16-222 Post-flight Assessment of Low Density Supersonic Decelerator Flight Dynamics Test 2 Simulation

Soumyo Dutta, NASA Langley Research Center; Angela Bowes, NASA LaRC; Joseph White, AMA, INC; Scott Striepe, NASA Langley; Eric Queen; Clara O'Farrell; Mark Ivanov, Jet Propulsion Laboratory

NASA's Low Density Supersonic Decelerator (LDSD) project conducted its second Supersonic Flight Dynamics Test (SFDT-2) on June 8, 2015. Program to Optimize Simulated Trajectories II (POST2) was one of the flight dynamics tools used to simulate and predict the flight performance and was a major tool used in the post-flight assessment of the flight trajectory. This paper compares the simulation predictions with the reconstructed trajectory. Additionally, off-nominal conditions seen during flight are modeled in the simulation to reconcile the predictions with flight data. The results of these analyses are beneficial for the simulation and targeting of the follow-on LDSD flights.

9:20 AAS 16-243 Cassini Maneuver Experience Through the Last Icy Satellite Targeted Flybys of the Mission

Sonia Hernandez, Jet Propulsion Laboratory; Sean Wagner, NASA/JPL; Mau C. Wong, JPL; Yungsun Hahn, Jet Propulsion Laboratory; Powtawche Valerino, NASA / Caltech JPL; Paul Stumpf, NASA / Caltech JPL; Mar Vaquero, NASA Jet Propulsion Laboratory; Frank Laipert, Jet Propulsion Laboratory

The Cassini spacecraft will reach its spectacular end-of-mission in September 2017, after having spent a successful twenty years in space gathering invaluable scientific data about Saturn, its rings, and moons. Cassini has flown the most complex gravity-assist trajectory ever designed, which requires frequent maneuvering to achieve the desired targets. After so many years in operation the propellant is starting to dwindle, making it of paramount importance that the maneuvers be designed to prioritize preserving propellant. This paper highlights the strategies for 50 planned maneuvers during twelve Titan flybys and the last Dione and Enceladus flybys of the mission.

9:40 AAS 16-305 Cassini Maneuver Performance Assessment and Execution-Error Modeling Through 2015

Sean Wagner, NASA/JPL

Since July 2004, the Cassini spacecraft has been gathering valuable data about Saturn and its moons. Cassini has performed 332 propulsive maneuvers through January 29, 2016. With over 30 maneuvers planned through the end of mission in September 2017, a dwindling propellant supply has become a chief concern. Efforts to improve Cassini's maneuver performance have led to several execution-error model updates and calibrations of on-board flight parameters. This paper presents a recent analysis of maneuvers executed through December 30, 2015 and validates the execution-error models in use since August 2012. Model update recommendations for the remainder of the mission are also provided.

10:00 **Morning Break**

10:20 **AAS 16-412** **Reactive Online Mission Design at Small Bodies**

David Surovik, University of Colorado at Boulder; Daniel Scheeres, University of Colorado

The complexity and sensitivity of strongly non-Keplerian orbital motion near asteroids and comets motivates an autonomous on-board approach to mission design. We apply heuristic-guided numerical reachability analysis in a receding horizon fashion to successively design impulsive maneuvers that ultimately enable fulfillment of science objectives. Previous work is extended to mitigate uncertainty in state estimates and dynamical modeling through the use of robust planning and feedback. These two approaches are compared via Monte Carlo sets of mission trials at the highly irregularly shaped comet 67/P to reveal the trade-offs between computational and operational effort necessary to consistently produce mission success.

10:40 **AAS 16-551** **Magnetic Attitude Control with Aerodynamic Stabilization for the LAICE Satellite**

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

The LAICE satellite will make use of magnetic torqueing coils augmented with aerodynamic stabilization to accomplish the mission attitude control requirements. The proposed control method relies on aerodynamic stabilization of the spacecraft to maintain pointing in the satellite normal frame. The aerodynamic stabilization reduces the dimensionality of the magnetic attitude control to a one-dimensional problem. As a result, it is possible to design an optimal controller for the magnetic torqueing coils based upon models of the orbital trajectory and the Earth's magnetic field. The design of the controller along with the results of a hardware-in-the-loop attitude control simulation is presented.

11:00 **AAS 16-454** **1 OPTIMAL SLIDING GUIDANCE FOR EARTH-MOON HALO ORBIT STATION-KEEPING, TRANSFER, AND RENDEZVOUS**

Joel Mueting, University of Arizona; Roberto Furfaro, The University of Arizona; Francesco Topputo, Politecnico di Milano; Jules Simo, University of Central Lancashire

An Optimal Sliding Guidance (OSG) is implemented in the Circular Restricted Three-Body Problem for spacecraft near libration points of the Earth-Moon system. Based on a combination of generalized Zero-Effort-Miss/Zero-Effort-Veloc-ity and time-dependent sliding control theory, OSG is capable of generating closed-loop guided trajectories that are demonstrated to be globally finite-time stable against uncertain perturbing accelerations with known upper bound. The application of the OSG for Halo orbit station-keeping, orbital transfer, and rendezvous will be studied in a perturbed four body dynamical model in order to evaluate response and effectiveness of the proposed guidance approach.

11:20 **AAS 16-329** **Optimal Attitude and Orbital Control Strategy of Spinning Solar Sail Spacecraft via Reflectivity Control**

Kenshiro Oguri, The University of Tokyo; Ryu Funase, The University of Tokyo

This paper presents the time-optimal attitude control for spinning solar sail driven by reflectivity control. Although solar sail needs no fuel for acceleration, conventional solar sail requires it for attitude control. Thereupon, a fuel-free attitude control system was demonstrated; however, no effective control strategy has been proposed. In addition, the long time-constant of attitude change causes coupling problem of attitude and orbital motion. The proposed controller gives a solution for the two problems. To demonstrate the capability, V-infinity leveraging problem is numerically solved. The result suggests that transient thrust during attitude maneuvers should be incorporated into orbital design.

11:40 **AAS 16-517** **Geostationary Satellite Station Keeping Using Drift Counteraction Optimal Control**

Robert Zidek, The University of Michigan; Ilya Kolmanovsky, University of Michigan

The framework of Drift Counteraction Optimal Control (DCOC) is used to generate a feedback control policy that maximizes the time until a geostationary satellite violates prescribed position, velocity, and fuel constraints. For this problem, we modify a recently developed DCOC algorithm to provide higher accuracy when large time horizons are considered. The nonlinear satellite model accounts for perturbations due to luni-solar gravity, solar radiation pressure, and J2. The example satellite is equipped with six on-off thrusters. Simulation results are presented.

Feb 15, 2016 - Pinot Noir BC

05 Mission Design 1

Chair: Jill Seubert

13:30 **AAS 16-257** **FINAL MISSION AND NAVIGATION DESIGN FOR THE 2016 MARS INSIGHT MISSION**

Fernando Abilleira, NASA / Caltech JPL

NASA's Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight) mission will launch the next lander to Mars in March 2016 arriving to the Red Planet in the fall. Derived from the Phoenix mission which successfully landed on Mars in May 2008, the InSight Entry, Descent, and Landing system will place a lander in the Elysium Planitia region. This paper specifies the mission and navigation requirements set by the Project and how the final mission and navigation design satisfies those requirements. Background information affecting navigation including spacecraft modeling and the physical environment which influences the spacecraft motion are included.

13:50 **AAS 16-288** **Construction of Supersonic Flight Dynamics Test Vehicle Monte Carlo Splashdown Footprints for use in Range Safety and Recovery Operations**

William Strauss, Jet Propulsion Laboratory; Mark Ivanov, Jet Propulsion Laboratory

The Low-Density Supersonic Decelerator project performed the second test flight of a supersonic inflatable device and ring-sail parachute on June 8, 2015 splashing down in the Pacific Ocean west of Kauai. In order for recovery ships to quickly extract the TV hardware from the ocean, and in the interest of safety to the population of the islands of Kauai and Nihau, statistical estimates of the splashdown location had to be performed. This paper describes the modeling assumptions used to generate the Monte Carlo splashdown trajectory simulation results and use of splashdown probability ellipses in support of satisfying range safety requirements.

14:10 **AAS 16-285** **The Lunar IceCube Mission Design: Construction of Feasible Transfer Trajectories with a Constrained Departure**

David Folta, NASA Goddard Space Flight Center; Kathleen Howell, Purdue University; Natasha Bosanac, Purdue University; Andrew Cox, Purdue University

Lunar Ice Cube, a 6U CubeSat, will prospect for water and other volatiles from a low-periapsis, highly inclined elliptical lunar orbit. Injected from Exploration Mission-1, a lunar gravity assisted multi-body transfer trajectory will achieve lunar capture and science orbit. The constrained departure asymptote and trans-lunar energy limit transfer trajectory types that re-encounter the Moon with the necessary Jacobi energy and flight duration. Purdue/GSFC's Adaptive Trajectory Design tool and dynamical system research uncovered Euclidian regions of Cis-lunar space permitting a transition onto stable/unstable manifolds that re-encounter the Moon. Numerically integrated transfer trajectory designs applying low-thrust and the design process are described.

14:30 **AAS 16-372** **Low Energy Escape Trajectory for the Mars Moon Sample Return Mission**

Makoto Horikawa, Waseda University; Yasuhiro Kawakatsu, JAXA / ISAS; Hiroaki Yoshimura, Waseda University

The world first sample return mission from the Martian moons, Phobos or Deimos, is currently being planned by the Japan Aerospace Exploration Agency (JAXA). In the design process, the hybrid usage of chemical and electric propulsion has been brought into consideration as the configuration for the inbound leg of the trajectory (from Mars to Earth). In this paper, we will study the low energy escape from Martian moons using Planar Circular Restricted Three-Body Problem of Sun-Mars-Spacecraft system and its connection to the low-thrust two-body interplanetary phase.

14:50 **AAS 16-393** **Dynamic Strategies for Mission Launches and other Scenarios Related to Secretary Problems**

Ingo Althöfer, Fakultät Mathematik und Informatik

For an interplanetary mission the launch typically has to happen within a certain time slot, for instance within 10 days. In case of problems (like bad weather) the launch may be postponed to the next day. We discuss and compute **dynamic strategies**, based on Bellman's dynamic programming, to get good launch decisions. The situation is a stopping problem, related to quantitative versions of the classic secretary problem. Variants are relevant for missions to Mars (including touring on and returning form Mars) and multi-target missions to families of small bodies. Good launch strategies will play a role for launch insurance rates.

15:10 **Afternoon Break**

15:30 **AAS 16-405** **The Earth-Moon Low-Energy Transfer in the 4-Body Problem**

Kaori Onozaki, Waseda university; Hiroaki Yoshimura, Waseda University; Shane Ross

A low energy transfer from Earth to Moon is proposed in the context of the 4-Body Problem. We will first regard the Sun-Earth-Moon-Spacecraft (S/C) 4-Body system as the coupled system of the

Sun-perturbed 3-Body system and the Moon-perturbed 3-Body system. In particular, we will clarify the tube-like structures of invariant manifolds of the 4-Body Problem by the Lagrangian coherent structures. Lastly, we will construct a low-energy transfer trajectory from Earth to Moon by patching two trajectories obtained from the perturbed systems at a Poincare section. We will develop an optimal trajectory by minimizing the Delta-v at the Poincare section.

15:50 AAS 16-418 TRANSFERS BETWEEN THE LAGRANGIAN POINTS AND THE PRIMARIES CONSIDERING RADIATION PRESSURE

Geraldo Oliveira, National Institute for Space Research - INPE; Antonio Fernando Bertachini Prado, INPE; Diogo Sanchez, National Institute for Space Research - INPE

The equilibrium Lagrangian points that appear in the restricted three-body problem have several applications, like the location of space stations, relay satellites for communications, etc. They are five points of equilibrium of the system and a spacecraft placed there with zero velocity will remain there forever. The present paper considers the problem of transfers between those Lagrangian points and the primaries, the Earth and the Sun, in the Sun-Earth system. Previous researches have been done in similar problems, but the present paper considers the effects of the Solar radiation pressure in the trajectory of the spacecraft.

16:10 AAS 16-467 L4, L5 Solar Sail Transfers and Trajectory Design: Solar Observations and Potential Earth Trojan Exploration

Rohan Sood, Purdue University; Kathleen Howell, Purdue University

The Sun-Earth triangular Lagrange point, L_5, provides an ideal location to monitor the space weather. Furthermore, $L_{4,5}$ may harbor Earth Trojans and space dust that are of significant interest to the scientific community. No spacecraft has entered an orbit about a Sun-Earth triangular point due to high mission costs. By incorporating solar sail dynamics in the CR3BP, the total ΔV required for a mission to $L_{4,5}$ can potentially be lowered. A solar sail is employed to increase the energy of the spacecraft and deliver the spacecraft to an orbit about the artificial Lagrange point without any insertion ΔV.

16:30 AAS 16-493 Commercial Cubesat Technology to Enhance Science: Communications, Space Debris Identification, and Moon Surface Reconnaissance Using Lagrangian Cyclers

Pedro J. Llanos, Embry-Riddle Aeronautical University; Abdiel A. Santos

This paper deals with novel cycler trajectories for cubesats that will depart from low-Earth orbit (LEO) to help determine the resources needed for interplanetary travel and infrastructure required for space colonization on the Moon. Our cubesats will depart from a 400-km parking orbit aboard the International Space Station (ISS) to provide significant opportunities to enhance communication and navigation strategies while improving space exploration capabilities. Different cycler orbits connecting the Lagrange points in the Earth-Moon system are explored, which will enable us to improve our communications and navigation from Earth via low ΔV connection nodes often referred to as the Interplanetary Superhighway.

Feb 15, 2016 - Cabernet

06 Guidance and Control 1

Chair: Morgan Baldwin

13:30 **AAS 16-391** **Robustification of a Class of Guidance Algorithms for Planetary Landing: Theory and Applications**

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

In this paper, the problem of robustifying a class of closed-loop guidance algorithms for landing on planetary bodies is considered. The behavior of the proposed closed-loop guidance algorithms is analyzed both from a theoretical and practical standpoint. Global finite-time stability is demonstrated by the application of Lyapunov stability theoty for non-autonomous systems.

13:50 **AAS 16-215** **Orion Entry Monitor**

Kelly Smith, NASA Johnson Space Center

NASA is scheduled to launch the Orion on Exploration Mission 1 in late 2018. When Orion encounters Earth's atmosphere, it will attempt its first precision-guided skip entry. A suite of algorithms collectively called the Entry Monitor has been developed to enhance crew situational awareness and enable high levels of onboard autonomy. The Entry Monitor determines the vehicle capability footprint in real-time, provides manual piloting cues, evaluates landing target feasibility, predicts the ballistic instantaneous impact point, and provides intelligent recommendations for alternative landing sites if the primary landing site is not achievable.

14:10 **AAS 16-220** **REENTRY TRAJECTORY OPTIMIZATION UNDER THE EFFECTS OF UNCERTAIN ATMOSPHERIC DENSITY AND WIND FIELD**

YUAN REN, York University; Jinjun Shan, York University

The problem of reentry trajectory optimization has been investigated by many researchers in the last several decades. In deterministic dynamic models, the reentry trajectory optimization problem can be summarized as a non-linear optimization problem with multiple constraints. In this paper, the reliability-based trajectory optimization method is used in the reentry trajectory design. The algorithm introduced in this paper can be used directly in planetary atmospheric entry problem, and it also provides referential experiences for the other trajectory optimization problem in uncertain model.

14:30 **AAS 16-245** **Surrogate Model for Probabilistic modeling of Atmospheric Entry for small NEOs**

Piyush Mehta, University of Strathclyde; Martin Kubicek; Edmondo Minisci; Massimiliano Vasile, University of Strathclyde

Near Earth Objects (NEOs) enter the Earth’s atmosphere on a regular basis. Depending on the size, object and entry parameters, these objects can burn-up through ablation (complete evaporation), undergo fragmentation of varying nature, or impact the ground un-perturbed. Parameters that influence the physics during entry are either unknown or highly uncertain. In this work, we propose a probabilistic approach for simulating entry. Probabilistic modeling typically requires a Monte Carlo approach. In this work, we develop and present a novel engineering approach of developing surrogate models for simulation of the atmospheric entry accounting for drag, ablation, evaporation, fragmentation, and ground impact.

14:50 **AAS** **Moving-Mass Actuator System Options for Entry Vehicles with Deployable**

16-373 Decelerators

Kevin Lohan, University of Illinois at Urbana-Champaign; Zachary Putnam, University of Illinois

This study assesses the effectiveness of internal moving mass actuation options to control trim conditions in the hypersonic regime of planetary entry. Trajectory control is achieved by shifting the location of the center of gravity relative to the aerodynamic center to modify the trim angle of attack. The vehicle is modeled as a cylinder with a large deployable hypersonic decelerator forebody. System parameters including vehicle size, track length, and track placement are varied to determine their impact on system performance.

15:10 **Afternoon Break**

15:30 **AAS 16-485** **Orion Exploration Mission Entry Interface Target Line**

Jeremy Rea, NASA

The Orion Multi-Purpose Crew Vehicle is required to return to the continental United States at any time during the month. In addition, it is required to provide a survivable entry from a wide range of trans-lunar abort trajectories. The Entry Interface (EI) state must be targeted to ensure that all requirements are met for all return scenarios, even in the event of no communication with the Mission Control Center to provide an updated EI target. This paper presents the techniques used to define the EI constraint manifold and to functionalize it as a set of polynomials in several dimensions.

15:50 **AAS 16-491** **Multi-Fidelity Uncertainty Quantification for Atmospheric Re-entry using High Dimensional Model Representation**

Martin Kubicek; Piyush Mehta, University of Strathclyde; Edmondo Minisci; Massimiliano Vasile, University of Strathclyde

The prediction of aerodynamic and aerothermodynamic variables in the harsh re-entry environment remains a challenge. High-fidelity computational methods such as the Direct Simulation Monte Carlo (DSMC) or Computational Fluid Dynamics (CFD) are typically employed. However, such tools are highly expensive and faster methods are required. On the other hand, low-fidelity models, which can be much cheaper, usually give a response with much higher error. The combination of responses obtained by models at different fidelity levels allows for a faster and more efficient propagation of the uncertainties. In this work, we present a novel approach for modeling the uncertainties with a

16:10 **AAS 16-504** **Semi-Analytical Adaptive Guidance Computation Based on Differential Algebra for Autonomous Planetary Landing**

Paolo Lunghi, Politecnico di Milano - Aerospace Science & Technology Dept.; Roberto Armellin, Universidad de La Rioja; Pierluigi Di Lizia, Politecnico di Milano; Michèle Lavagna, Politecnico di Milano

A novel algorithm for autonomous landing guidance computation is presented. Trajectory is expressed in polynomial form of minimum order to satisfy a set of 17 boundary constraints, depending on 2 parameters: time-of-flight and initial thrust magnitude. The consequent control acceleration is expressed as Differential Algebra variable, expanded around the point of the domain along the nominal trajectory followed at the retargeting epoch. The DA representation of objective and constraints gives additional information about their sensitivity to variations of optimization variables, exploited to find the desired fuel minimum (if exists) avoiding less robust processes with a very light computational effort.

16:30 **AAS 16-410** **Autonomous Guidance Algorithm for Multiple Spacecraft and Formation Reconfiguration Maneuvers**

Theodore Wahl, Purdue University; Kathleen Howell, Purdue University

Spacecraft formations operating autonomously have the potential to be used in a wide variety of missions. This investigation explores the creation of an autonomous guidance algorithm for a formation reconfiguration maneuver of an arbitrary number of spacecraft. The maneuver is broken into 2 problems: assignment and guidance. The guidance algorithm uses an auction process to assign each spacecraft a position in the formation. The guidance algorithm then uses Adaptive Artificial Potential Functions (AAPF) to guide each spacecraft to its target position. Ultimately, the guidance algorithm requires from the user only the initial targets states to perform the reconfiguration maneuver.

Feb 15, 2016 - Sauvignon

07 Estimation

Chair: Christopher DSouza

13:30 **AAS 16-399** **Development of a satellite group tracking method**

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

When multiple objects are orbiting in close proximity to one another, as in the early stages of a breakup or a deployment, conventional tracking is difficult because of the observation association problem. However, the ability to characterize and track these objects quickly is important for spaceflight safety. This paper explores the concept of group tracking for space surveillance. Explicit observation association is not required, as the "cloud" of objects is tracked as a parameterized collective. A scheme for tracking the centroid and extent parameters of the collection separately is presented, along with preliminary results.

13:50 **AAS 16-402** **The Gaussian Mixture Consider Kalman Filter**

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

The consider Kalman filter is a tool developed in the 1960s to account for uncertain parameters or biases within the system and observational models of a tracking algorithm. Its novelty is in that it "considers" the effects of the uncertain parameters rather than other Kalman-filter-based approaches, which instead estimate these parameters directly. The consider Kalman filter, however, is an approach that works solely with the mean and covariance of the posterior distribution. This work presents a consider formulation that works with a Gaussian sum approximation of the true distribution, permitting the Gaussian mixture consider Kalman filter.

14:10 **AAS 16-336** **Relative Motion Estimation using Rectilinear and Curvilinear Linearized Relative Orbit Elements**

Trevor Bennett, University of Colorado; Hanspeter Schaub, University of Colorado

Relative motion estimation finds application in space-based space situational awareness and proximity operations. Prior work demonstrates the capability and insight provided by a relative motion state vector chosen to be the Clohessy-Wiltshire integration constants, referred to as Linearized Relative Orbit Elements (LROEs). This study develops a curvilinear coordinate state vector and compares the estimation performance to both dimensional and non-dimensional rectilinear state estimation approaches. The curvilinear formulation demonstrates observability and improved estimation performance for the presented relative orbits. All LROE estimation approaches preserve much of the geometrical insight of the relative orbit while accommodating large initial condition errors.

14:30 **AAS 16-414** **Analytic Uncertainty Propagation in Satellite Relative Motion along Elliptic Orbits**

Sangjin Lee, Purdue University; Hao Lyu, Purdue University; Inseok Hwang, Purdue University

In this study, an analytical closed-form solution is developed for uncertainty propagation in satellite relative motion near general elliptic orbits. The Tschauner-Hempel equations are used to describe the linearized relative motion of the deputy satellite where the chief orbit is eccentric. Under the assumption of the linearized relative motion and white Gaussian process noise, the uncertainty propagation problem is defined to compute the mean and covariance matrix of the states of the deputy satellite. This study discusses the difficulties in evaluating the mean and covariance, and proposes a method to alleviate the difficulties in order to find a closed-form solution.

14:50 **AAS 16-512** **Angles-Only Initial Relative-Orbit Determination Via Successive Maneuvers**

Laura Hebert, Auburn University; Andrew Sinclair, Auburn University; Alan Lovell, Air Force Research Laboratory

For relative-orbit determination using linear, Cartesian dynamics, angles-only measurements are not sufficient. A known maneuver performed by either the chief or deputy spacecraft can provide observability. However, some maneuvers result in singular measurement equations and therefore do not provide full-state observability. These singular maneuvers can be avoided, but no further information can be provided about desirable maneuvers. The goal of this paper is to provide an iterative method by which to improve observability and the accuracy of the solution. Successive maneuvers planned using covariance predictions from previous estimates give increasingly good estimates.

15:10 **Afternoon Break**

15:30 **AAS** **Improved Maneuver-Free Approach to Angles-Only Navigation for Space Rendezvous**

16-530 *Joshua Sullivan, Stanford Space Rendezvous Laboratory; Simone D'Amico, Stanford University*

This paper presents a novel strategy for improving angles-only relative navigation for distributed space systems without requiring reconfiguration maneuvers. A rigorous state comparison and observability assessment result in new insight into the coupling of state elements, modeling accuracy, and the effects of relative orbit geometry on the feasibility of relative orbit determination from camera-based measurements. The results of this assessment are then leveraged in a state-of-the-art navigation filter design which uses an Extended Kalman Filter approach combined with a deterministic relative orbit determination method to provide accurate navigation solutions. Finally, the proposed algorithms are tested and validated in high-fidelity simulation.

15:50 **AAS 16-341** **Moon and Earth Image Processing using Asymmetric 2-Dimensional Functions on Image Gradient**

Daniele Mortari, Texas A&M University; Stoian Borissov, Texas A&M University

Asymmetric Gaussian-type data distribution is found in the image processing at the edge of an observed illuminated body (Moon, Earth, planet) using the image gradient. The reason is, one side of this Gaussian behavior is associated with the dark background (pretty uniform) while the other side is associated with the illuminated part, which is perturbed by different reflecting areas: craters for Moon and high clouds for Earth. This variation is here implemented by modeling the standard deviation as a sigmoid function. Nonlinear least squares estimate is then applied for OpNav problem using synthetic Moon and Earth images.

16:10 **AAS 16-489** **An Update to the THEMIS Thermal Gauging Fuel Estimation Process and Its Use in a Fuel Imbalance Anomaly**

Aaron Burgart, UC Berkeley, Space Sciences Laboratory; Daniel Cosgrove, UC Berkeley, Space Sciences Laboratory; Jeffrey Marchese, UC Berkeley, Space Sciences Laboratory; Manfred Bester, UC Berkeley, Space Sciences Laboratory

Accurate knowledge of propellant mass is crucial to a spacecraft mission's success, especially as propellant mass decreases as the mission progresses. When the fuel loads are imbalanced between multiple tanks, as has been discovered on the THEMIS spacecraft, this knowledge becomes even more crucial. This paper discusses improvements to a previously developed thermal gauging fuel mass estimation process and how this process has been utilized to quantify and monitor the fuel imbalances between tanks. This has allowed the operations team to thoughtfully judge when to draw from individual tanks for maneuvers in order to level the fuel load.

16:30 **AAS 16-423** **State Estimation and Maneuver Reconstruction with The Nonlinear Adaptive Optimal Control Based Estimator**

Daniel Lubey; Daniel Scheeres, University of Colorado

The data sparse and non-cooperative nature of observation sets within Space Situational Awareness applications require tracking algorithms to be robust to dynamic mismodeling and long observation gaps in addition to being automated. The Nonlinear Adaptive Optimal Control Based Estimator was designed to address this type of estimation problem. It is capable of real-time state estimation and maneuver detection and reconstruction in a way that yields continuous state trajectories across observation gaps. This paper develops this algorithm and its maneuver detection capabilities with an emphasis on nonlinear estiamtion. The method is demonstrated through sample tracking scenarios with comparisons made to the linear verion of the estimator.

Feb 15, 2016 - Chardonnay AB

08 Dynamics and Perturbations 1

Chair: Diane Davis

13:30 AAS 16-342 HIGH-ORDER STATE TRANSITION TENSORS OF PERTURBED ORBITAL MOTION USING COMPUTATIONAL DIFFERENTIATION

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

The computation of high-order State Transition Tensors (STTs) for perturbed orbital motion using computational differentiation is presented. We first discuss the automatic differentiation tool that enables computation exact higher-order partial derivative models of the perturbed orbital motion. The perturbed two-body problem, where the earth gravity potential is the spherical harmonic Earth gravitational model, is studied. High-order gradient tensor models are required for computing the STTs model. Generating these gradient tensors is only practical by invoking the use of Computational Differentiation (CD) tools, which are briefly described. The general modeling methodology is expected to be broadly useful for science and engineering applications in general, as well as grand challenge problems

13:50 AAS 16-461 HIGH-ORDER STATE TRANSITION TENSOR MODELS FOR THE UNCERTAINTY PROPAGATION OF PERTURBED ORBITAL MOTION

Ahmad Bani Younes, Khalifa University; James Turner, Khalifa University, Abu Dhabi

Modeling and simulation for complex applications in science and engineering develop behavior predictions based on mechanical loads. Imprecise knowledge of the model parameters or external force laws alters the system response from the assumed nominal model data. As a result, one seeks algorithms for generating insights into the range of variability that can be the expected due to model uncertainty. Two issues complicate approaches for handling model uncertainty. First, most systems are fundamentally nonlinear, which means that closed-form solutions are not available for predicting the response or designing control and/or estimation strategies. Second, series approximations are usually required, which demands

14:10 AAS 16-265 Nonlinear Uncertainty Propagation in Astrodynamics: Comparing Taylor Differential Algebra with Monte-Carlo on GPUs

Mauro Massari, Politecnico di Milano; Pierluigi Di Lizia, Politecnico di Milano; Mirco Rasotto, Dinamica Srl

In this paper two approaches for nonlinear uncertainty propagation in astrodynamics are compared. The first approach is based on Taylor Differential Algebra and is aimed at the improvement and generalization of standard linear methods.
The second approach is aimed at increasing the computational performances of classical Monte-Carlo simulations exploiting their intrinsic parallel structure and taking advantage of the massively parallel architecture of modern GPUs.
The two proposed approaches are applied to test cases considering both simple two-body dynamics and full n-body dynamics with JPL ephemeris. The results of the propagations are thoroughly

compared with particular emphasis on the computational performances.

14:30 **AAS 16-500** **HIGH GEOMETRIC FIDELITY MODELING OF SOLAR RADIATION PRESSURE USING GRAPHICS PROCESSING UNIT**

Patrick Kenneally; Hanspeter Schaub, University of Colorado

This paper presents a method for the fast computation of spacecraft force and torque due to solar radiation pressure (SRP). The method uses the highly parallel execution capabilities of commodity Graphics Processing Unit (GPU) and the Open Graphics Library (OpenGL) vector graphics software library to render a Computer Aided Design (CAD) generated spacecraft model on the GPU. The SRP forces and torques are resolved per model facet in the custom-developed render pipeline. Material properties are encoded with the model to provide realistic specular, diffuse and absorption surface light interactions.

14:50 **AAS 16-520** **Monte Carlo Propagation of Orbital Elements Using Modified Chebyshev Picard Iteration**

Julie Read, Texas A&M University; Tarek Elgohary, Texas A&M University; Austin Probe; John Junkins, Texas A&M University

The present study incorporates a Monte Carlo analysis using a local Taylor Series model that reduces the computational time and provides a high-accuracy solution for propagating the Modified Equinoctial Orbital Elements. Prior works have shown promising efficiency while propagating perturbed two-body motion using orbital elements, combined with a novel integration technique called Modified Chebyshev Picard Iteration (MCPI). While previous studies show that MCPI is a powerful tool used to propagate position and velocity, instead using orbital elements to propagate the state vector reduces the number of MCPI iterations, which is especially useful for reducing the calculation time for computationally-intensive calculations such gravity.

15:10 **Afternoon Break**

15:30 **AAS 16-279** **On the astrodynamics applications of Weierstrass elliptic and related functions**

Dario Izzo, European Space Agency; Francesco Biscani, Max Plank Institute

Weierstrass elliptic and related functions have been recently shown to enable finding explicit solutions to classical problems in astrodynamics. These include the constant radial acceleration problem, the Stark problem and the two-fixed center (or Euler) problem. In this paper we review the basic technique that allows for these results and we discuss the limits and merits of the approach. Applications to interplanetary trajectory optimization are discussed as well as to the motion of satellites under the J2 influence.

15:50 **AAS 16-301** **SSL Commercial Geosynchronous Spacecraft Orbit Raising Considerations**

Andrew Turner, SSL; Gregory Lemieux, SSL

In a typical year 5-7 geosynchronous (GEO) spacecraft built by SSL for various customers are orbited by a variety of launch vehicles (LV), a rate which has been maintained for decades. The spacecraft are first injected into Geosynchronous Transfer Orbit with apogee in the vicinity of GEO altitude, perigee at a low altitude and a typical inclination of 7˚ or 27˚. The early orbit activities and orbit raising maneuvers to insert the spacecraft into its assigned GEO slot are discussed, also total orbit raising duration and propellant consumption, tracking station location and coverage, eclipse occurrence and spacecraft attitude control considerations.

16:10 AAS 16-313 GPU-Accelerated Computation of SRP and Drag Forces and Torques with Graphical Encoding of Surface Normals

Sergei Tanygin, Analytical Graphics, Inc.; Gregory M. Beatty, Analytical Graphics, Inc.

The forces and torques due to atmospheric drag and solar radiation pressure (SRP) acting on complex and articulated space objects are efficiently calculated by combining traditional OpenGL rendering of 3D models with general-purpose computing on graphics processing units (GPGPU) techniques via OpenCL. In cases when the forces and torques include contributions that depend on surface normals, their directions are encoded as pseudo-colors which allows OpenCL kernel methods to efficiently unpack this additional information and perform the necessary computations. By utilizing the highly parallelized processing units available in commodity GPUs, the time required run the calculations is significantly reduced.

16:30 AAS 16-351 Quantification of the Performance of Numerical Orbit Propagators

Hodei Urrutxua, University of Southampton; Javier Roa, Technical University of Madrid (UPM); Juan Luis Gonzalo, Technical University of Madrid (UPM); Jesus Pelaez, Technical University of Madrid (UPM); Claudio Bombardelli, Technical University of Madrid (UPM)

The characterization of the performance of numerical orbit propagation methods is addressed using performance curves. A systematized algorithmic approach is presented to compute the performance curves, identify the linear and non-linear regimes, and parameterize the linear zone. Also, the “performance index” concept is introduced, which aims to reduce the meaningful information of a performance curve into a single figure of merit. Several such performance indices are proposed.

Feb 16, 2016 - Pinot Noir BC

09 Attitude Dynamics and Control 1

Chair: Stefano Casotto

8:00 AAS 16-290 Fast Autonomous Three-Axis Constrained Attitude Pathfinding and Visualization for Boresight Alignment

Sergei Tanygin, Analytical Graphics, Inc.

A new algorithm is presented suitable for fast on-board implementation of attitude maneuver planning that achieves desired boresight alignment in the presence of multiple three-axis attitude constraints. The algorithm discretizes admissible attitude on grid points placed in distortion-minimizing three-parameter space. It also employs a transformation that makes the continuum of possible attitudes representing various rotations about the desired boresight appear along a single coordinate axis of the grid. As a result, the pathfinding algorithms can efficiently determine the shortest overall path to the whole continuum, which corresponds to the shortest admissible attitude maneuver path that achieves the desired boresight alignment.

8:20 **AAS 16-325** **CONSTRAINT FORCE ALGORITHM FOR DYNAMICS MODELING OF MULTIBODY SPACECRAFT IN ARBITRARY TOPOLOGY**

Fei Liu, School of Astronautics, Beijing Institute of Technology; Quan Hu, School of Astronautics, Beijing Institute of Technology; Jingrui Zhang; Youyi Wang; Wenbo Li, Beijing Institute of Control Engineering; Liang Tang, Beijing Institute of Control Engineering; Xiaoyu Chu, Beijing Institute of Technology

The magnitudes of the constraint forces at the joints in a multibody spacecraft are critical parameters in designing the joints structure. Therefore, it is desirable to efficiently calculate the constraint forces in the dynamics simulation. In this work, a modified constraint force algorithm (MCFA) for dynamics of arbitrary multibody spacecraft is developed. The constraint forces can be directly obtained when solving for the system motion. The MCFA is applicable to an arbitrary multibody spacecraft in tree topology or with closed-loop structures. The accuracy of MCFA is validated through numerical simulations of a space robot with multiple manipulators.

8:40 **AAS 16-337** **Fuzzy Attitude Control of Solar Sail with Translating Control Masses via Linear Matrix Inequalities**

Joshua Baculi, Santa Clara University; Mohammad Ayoubi, Santa Clara University

We present a fuzzy model-based attitude controller for a solar sail. First, a Takagi-Sugeno fuzzy model is derived based on the existing equations of motion. Then, by using the Parallel Distributed Compensation technique, a nonlinear fuzzy control law is developed. The proposed controller stabilizes the attitude of the solar sail while it minimizes the L2 gain of the closed-loop system and satisfies actuator amplitude constraint. The fuzzy controller design problem is cast in the form of linear matrix inequalities. In the end, the stability and performance of the proposed controller is examined for a typical solar sail.

9:00 **AAS 16-340** **Strategy and Algorithm Study on Evasion of Incident Light of Sun and Moon for Star Tracker**

Wang Haiyong; Li Jingjin

Attitude determination of star tracker is executed by observing star light, which is rather weak. The optics and imaging array designed for star light are not applicative to the sun and the moon, the two strong light sources, so a geometrical analytic method is put forward for star tracker to evade strong light sources. The commanded orientation of the boresight calculated by the algorithm could make star tracker work wihtout incident lights. This algorithm can achieve the purposes of protecting the optics of the star tracker autonomously and securing the validity of the star observation window.

9:20 **AAS 16-352** **Dynamically Scaled Immersion and Invariance Approach for Spacecraft Attitude Tracking Control**

Sungpil Yang, The University of Texas at Austin; Maruthi Akella, The University of Texas at Austin

This paper addresses the spacecraft attitude tracking problem with the quaternion representation when model parameters are unknown but the lower bound of the inertia matrix norm is known. Using the dynamic scaling method, Immersion and Invariance adaptive controllers are proposed without employing a filter for the regressor matrix. Based on where the dynamic factor appears, we propose both filter-free and filter-dependent controllers, where the dynamic factor is later replaced

by a new state which is not monotonically increasing by introducing three dimensional dynamic extensions. The performances of both controllers are demonstrated through simulations.

9:40 **AAS 16-354** **Using shifting masses to reject aerodynamic perturbations and to maintain a stable attitude in Very Low Earth Orbit.**

Josep Virgili llop, Naval Postgraduate School; Halis C. Polat, Naval Postgraduate School; Marcello Romano, NPS

At very low orbital altitudes the aerodynamic forces caused by the residual atmosphere become the strongest attitude perturbation. In this paper, the use of shifting masses, actively changing the location of the spacecraft center-of-mass, and thus modulating the aerodynamic torques is proposed as a method to reject the variable and unpredictable aerodynamic disturbances. The required mass and shifting range is explored with respect to the host vehicle mass, inertia, aerodynamic properties and orbital altitude. Finally, two case studies are presented to show the performance of such a method in a realistic scenario.

10:00 **Morning Break**

10:20 **AAS 16-398** **Attitude Control Actuator Design with Magnetorheological Fluid Rings**

Dongeun Seo, Embry-Riddle Aeronautical University; Yongho Lee, Embry-Riddle Aeronautical University

A new application of magnetorheological (MR) fluid is proposed as an active ring actuator for the spacecraft attitude control system (ACS). By regulating the magnetic field around the MR fluid ring, a wide range of the viscoelastic property change can be achieved, which is not available to conventional passive/active fluid ring actuators. Due to the characteristics of the MR fluid, the MR fluid ring actuator may act in the range from the solid to the highly viscous fluid state. The dynamical properties of the proposed MR ring design and the attitude stability of the controlled system with the MR rings are investigated.

10:40 **AAS 16-429** **ATTITUDE ERROR KINEMATICS: APPLICATIONS IN CONTROL**

Ahmad Bani Younes, Khalifa University; Daniele Mortari, Texas A&M University

Several attitude error representations are presented for describing the tracking orientation error kinematics. Compact forms of attitude error kinematics are derived for each representation. The attitude error is initially defined as rotational error between the current and the reference orientation. The development of nonlinear kinematic models enables arbitrarily large relative rotations and rotation rates for several standard attitude representations. An optimal tracking control is developed where the optimal control is calculated by optimizing a universal quadratic penalty function. An open-loop optimal nonlinear control spacecraft maneuver is solved first for reference motion. The tracking error is defined yielding a nonlinear error dynamics in a compact form. Two distinct approaches to

11:00 **AAS 16-451** **Minimum Energy, Reaction-Wheel Based, CubeSat Attitude Control: A comparion of Cost Functions**

Dmitriy Rivkin, University of California Santa Cruz; Qi Gong, University of California, Santa Cruz; Gabriel Elkaim, University of California, Santa Cruz

A Legendre pseudospectral method is used to the solve the minimum-energy reorientation problem for a 3U Cubesat. Optimization is performed with respect to a cost functional that is representative of battery energy losses, and includes terms arising from three different loss sources. Modeling the system's lack of regenerative braking introduces computational difficulties which are overcome with a smoothing approximation. Results are compared to those obtained using the convenient "integral-of-control-torque-squared" cost functional, and it is shown that optimization with respect to the convenient cost functional does not produce an energy-optimal solution when the ratio between wheel and satellite moments of inertia is large.

11:20 AAS 16-472 AUTOMATED SPHERE GEOMETRY OPTIMIZATION FOR THE VOLUME MULTI-SPHERE METHOD

Philip Chow, University of Colorado; Joseph Hughes; Hanspeter Schaub, University of Colorado

At GEO, electric charging can have an impact on spacecraft dynamics comparable with SRP and drag at 500 km. The Volume Multi Sphere Method (VMSM) is a recent method for finding the electrostatic forces and torques acting on a spacecraft. Prior work illustrated that the VMSM approach required considerable hand tuning to reach a suitable solution. This paper investigates the VMSM setup process. The classic formulation is shown to have non-unique answers. An optimization approach is presented which seeks to automate setup. The symmetric cylinder problem is investigated with various setups and metrics suitable for three-dimensional force and torque matching.

11:40 AAS 16-515 Dynamic Observability Analysis for Attitude, Angular Velocity, Shape, and Surface Parameters

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

This paper discusses a dynamic observability analysis for attitude, angular velocity, shape, and surface parameters of Space Objects (SOs) using non-resolved images or light curve measurements. The Fisher information matrix and Cramer-Rao lower bound are introduced for calculating the observability of parameters used in SO models. An illustrative two-dimensional example is considered. The Cramer-Rao lower bound is used to study the effects of geometry on estimation performance. Finally, Cramer-Rao lower bound is compared with actual performances from estimation approaches for estimating the attitude of an SO.

Feb 16, 2016 - Cabernet

10 Orbital Debris and Space Environment

Chair: Thomas Starchville

8:00 AAS 16-233 Using Space Population Models to Generate Representative Space Object Catalogs

Daniel Oltrogge, Analytical Graphics Inc; Vitali Braun, IMS Space Consultancy

A method is presented for generating Resident Space Object (RSO) catalogs which include RSOs smaller than those currently included in today's RSO catalogs. Such catalogs can be very useful in assessing anticipated sensor performance, throughput and coverage for new sensor concepts, locations and phenomenologies than those in use today. The method is invoked to generate both LEO-crossing and GEO-crossing RSO catalogs containing the representative population for all RSOs larger than 2 cm in size. The method's only assumptions are that at any altitude of interest, (1) the 2-dimensional PDF distribution at that same altitude of semi-major axis versus eccentricity derived

8:20 **AAS 16-240** **REENTRY PREDICTION OF SPENT ROCKET BODIES IN GTO**

David Gondelach, University of Southampton; Aleksander Lidtke, University of Southampton; Roberto Armellin, Universidad de La Rioja; Camilla Colombo, University of Southampton; Quirin Funke, European Space Agency; Tim Flohrer, European Space Agency

Spent upper stages are bodies consisting of components likely to survive re-entry, for example propellant tanks. Therefore, the atmospheric re-entry of upper stages might be associated with high on-ground casualty risk. The paper presents a tool for re-entry prediction of spent rocket bodies in GTO based exclusively on Two Line Element set (TLE) data. TLE analysis and filtering, spacecraft parameters estimation, and combined state and parameters estimation are the main building blocks of the tool. The performances of the tool are assessed by computing the accuracy of the re-entry prediction of 26 GTO objects, which re-entered between 1981 and 2015.

8:40 **AAS 16-254** **Evaluation of Net Capture of Space Debris in Multiple Mission Scenarios**

Eleonora Botta, McGill University; Inna Sharf, Mcgill University; Arun Misra, McGill University

One proposed method to mitigate the space debris problem is to actively capture and remove debris by means of tether-nets. In this paper, the effectiveness of the capture maneuver in multiple net deployment and debris tumbling conditions is evaluated. The sensitivity study is performed by means of simulations based on a lumped-parameter modeling approach with inclusion of bending stiffness for the net, a rigid body model for the debris, and regularized contact dynamics to represent all relevant impact and contact conditions. The effectiveness of capture is evaluated by inspection of the simulation results, to identify preferred capture conditions.

9:00 **AAS 16-278** **Mission Design and Disposal Methods Comparison for the Removal of Multiple Debris**

Lorenzo Casalino, Politecnico di Torino; Dario Pastrone, Politecnico di Torino

Mission design for multiple debris removal is performed by selecting the most favorable sequences of the objects to be removed among a large set. Different options and disposal methods will be compared. For a given sequence, starting in rendezvous conditions with an object, the mass of the removal kit is evaluated, based on debris orbit and mass, and selected removal method. The propellant consumption to the next debris is computed based on a fast and accurate approximate analysis and the overall mission mass budget is thus defined. All the passible sequences can be evaluated in a short time.

9:20 **AAS 16-330** **MULTI-GOAL-BASED COLLISION AVOIDANCE PATH PLANNING FOR REDUNDANT SPACE ROBOT**

Suping Zhao; zhanxia zhu; Qiuyue Luo

This paper studies the multi-goal-based collision avoidance path planning problem for redundant free-floating space robot. The end-effector of the robot is required to avoid the irregular obstacles and pass through a set of waypoints, with an optimum distance. The position of the obstacles and the poses of the waypoints are predefined in the three-dimensional Cartesian space. However, the sequence of the waypoints is not given. Two cases are considered in this paper. One is that the end-effector is to go back to the starting point after the travel, the other one is to remain in the last waypoint.

9:40 **AAS 16-386** **On Intercepting a Tumbling Target by a Space Robot Using a Developed Navigation Guidance Method**

Qiuyue Luo; zhanxia zhu; Jianping Yuan; Suping Zhao

This paper proposed a novel method for free floating space robot to intercept a fast-maneuvering target based on the proportional navigation guidance method. When the target is fast-maneuvering, classic servoing methods lose their time-efficiency feature because they fail to predict the object's long-term motion. A developed augmented ideal proportional navigation method is proposed in this paper for the trajectory planning of the end manipulator of the robotic arm. In addition, the disturbance of the robotic arm to the carrier satellite must be eliminated, thus a 3-link redundant robotic arm, which allows three controllable degrees of freedom, is studied.

10:00 **Morning Break**

10:20 **AAS 16-406** **A Smooth and Robust Harris-Priester Atmospheric Density Model**

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

The modified Harris-Priester model is a computationally inexpensive method for approximating atmospheric density in the thermosphere and lower exosphere -- a vital step in low-Earth orbit trajectory propagation. This work introduces a revision, dubbed cubic Harris-Priester, which ensures continuous first derivatives, eliminates singularities, and adds a mechanism for introducing smooth functional dependencies on environmental conditions. These changes increase the accuracy, robustness, and utility of the model, particularly for preliminary propagation, estimation, and optimization applications in which fast, reasonably accurate force models and sensitivities are desirable. Density results and computational efficiency are compared to other density models.

10:40 **AAS 16-416** **ROTATIONAL DYNAMICS OF THE GOES 8 AND GOES 10 SATELLITES DUE TO THE YORP EFFECT**

Antonella Albuja; Rita Cognion, Oceanit; William Ryan; Eileen Ryan; Daniel Scheeres, University of Colorado

The Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effect is a proposed explanation for the observed rotation behavior of inactive satellites in Earth orbit. This paper propagates the rotational dynamics of the GOES 8 and GOES 10 satellites and compares the simulated rotation periods to the observed rotation periods. The observations of each satellite are taken over a few months, therefore, the short period terms are included in the propagation of the satellite's rotational dynamics. The comparison between YORP theory and the observed changes in rotation rate for both satellites show that the YORP effect could be the cause for the observed behavior.

11:00 **AAS 16-430** **Structure and evolution of a debris cloud in the early phases**

Liam Healy, Naval Research Laboratory; Scott Kindl, Naval Research Laboratory; Eric Rolfe, Naval Research Laboratory; Christopher Binz, Naval Research Laboratory

The early phases of a debris cloud from an instantaneous fragmentation on orbit are dominated by the effect of the two-body gravitational force on the delta-v imparted on each fragment, which gives an in-track spreading of the cloud. This spreading is seen to form radial bands opposite to the fragmentation point. The bands may be motivated by straightforward orbit mechanics. Accurate density maps are computed with the transformation of variables technique, which opens a world of \emph{cloud dynamics} to contrast with the point dynamics of traditional astrodynamics. Structure and evolution of the bands and finer details are noted and discussed.

11:20 **AAS 16-474** **Satellite Breakup Debris Cloud Model**

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

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

11:40 **AAS 16-437** **A Particle Filter for Orbit Determination of Space Debris based on Mono- and Multi-static Laser Ranging**

Christoph Bamann, Technische Universität München; Urs Hugentobler, Technische Universität München

Orbit determination of space debris is typically complicated by rather imprecise and ill-distributed tracking data. Mono- and multi-static laser ranging are promising techniques to overcome such issues. To properly process their precise but sparse data we present a particle filter (PF), which fully captures system nonlinearities and yields complete state probability density functions (PDFs).
For statistical consistency our PF is provided with an initial PDF that is obtained by Monte-Carlo runs of classical initial orbit determination (IOD). Moreover, we propose a method to fuse IOD solutions of several simultaneously observing stations. Eventually, we analyze the resulting state PDFs with regard to the considered observation techniques.

12:00 **AAS 16-465** **Spatial density approach for modelling of the space debris population**

Camilla Colombo, University of Southampton; Francesca Letizia, University of Southampton

This article proposes a continuum density approach for debris modelling. The debris population in Low Earth Orbit (LEO) is represented through its spatial density in orbital elements of semi-major axis, eccentricity and inclination. The time evolution of the density in orbital elements is modelled through the continuity equation. A source term is used to model the future launch traffic in LEO, while the effect of orbit perturbation due to aerodynamic drag and the Earth's oblateness is included in the divergence term. As initial condition the ESA MASTER 2009 population is used. Furthermore, a breakup on an 800 km Sun-synchronous orbit

Feb 16, 2016 - Sauvignon

11 Mission Design 2

Chair: Ryan Park

8:00 **AAS 16-326** **Trajectory Planning for Multi-arm Space Walking Robot**

Xiaoyu Chu, Beijing Institute of Technology; Jingrui Zhang; Quan Hu, School of Astronautics, Beijing Institute of Technology; Fei Liu, School of Astronautics, Beijing Institute of Technology; Youyi Wang; Wenbo Li, Beijing Institute of Control Engineering; Liang Tang, Beijing Institute of Control Engineering

A trajectory planning algorithm for a multi-arms space robot is proposed. The robot is capable of walking on the exterior of a large space station. Based on the maneuver strategy of the walking, continuous and smooth trajectories of the manipulator end-effectors are firstly determined by a five times polynomial interpolation method. Then, the kinematics describing the relationship between the end-effector and the joint angles, as well as the platform, is formulated. An optimization solution of the joint motions is calculated to describe the motion of the manipulators. Finally, a collision detection algorithm is developed to guarantee the security during the operation.

8:20 **AAS 16-488** **Earth-Moon multipurpose orbiting infrastructure**

Michele Lavagna, Politecnico di Milano; Simone Flavio Rafano Carnà

The paper discusses the strategy to bring and connect single building blocks together under a non Keplerian dynamics modelling to build up a multipurpose large orbiting infrastructure in EML1. Mission analysis, guidance and control designed to build up the operational hub and to run nominal operations to dock and undock modules exploiting the orbiting structure for different functionalities are presented.

8:40 **AAS 16-208** **New Horizons Trajectory Correction Maneuver Flight Implementation and Performance**

Gabe D. Rogers, The Johns Hopkins University Applied Physics Laboratory; Sarah Flanigan, The Johns Hopkins University Applied Physics Laboratory; Madeline N. Kirk, The Johns Hopkins University Applied Physics Laboratory

To meet key science observations during its flyby of the Pluto / Charon system in July, 2015 the New Horizons spacecraft executed trajectory correction maneuvers (TCMs) throughout the mission. This paper discusses the design of New Horizons Guidance and Control (G&C) system, including details of the propulsion system and how TCMs are conducted onboard the spacecraft. It will present the TCM requirements, the flight software and hardware, and the algorithms used during 3-axis and spin mode closed-loop maneuvers. The historical performance of the TCMs conducted to date and lessons learned during flight operations will also be presented.

9:00 **AAS 16-259** **New Horizons Pluto Encounter Maneuver Planning and Analysis**

Dale Stanbridge, KinetX Aerospace, Inc.; Kenneth Williams, KinetX Aerospace, Inc.; Frederic Pelletier, KinetX Inc.

With the Pluto phase of the New Horizons mission completed, analysis of propulsive maneuvers has been revisited. The analysis accounts for spacecraft state knowledge and control errors relative to target bodies, with consideration of various possible combinations of final maneuvers prior to Pluto closest approach. This paper also includes details of actual maneuvers planned and executed during and after the Pluto approach and flyby. This encompasses both statistical maneuvers and contingencies for collision avoidance of any newly encountered satellites during approach.

9:20 **AAS 16-419** **NEW HORIZONS ORBIT DETERMINATION PERFORMANCE DURING APPROACH AND FLYBY OF THE PLUTO SYSTEM**

Frederic Pelletier, KinetX Inc.; Bobby Williams, KinetX SNAFD; Jeremy Bauman, KinetX Inc.; Dale Stanbridge, KinetX Aerospace, Inc.

Navigating the New Horizons spacecraft on approach to Pluto was not only a technical challenge; it was also a race against the clock. With 9 years of cruise behind, all of the navigation critical activity culminated in the last few months when the spacecraft could finally observe and learn from its target. Key functions of the orbit determination process are discussed, which includes the processing of radio metric and optical measurements, the estimation of the Pluto barycenter and satellites ephemerides as well as the characterization of the attitude control small forces acting on spacecraft. Performance and results of the overall

9:40 **AAS 16-359** **Mission Design Considerations for Mars Cargo of the HAT EMC**

Waldy Sjauw, NASA Glenn Research Center; Melissa McGuire, NASA GRC; Josh Freeh, NASA Glenn Research Center

Recent NASA interest in human missions to Mars has led to an Evolvable Mars Campaign by the agency's Human Architecture Team. Delivering the crew return propulsion stages and Mars surface landers, SEP based systems are employed because of their high specific impulse characteristics enabling missions requiring less propellant with longer transfer times. The Earth departure trajectories start from an SLS launch vehicle delivery orbit and are spiral shaped because of the low SEP thrust. Previous studies have led to interest in assessing the split between the Earth departure and interplanetary legs of the mission for a representative SEP cargo vehicle.

10:00 **Morning Break**

10:20 **AAS 16-361** **Jupiter Tour of the Jupiter Icy Moon Explorer**

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

This paper presents the mission analysis of the Jupiter tour for JUICE. It starts with the design of the sequence after Jupiter's capture which complies with the Europa fly-bys illumination constraint. Then the Jupiter science phase is achieved via multiple Callisto fly-bys with different resonance ratios. The transfer to Ganymede is presented, showing how the DeltaV optimisation and the scientific constraints are tackled through the Ganymede-Callisto ladder sequence and the low energy endgame with Ganymede. The Ganymede in-orbit phase is also presented. The strong impact of the superior conjunctions on the design is highlighted throughout the entire tour.

10:40 **AAS 16-494** **Preliminary trajectory design for a multi-target Active Debris Removal mission using the Atom solver**

Kartik Kumar, Dinamica Srl; Francesco Topputo, Politecnico di Milano

Active Debris Removal is a burgeoning field of research that has gained prominence due to recent studies that suggest that action must be undertaken to guarantee the sustainability of the space environment. We present the preliminary trajectory design for a Multi-Target Active Debris Removal mission to remove hazardous objects in Low-Earth Orbit using the Accurate Transfer Orbit Model (Atom) solver. The Atom solver, which accounts for perturbations around the Earth by employing the SGP4/SDP4 propagator, is employed to generate high-thrust, multi-revolution, transfer trajectories to remove five debris objects. The trajectories obtained are compared against the classical Lambert problem solver.

11:00 **AAS 16-231** **Interplanetary nanospacecraft travel capabilities**

Simon Tardivel, Jet Propulsion Laboratory; Stefano Campagnola, JAXA / ISAS; Andrew Klesh, NASA / Caltech JPL

This paper investigates the solar system travel capabilities of nanospacecraft, which have already proven their worth in Earth orbit and can reach further goals. Recent developments in nanopropulsion now theoretically enable high ΔV budget for nanospacecraft, but mission, system and operations constraints limit these optimistic abilities. Interplanetary nanospacecraft, as hitchhikers of larger spacecraft launches, then have only a select number of rideshare opportunities. Nevertheless, appropriate initial injections coupled with new propulsion technologies allows them to timely reach and effectively explore a vast range of targets.

11:20 **AAS 16-237** **Maven Navigation Overview**

Mark Jesick, Jet Propulsion Laboratory

The Mars Atmosphere and Volatile Evolution mission (MAVEN) is the first mission devoted to studying the Martian atmosphere. The MAVEN navigation team reconstructs and predicts thespacecraft's position and velocity, and designs and reconstructs propulsive maneuvers. After Mars orbit insertion, the team faced additional challenges unique to MAVEN's orbit and tracking data schedule, including the determination of the atmospheric density at each periapsis to keep the spacecraft within a density corridor. This paper describes the MAVEN mission, how it fits into previous Mars exploration efforts, and overviews the operations of MAVEN's navigation team from launch through the nominal science phase.

11:40 **AAS 16-277** **Reinforcement Learning for Spacecraft Maneuvering Near Small Bodies**

Dario Izzo, European Space Agency; Daniel Hennes, DFKI; Stefan Willi, European Space Agency

We use neural reinforcement learning to control a spacecraft around a small celestial body whose gravity field is unknown. The small body is assumed to be a triaxial ellipsoid and its density and dimensions are left unknown within large bounds. We experiment with different proprioceptive capabilities of the spacecraft emphasising lightweight neuromorphic systems for optic flow detection. We find that even in such a highly uncertain environment and using limited perception capabilities, our approach is able to deliver a control strategy able to hover above the asteroid surface with small residual drift.

Feb 16, 2016 - Chardonnay AB

12 Satellite Constellations

Chair: Jeff Parker

8:00 **AAS 16-203** **An "Adjacent Swath" Method to Design Efficient LEO Constellations**

Thomas Lang, The Aerospace Corp

This study examines an "Adjacent Swath" approach to minimize the maximum revisit time (MRT) for coverage of the entire earth surface using constellations of low earth orbit (LEO) satellites. Since the portion of the earth that a single satellite can cover is quite small at LEO, it is clear that many satellites will be required to achieve low values of MRT. To make this economically feasible, the satellites must be small enough that a number of them could be launched into a single orbit plane using one launch vehicle. For this reason, it is important to minimize not only the

8:20 **AAS 16-218** **Operational Considerations for Satellite Constellations in Tundra Orbits**

James Wilson, The Aerospace Corporation; Joseph Gangestad, The Aerospace Corporation; Thomas Lang, The Aerospace Corp; Chia-Chun Chao, The Aerospace Corporation

Tundra constellation design and the stationkeeping costs of operating a Tundra satellite have been periodically studied by satellite constellation designers. However, there has been little research done on how constellation design affects stationkeeping costs, and vice versa. This paper synthesizes these two distinct design points to inform the overall design of a Tundra satellite constellation. Coverage patterns for different numbers of satellites and plane configurations are shown. Mean longitude and eccentricity maintenance is shown to reduce stationkeeping costs by 33 percent while largely conserving coverage. Judicious selection of orbital elements can reduce stationkeeping costs by up to 95 percent.

8:40 **AAS 16-224** **Corrections on repeating ground-track orbits and their applications in satellite constellation design**

David Arnas, Centro Universitario de la Defensa - Zaragoza; Daniel Casanova, Centro Universitario de la Defensa; Eva Tresaco, Centro Universitario de la Defensa

The aim of the numerical model proposed in this work is to design constellations whose satellites share the same ground-track. The model takes into account a series of orbital perturbations such as the gravitational potential of the Earth, the atmospheric drag, the Sun and the Moon as disturbing third bodies or the solar radiation pressure. It also includes a numerical method that improves the repeating ground-track property of any given satellite subjected to these perturbations. Moreover, the model as a whole allows to design constellations with multiple tracks distributed in a minimum number of inertial orbits.

9:00 AAS 16-271 Reducing Wall-Clock Time of Metaheuristic-Driven Constellation Design with Coarse Parametric Mapping

Lake Singh, The Aerospace Corporation; Marc DiPrinzio, The Aerospace Corporation; William Whittecar, The Aerospace Corporation

The successful application of many-objective evolutionary algorithms (MOEAs) to satellite constellation design can produce superior constellations which better meet user objectives. Previous efforts have focused on optimizing access and coverage statistics of constellations while minimizing the required number of satellites. Stationkeeping requirements in particular require the use of computationally intensive high fidelity modeling in order to accurately incorporate them into problem formulations. This work reports on a technique to reduce the computing requirements without ultimately compromising the fidelity of the resulting solution in order to save wall-clock time.

9:20 AAS 16-360 SATELLITE CONSTELLATION DESIGN FOR THE SOLVE MISSION INVESTIGATING DIURNAL CYCLES OF VEGETATION PHENOMENA

Sung Wook Paek, MIT; Luzius Kronig, EPFL; Anton Ivanov, EPFL; Olivier de Weck

This paper discusses the problem of finding an optimal satellite constellation for the SOLVE (Satellites Observing Lakes and Vegetation Environments) Mission. A key requirement of this mission is a temporal resolution of several observations per day. A semi-analytical approach is proposed. After some analytical design steps which reduces the problem space to circular sun synchronous orbits, a genetic algorithm is used for finding all remaining orbital parameters. The result is an easy to use tool which allows to study cost impact from given science requirements enabling a good understanding of the relation between temporal, spatial resolution and cost.

9:40 AAS 16-469 EMULATING OF THE STATIONARY OBSERVATION OF THE EARTH LOCAL REGION USING LOCALLY GEOSTATIONARY ELLIPTIC ORBITS

Yury Razoumny, Peoples' Friendship University of Russia / Moscow Aviation Institute

The problem of optimization the satellite orbits for local Earth coverage is considered. The class of so-called locally geostationary orbits (LGO) is suggested and substantiated. LGO includes the famous geostationary orbit, the only circular orbit in the class, as well as an infinite set of elliptical orbits corresponding to the maximum duration of the visibility zone of the local Earth region. Particularly, LGO includes Molniya, Supertundra, some other known and unknown orbits. The optimization in the LGO domain, while the local coverage is considered, leads to maximum effectiveness of orbit and constellation design and minimum cost of the optimization process.

10:00 Morning Break

10:20 AAS 16-490 METHOD FOR CONSTELLATION DESIGN FOR EARTH PERIODIC COVERAGE USING COMPOUND SATELLITE STRUCTURES ON ORBITS WITH SYNCHRONIZED NODAL REGRESSION

Yury Razoumny, Peoples' Friendship University of Russia / Moscow Aviation Institute

The method for orbit and constellation design for Earth periodic coverage using compound satellite structures on orbits with synchronized nodal regression is developped. Compound structures, multi-tiered constellations, are based on orbits with defferent values of altitude and inclination providing nodal regression synchronization. It is shown that using the multi-tiered constellations, optimized for periodic coverage, makes it possible to sufficiently improve the Earth coverage, as compared to the tradiional constellations based on orbits with common altitude and inclination for all the satellites in the constellation, and, as a consequence, decrease the number of satellites in the constellation required or decrease the revisit time in observations.

10:40 **AAS 16-298** **The Theory of Lattice Flower Formations and its Application to Intensity Correlation Interferometry**

Daniele Mortari, Texas A&M University; David Hyland, Texas A&M University

This paper introduces the theory of Lattice Flower Formations to extend the Flower Constellations theory to configurations of satellites with small relative distances. This paper shows how to design a Lattice Flower Formations for a multi-spacecraft interferometric systems based on Hyland's intensity correlation approach. For a number of satellites, the optimal formation is obtained by covering the resolution disk of the frequency plane within the minimum time. Genetic algorithm is used to estimate the formation design parameters. Numerical results obtained when observing a star or a satellite in geosynchronous orbit are provided.

11:00 **AAS 16-253** **A GNC Simulation of a Far-Range Approach towards a Target in Near-Geostationary Orbit**

Sofya Spiridonova, DLR / GSOC; Ralph Kahle, DLR/GSOC

This paper describes a GNC simulation as part of a feasibility analysis conducted by DLR/GSOC for future on-orbit servicing missions in near-geostationary orbit. The simulation addresses a far-range approach from several kilometers down to a few hundred meters, which includes relative orbit determination based on simulated optical measurements, and autonomous maneuver planning for relative trajectory control. One hundred simulation runs are performed with varying initial conditions based on the expected absolute orbit determination errors prior to the approach initiation. The safety of the formation is granted, as the servicer satellite never enters a pre-defined collision-avoidance area around the target spacecraft.

11:20 **AAS 16-347** **CONTROL OF HIGH FIDELITY LINEARIZED MODEL FOR SATELLITE FORMATION FLIGHT USING AERODYNAMIC DRAG**

Mohamed Shouman, National Authority for Remote Sensing and Space Sciences; Ahmed Atallah, National Authority for Remote Sensing and Space Sciences

This paper looks insight the relative motion between two satellites using high-fidelity modified equations of Clohessy–Wiltshire. These equations are derived from Hill's relative equations and extended to consider the effects of main perturbations: J2 and aerodynamic drag. Based on them, a control algorithm is designed to achieve relative position by dynamically adapting drag plate cross-sectional areas to meet the desired formation keeping. The control technique uses the linear quadratic regulator (LQR) which is developed to track periodic trajectory input. It tests control algorithm performance using high-fidelity perturbations- based orbit propagator

11:40 **AAS 16-478** **FORMATION FLYING CONCEPT FOR BI-STATIC SAR MAPPING OF TITAN SURFACE**

Michele Lavagna, Politecnico di Milano; Tommaso Guffanti, Politecnico di Milano

Multiple spacecraft flying in close formation allow implementing single pass SAR interferometry. Thanks to the orbiting vehicles separation along cross-track direction along-track direction, the derivation of the illuminated ground Digital Elevation Model (DEM) and the on ground objects velocity measurement is available. This paper develops a formation flying concept around Titan, which ensures the baselines for SAR interferometry, while minimizing the collision hazard during proximity operations. The formation flying smartly exploits the natural perturbations acting on the formation,giving a solution with big variety of baselines at all latitudes and high resolution and unambiguous DEM off the whole Titan surface.

12:00 **AAS 16-363** **A NOTE ON A GEOMETRICAL METHOD TO SOLVE SPACECRAFT FORMATION FLYING CONTROL**

Diogene Alessandro Dei Tos, Politecnico di Milano; Daniele Filippetto, Politecnico di Milano; Aureliano Rivolta

Spacecraft formation flying is becoming more important since the use of multiple satellites has been demonstrated to be cost-effective. In some applications, the spacecraft need to satisfy certain geometrical constraints; e.g.,regarding formation pointing. In this paper an efficient method has been devised that minimises the variation of orbital elements to achieve the requested states. The positions that minimise displacement from a reference plane are computed, and the compatible velocities that reduce shape and plane variation for all S/C are evaluated. This allows to find optimal values for a TPBVP. The algorithm has been applied to close-range GEO formations.

Feb 16, 2016 - Pinot Noir BC

13 Attitude Dynamics and Control 2

Chair: Maruthi Akella

13:30 **AAS 16-462** **Stochastic Modeling of Hypervelocity Impacts on Attitude Propagation of Space Debris**

Luc Sagnières, McGill University; Inna Sharf, Mcgill University

Bombardment of orbital debris and micrometeoroids on active and inoperative satellites is becoming an increasing threat to space operations and has significant consequences on space missions. A new method is proposed, enabling the inclusion of impacts to spacecraft attitude propagation models by considering the transfer of angular momentum from collisions as a stochastic jump process. In order to assess the importance of collisions on attitude propagation, the developed model is then applied to various categories of space debris by using impact fluxes from ESA's Meteoroid and Space Debris Terrestrial Environment Reference model.

13:50 **AAS 16-498** **Development of CubeSat Attitude Determination and Control System with Hybrid Control Strategy and its Simulator on SO(3)**

Dae Young Lee, Aerospace engineering, University of Michigan; Hyeongjun Park, Naval Postgraduate School; James Cutler, University of Michigan

In this paper, a hybrid strategy for active attitude determination and control system (ADCS) of a CubeSat is developed. The ADCS system requires fine pointing accuracy within one degree and, to accomplish this goal, the pre-developed control and estimation methods are modified and merged into the state machine based hybrid control. The operating conditions of the state machine are also defined and tested with simulations. To demonstrate accurate simulation results, the dynamic satellite simulator implements a Lie Group Variational Integrator of a spacecraft. The developed ADCS is applied to the CubeSat investigating Atmospheric Density Response to Extreme driving (CADRE) mission.

14:10 AAS 16-458 ATTITUDE ERROR KINEMATICS: APPLICATIONS IN ESTIMATION

Ahmad Bani Younes, Khalifa University; Daniele Mortari, Texas A&M University

Several attitude error representations are presented for describing the orientation error kinematics. Compact forms of attitude error kinematics are derived for each representation. The attitude error is initially defined as rotational error between the current and the reference orientation. The development of nonlinear kinematic models enables arbitrarily large relative rotations and rotation rates for several standard attitude representations. Two distinct approaches to attitude error kinematics are developed. In the first one the estimated angular velocity is defined in the true attitude axes frame while in the second one is defined in the estimated attitude axes frame. The first approach is of interest in simulation, where the true attitude is

14:30 AAS 16-511 REPETITIVE CONTROL USING REAL TIME FREQUENCY RESPONSE UPDATES FOR ROBUSTNESS TO PARASITIC POLES

Pitcha Prasitmeeboom, Columbia University; Richard Longman, Columbia University

Repetitive control (RC) can in theory completely cancel the effects of a periodic disturbance to a control system. It has application to vibration isolation of fine pointing equipment on spacecraft with vibrations caused by slight imbalance in CMGs or reaction wheels. RC convergence require less than 90 degree model phase error at all frequencies up to Nyquist. A zero-phase cutoff filter is used to robustify to high frequency error, thus failing to cancel errors above cutoff. Instead this paper creates real time frequency response model updates of the RC law at needed frequencies, producing robustification without cutting off the learning.

14:50 AAS 16-532 CROSS FERTILIZATION BETWEEN ITERATIVE LEARNING CONTROL AND REPETITIVE CONTROL

Jianzhong Zhu, Columbia University; Richard Longman, Columbia University

Repetitive Control (RC) and Iterative Learning Control (ILC) are methods to converge to zero tracking error in feedback control systems. ILC applies to repeated tasks, RC eliminates error following periodic commands or from periodic disturbances. Spacecraft applications include vibration isolation of fine pointing equipment. The objectives are similar, but ILC is a finite time problem, RC asks for zero error asymptotically, making control laws and stability conditions significantly different. This paper investigates how ILC laws can be converted for use in RC to improve performance, and vice versa. Also robustification by control penalty is compared to a frequency cutoff.

15:10 Afternoon Break

15:30 AAS 16-540 INCREASING SPEED OF TRACKING IN ITERATIVE LEARNING AND REPETITIVE CONTORL USING MARKOV PARAMETER / ADAPTIVE UPDATES

Bing Song, Columbia University; Richard Longman, Columbia University

Iterative learning control (ILC) aims for zero tracking error to a repeated command, each run starting from the same initial condition. Repetitive control (RC) aims for zero error with a periodic command or disturbance. Spacecraft applications include repeated scanning maneuvers or active vibration isolation mount for fine pointing equipments. In some applications it is desirable to start the learning process at a slow speed, and then increase the speed as one learns. This paper develops method of intelligently using information about the system to facilitate the learning when the speed is increased.

15:50 AAS 16-541 Modified Hybrid Modeling Technique for Flexible Spin-Stabilized Spacecraft Applied to NASA's Magnetospheric MultiScale (MMS) Mission TableSat Generation IC (TableSat IC)

Christopher Hashem, University of New Hampshire; May-Win Thein, University of New Hampshire

This continued research uses a hybrid dynamic algorithm to mathematically model the attitude dynamics of a flexible spacecraft. The algorithm uses Euler's rigid body equation to propagate the dynamics of the spacecraft bus while finite element analysis is used to calculate the flexible boom displacements and update the systems mass moment of inertia tensor. This algorithm is iterative and should acurately model the system while still being computationally reasonable. Upon experimental validation using the TableSat IC test bed, three controllers will be designed and applied to the plant: PID Control, Sliding Mode Control, and H-Infinity Control.

16:10 AAS 16-549 HARDWARE IN LOOP SIMULATION FOR ATTITUDE DETERMINATION AND CONTROL OF ILLINISAT-2 BUS

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

The University of Illinois is developing the IlliniSat-2 bus, which uses magnetic attitude determination and control. A hardware-in-loop simulation package (CubeSim), is used to test the attitude determination and control system. Magnetometers estimate the attitude using the magnetic field produced by a Helmholtz cage. CubeSim uses the torque produced to propagate the satellite state. Magnetic environment is updated according to new satellite state. This paper demonstrates testing control strategies using CubeSim.

16:30 AAS 16-503 Stabilization of a Satellite with a Moving Antenna for a Relay Satellite Tracking During Imaging Session

Mohammad Abdelrahman, International Islamic University Malaysia

A novel combination of model predictive control MPC and sliding mode control SMC is presented. The control algorithm is applied to a spacecraft in LEO with a moving antenna for communication with another relay satellite in a geosynchronous orbit. Gimbal-Based Antenna Pointing Mechanism Concept is utilized. Two design approaches are introduced based on dynamics coupling between the moving antenna and the satellite body. The new control approach is implemented and verified via

simulations. The simulations results show successful tacking of an object on earth during imaging session with a pre-specified pointing accuracy without any communication interruption with the relay satellite.

Feb 16, 2016 - Cabernet

14 Dynamics: Models

Chair: Brandon Jones

13:30 **AAS 16-276** **Extended Analysis on The Free-Molecular Flow Effects on a GRACE-Like Satellite**

Takahiro Kato, ZARM, University of Bremen; Florian Wöske, ZARM (Center of Applied Space Technology and Microgravity), University of Bremen; Benny Rievers, ZARM (Center of Applied Space Technology and Microgravity), University of Bremen; Meike List, ZARM (Center of Applied Space Technology and Microgravity), University of Bremen

This paper investigates the effects of the free-molecular flow on the dynamics of LEO satellites, especially for gravimetry missions like GRACE. Based on the contributions from the previous gravimetry missions, follow-on missions are planned to determine even higher accuracy and resolution. This motivates the development of precise non-gravitational force models and a high fidelity dynamics simulator which incorporates them. We focus on the dynamical effects of free-molecular flow on a LEO satellite regarding its geometry and surface temperature variations on orbit. The GRACE satellite and orbit configurations are employed for the illustration and discussed.

13:50 **AAS 16-282** **Advanced Thermal Radiation Pressure modeling and its benefits for the MICROSCOPE mission**

Benny Rievers, ZARM (Center of Applied Space Technology and Microgravity), University of Bremen; Meike List, ZARM (Center of Applied Space Technology and Microgravity), University of Bremen; Stefanie Bremer, Center of Applied Space Technology and Microgravity (ZARM), University of Bremen

A thorough modelling of the propagation of spacecraft motion is of utmost importance for scientific space missions. As a consequence, models of non-gravitational effects need to employ an accuracy corresponding to the designated mission goal. We show a high-precision approach for the analysis of thermal radiation pressure (TRP) and apply the method to the french space mission MICROSCOPE aiming at an analysis of a possible violation of the equivalence principle at an accuracy of 10-15. We discuss the influence of the mission profile, the evolving surface temperatures and the effect of surface degradation during the mission on the resulting TRP.

14:10 **AAS 16-308** **Cartesian development of the gravitational potential within the Hotine sphere**

Stefano Casotto, Universita' di Padova; Roberto Casotto, University of Padua

A new method to develop the gravitational potential near the surface of highly irregular bodies is presented. It is based on an expansion in Cartesian coordinates and makes us of a generalization of the coefficients introduced by MacMillan in 1930 and known as inertial integrals. A method for computing these coefficients is given which makes use of the coordinates of the vertices of a polyhedral model of the body and its connectivity matrix. Results are presented in terms of its efficiency in computing near surface orbits and compared with the finite Werner's polyhedron method.

14:30 AAS 16-331 A Novel Semi-Analytical solar Radiation Pressure Model with the Shadow Effect for Spacecraft of Complex Shape

Satoshi Ikari, The University of Tokyo; Takuji Ebinuma, Chubu University; Ryu Funase, The University of Tokyo; Shinichi Nakasuka, The University of Tokyo

A Calculation of Solar Radiation Pressure (SRP) for complex shape spacecraft is convoluted because the calculation cost increases with the number of surfaces, and the error caused by the shadow effect tends to increase by the complexity of the spacecraft's structure. This research newly proposes a generalized semi-analytical SRP calculation method for such a complex shape spacecraft. It was derived from the idea of Generalized Sail Model and a computer graphics rendering method called Pre-computed Radiance Transfer. In order to verify the utilities of our method, comparison results with the ray-trace method and optical parameter estimations will be shown in this paper.

14:50 AAS 16-338 A New Kinetic Theory of Particle Collisions

James Miller, Consultant; Gerald Hintz, University of Southern California; Pedro J. Llanos, Embry-Riddle Aeronautical University

See first paragraph of long abstract.

15:10 Afternoon Break

15:30 AAS 16-483 Potential Eff ects of a Realistic Solar Sail and Comparison to an Ideal Sail

Jules Simo, University of Central Lancashire

Solar sail technology offers new capabilities for space missions due to the opportunities for non-Keplerian orbits. 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. Based upon the first-order approximation, an analytical formulation of the periodic orbits at linear order is presented. Thereafter, the resulting effects of the non-ideal flat sail model have been computed and compared with an ideal solar sail.

15:50 AAS 16-508 The Effect of Tidal Forces on the Evolution of Minimum Energy Configurations of the Full Three-Body Problem

Edward Levine, University of Maryland

The 3-Body Problem (3BP) involving three self-gravitating bodies is not well understood when the bodies are no longer assumed point masses and are modeled with finite size and densities, called the Full 3-Body Problem. Unlike with the point particle assumption, the Full-3BP contains nine distinct equilibrium configurations. We numerically simulate the dynamics of the Full 3BP, as the transition between these states cannot be analytically known because there exists an energy hysteresis. New to this study is the inclusion of tidal forces, serving to gradually decay excess energy in the system until a new minimum energy equilibrium configuration is settled upon.

16:10 **AAS 16-314** **Semi-Analytic Electrodynamic Tether Guidance Using Rotating Dipole Model of Earth**

Scott Silver; Steven Tragesser, University of Colorado at Colorado Springs

Several proposed applications of the electrodynamic tether require a general change in the orbit, such as rendezvous for space surveillance or debris mitigation. This paper derives a current control law for electrodynamic tethers to achieve a specific general orbital change using a tilted, rotating dipole model of Earth's magnetic field. The control law is developed using the Gaussian Variation of Parameters, allowing for a semi-analytic solution even with the added complexity of a tilted, rotating dipole. The solution is more accurate than the fixed dipole model while maintaining greater computing efficiency than numerical solutions.

16:30 **AAS 16-444** **Exploration of Non-Conventional Techniques for the Generation of Element-based Analytical Ephemerides**

Hodei Urrutxua, University of Southampton; Camilla Colombo, University of Southampton; Francesca Letizia, University of Southampton

Various non-conventional techniques for the generation of analytical planetary ephemerides are investigated, built upon the fitting of numerical n-body simulations. In particular, the use of non-classical orbital elements will be explored, combined with frequency analysis techniques, in order to achieve a higher fidelity parameterization of the ephemerides, which also discerns between the secular, long and short period variations.

Feb 16, 2016 - Sauvignon

15 Orbit Determination

Chair: Sean Wagner

13:30 **AAS 16-364** **ON-BOARD ORBIT DETERMINATION USING SUN SENSOR AND OPTICAL NAVIGATION CAMERA FOR INTERPLANETARY TRAJECTORY**

Yosuke Kawabata, The University of Tokyo; Yasuhiro Kawakatsu, JAXA / ISAS

The realization of Autonoumous Navigation (AutoNav) in deep space can eliminate the complexity of operation on the ground station, and especially it has the significant impact on the operation cost reduction. This paper proposes AutoNav by observations of planets in solar system with Optical Navigation Cameras and some on board equipment (e.g. sun sensor). In paticular, this paper focuses on the configuration of observation objects, the selection of observation, and Earth resonant trajectory for actual missions and observation.

13:50 **AAS 16-475** **Precomputing Process Noise for Onboard Sequential Filters**

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

Process noise is often used in estimation filters to account for unmodeled accelerations in the dynamics, inflating the covariance over propagation intervals. Standard process noise techniques assume a Markov process (i.e. uncorrelated in time) and employ a trial-and-error approach that attempts to match the formal covariance to the distribution of errors generated by a Monte Carlo simulation. For autocorrelated (non-Markov) noise processes, such as gravitational perturbations for a spacecraft descent trajectory, the standard process noise approach can fail. The divided difference sigma point transformation provides a mechanism for empirically determining the process noise using model parameter uncertainties.

14:10 AAS 16-256 PRELIMINARY INVESTIGATION OF ON-BOARD ORBIT DETERMINATION USING DEEP SPACE ATOMIC CLOCK BASED RADIO TRACKING

Todd Ely, Jet Propulsion Laboratory; Jill Seubert, NASA / Caltech JPL; Jeanette Veldman, Aerospace Engineering Sciences Department

The Deep Space Atomic Clock mission is developing a small, mercury ion atomic clock with Allan deviation of less than 1e-14 at one day (current estimates < 3e-15) for a yearlong space demonstration beginning mid-2016. DSAC's stability yields one-way radiometric data precision on par with current two-way data. Uplink one-way tracking with an appropriately configured radio enables the possibility of on-board, autonomous radio navigation. This study examines the modeling needed to efficiently process this data for an on-board implementation.

14:30 AAS 16-258 Deep Space Atomic Clock Technology Demonstration Mission On-Board Navigation Analog Experiment

Jill Seubert, NASA / Caltech JPL; Todd Ely, Jet Propulsion Laboratory

The timing and frequency stability provided by the Deep Space Atomic Clock will enable one-way radiometric measurements with accuracy equivalent to current two-way tracking data. A demonstration unit of the clock will be launched in 2016 into low Earth orbit for the purpose of validating its performance in the space environment. GPS data collected throughout the mission will serve as a means to do this validation and as a proxy for deep space tracking data. DSAC's utility as an on-board navigation instrument will be demonstrated through an on-orbit experiment reflecting navigation conditions typical for a low altitude Mars orbiter.

14:50 AAS 16-344 On Selecting the Correct Root of Angles-Only Initial Orbit Determination Equations of Laplace and Gauss

Bong Wie, Iowa State University; Jaemyung Ahn, Korea Advanced Institute of Science and Technology

This paper examines a classical, yet still mystifying, problem of determining the correct root of the 8th-order polynomial equations of Laplace and Gauss, which was recently reassessed in [1]. Various numerical examples are examined whether they have in fact two physically feasible solutions (i.e., two correct roots) or not. The theory of Charlier and Gronchi on multiple solutions are also examined to further develop a new analytical method of determining the correct root (but without using any a priori knowledge about the object). [1] Der, G., "Angles-Only Algorithms for Initial Orbit Determination Revisited," AAS 15-539, AAS/AIAA Astrodynamics Specialist Conference.

15:10 **Afternoon Break**

15:30 **AAS 16-349** **A Comparison Between Gibbs and Herrick-Gibbs Orbit Determination Methods**

Arvind Kaushik, Texas A&M University; Kohei Fujimoto, Utah State University; Kyle T. Alfriend, Texas A&M University; John Hurtado, Texas A&M University; John Junkins, Texas A&M University

There is a strong need for accurate resident space object (RSO) state estimates. For radar RSO measurements, these estimates are initiated by Gibbs and Herrick-Gibbs algorithms. Presently, there isn't a clear distinction on when to switch between these two methods. In this paper, we present a statistical comparison between Gibbs and Herrick-Gibbs, taking into account measurement error via Monte Carlo. The overall trend of the performances of the methods is consistent with what is expected. However, the results also show that Herrick-Gibbs can remain the more accurate method for much larger track length arclengths than is suggested in the literature.

15:50 **AAS 16-477** **Satellite Navigation in Cis-Lunar Space Using High Definition Television Signals**

Ryan Handzo, University of Colorado - Boulder; Jeff Parker, University of Colorado Boulder; George Born, University of Colorado at Boulder; Austin Anderson, University of Colorado - Boulder; Jorge Cervantes

This paper considers using terrestrial HDTV transmissions for satellite navigation in cis-lunar space. The work presented in this paper constructs navigation simulations using a Conventional Kalman Filter for both initial orbit determination and for continuing orbit determination. The filters use observations obtained from HDTV signals transmitted from North America. These signals utilize the ATSC transmission standard and provide a Doppler count measurement, a pseudorange measurement, and a differential time offset measurement.

16:10 **AAS 16-236** **Probabilistic Initial Orbit Determination**

Roberto Armellin, Universidad de La Rioja; Pierluigi Di Lizia, Politecnico di Milano

Future space surveillance requires dealing with uncertainties directly in the initial orbit determination phase. We propose an approach based on Taylor differential algebra to both solve the initial orbit determination (IOD) problem and to map uncertainties from observables space into orbital element space. This is achieved by approximating in Taylor series the general formula for pdf mapping through nonlinear transformations. In this way the mapping is obtained in an elegant and general fashion. The proposed approach is applied to both angles-only and radar IOD for objects in LEO, GEO and high elliptical orbits.

16:30 **AAS 16-380** **Robust On-orbit Optical Position Determination of Non-Cooperative Spacecraft**

Tomohiro Narumi

An autonomous rendezvous with a non-cooperative space object is an essential technique for active debris removal. In order to approach closely and attach a decelerating device safely, precise orbit determination of the target is necessary in advance. However, since a chaser satellite is desired to be low-cost because of its auxiliary role, its performance is restricted by sensor cost constraints. We propose a new, robust, and stable batch orbit determination method guaranteeing observability using a luminous dot taken by a small camera system that can be installed even on a small satellite.

Feb 16, 2016 - Chardonnay AB

16 Asteroid and non-Earth Orbiting Missions 1

Chair: Ryan Weisman

13:30 **AAS 16-219** **The deployment of Mascot-2 to Didymoon**

Simon Tardivel, Jet Propulsion Laboratory; Caroline Lange, Institute of Space Systems, German Aerospace Center (DLR); Stephan Ulamec, RB-MUSC, German Aerospace Center (DLR); Jens Biele, DLR

This paper presents a strategy for the deployment of the Mascot-2 lander of the Asteroid Impact Monitoring mission proposal, to the secondary of the binary asteroid system Didymoon. The spacecraft releases the lander with a spring, near the L$_2$ region. The lander free falls to the surface and comes to rest after several bounces. Considering inaccuracies of the spacecraft navigation and of the spring mechanism, the different trade-offs of mission design are analyzed. Pushing the strategy to its working limits, the paper investigates whether it could be applied to the deployment of objects from smaller and less capable spacecraft.

13:50 **AAS 16-242** **A GPU-Accelerated Multiphase Computational Tool for Asteroid Pulverization and Orbital Dispersion Simulation**

Ben Zimmerman, Iowa State University; Bong Wie, Iowa State University

The focus of this research is simulation of hypervelocity kinetic energy impactors to pulverize target asteroid bodies. Current work investigates single and multiple kinetic-energy impactors, along with asteroids which vary in shape and size. Numerical simulations are of interest, as non-ideal target fragmentation can occur from the impact (large fragments maintaining an Earth-impacting trajectory). All simulations are completed via GPUs (Graphics Processing Units), which allows solutions to be generated at orders of magnitudes faster than the CPU (Central Processing Unit) counterpart. Target damage and particle dispersal speeds are shown to determine the orbital dispersion effectiveness of specific impact cases against asteroid bodies.

14:10 **AAS 16-274** **Two Body Formulation for Modeling Tether-Ballast Asteroid Diversion Systems**

Nickolas Sabey, University of Colorado at Colorado Springs; Steven Tragesser, University of Colorado at Colorado Springs

Attention has been focused on the dangers of Earth impacting asteroids, as the discovery rates of new hazardous bodies are increasing. Consequently, mitigation techniques have been proposed to prevent catastrophic events. It has been shown through numerical analysis that by attaching a tether and ballast to an asteroid over long periods of time, an asteroid may be diverted sufficiently to avoid an Earth impact event. This study demonstrates that a closed-form solution can be obtained, through the two-body formulation of perturbed motion. Using an analytic approach, Monte Carlo simulations and sensitivity studies see improvements to performance without sacrificing accuracy.

14:30 **AAS 16-320** **On the dynamics of a spacecraft in the irregular Haumea-Hi’iaka binary system**

Diogo Sanchez, National Institute for Space Research - INPE; Kathleen Howell, Purdue

University; Antonio Fernando Bertachini Prado, INPE

This work aims to describe the dynamics of a small spacecraft around a binary system comprised of irregular the bodies Haumea and Hi'iaka. In this model, the dynamics of Haumea and Hi'iaka is assumed as a full two body problem, and the equations of motion of the spacecraft incorporate the information from this model. We assume some configurations for the ellipticity of the primaries and seek orbits of interest for future missions to this system.

14:50 **AAS 16-371** **The Lift-Off Velocity on Solar System Small Bodies**

Stefaan Van wal, University of Colorado Boulder; Daniel Scheeres, University of Colorado

We investigate the velocity, at which a particle moving on the surface of some body with arbitrary shape, rotation, and gravity, will lift off from that surface and enter orbit. Expressions for both continuous and discrete models are derived, and applied to generate lift-off velocity distributions on the reference ellipsoids and polyhedra of asteroid Itokawa and the Mars moon Phobos. These results have numerous applications to the mission design of lander/rover operations, manned mission, and geophysical processes on the considered bodies.

15:10 **Afternoon Break**

15:30 **AAS 16-387** **Low-Thrust Trajectory Design for the DESTINY Mission to 3200 Phaethon**

Bruno Sarli, Institute of Space and Astronautical Sciences; Chit Hong Yam, Japan Aerospace Exploration Agency; Yasuhiro Kawakatsu, JAXA / ISAS

DESTINY is a mission candidate for ISAS small science satellite series. If selected, it will be launched by Epsilon-4 placing it initially into a low elliptical orbit. Using its ion engine the spacecraft will raise its altitude and by performing a series of lunar gravity assists places the vehicle into an escape orbit with a velocity of up to 1.5km/s. The escape velocity combined with the ion engine guides the spacecraft to perform a close flyby of 3200 Phaethon and later return to Earth. This paper presents details of the deep-space exploration mission plan as well as the mission overview.

15:50 **AAS 16-439** **Orbital stability regions for hypothetical natural satellites of 101955 Bennu (1999 RQ36)**

Samantha Rieger; Daniel Scheeres, University of Colorado; Brent Barbee, NASA Goddard Space Flight Center

During OSIRIS- REx's time at Bennu, the spacecraft will occupy two distinct Sun-terminator plane orbits. Bennu might possess natural satellites in long-term stable orbits that could interfere with spacecraft operations in Bennu's vicinity. By constructing and executing an array of detailed simulations modeling the evolution of Bennu natural satellite orbits over thousand-year time scales, we will assess the possible sizes, orbital locations, and longevities of Bennu natural satellites. From these data we will draw conclusions about the likelihood of Bennu possessing natural satellites in the current epoch and whether such natural satellites might interfere with OSIRIS-REx spacecraft operations around Bennu.

16:10 **AAS 16-450** **Polyhedral Potential Models for Close Proximity Orbital Simulations about Small Celestial Objects**

Stephanie Wood, University of Vermont; Jason Pearl, University of Vermont; Darren Hitt, University of Vermont

The imaging capabilities of the current generation of deep space probes are such that detailed, 3-D topological data can be obtained for small celestial bodies, thus enabling the reconstruction of a `digital' version of the body. Using this information, a polyhedral potential-based approach can be used to predict the non-uniform, time-varying gravitational potential environment about these small bodies. A detailed potential model is critical to the accurate orbital trajectory planning of spacecraft when operating in close proximity of the body. In this work, the performance and limitations of two variants of a polyhedral potential approach are examined in this context.

16:30 **AAS 16-502** **Initial Navigation Analysis for the Europa Multiple Flyby Mission**

Sumita Nandi, NASA / Caltech JPL; Powtawche Valerino, NASA / Caltech JPL; Julie Kangas, JPL; Brent Buffington, JPL; Rodica Ionasescu, Jet Propulsion Laboratory

Earth and spacecraft-based observations of the Jovian moon Europa have identified it as the most plausible habitat for extraterrestrial life in our solar system. Recently, NASA has formed a Europa Mission to explore this icy world with a sophisticated instrument suite operating from a spacecraft in orbit about Jupiter. Candidate trajectories have been designed that use the Jovian moons to repeatedly bring the spacecraft near Europa, providing multiple observation opportunities over the mission duration. This paper describes navigation analyses associated with these trajectories that are being used to assess their operational feasibility. The analysis includes determination of the ΔV requirements

Feb 17, 2016 - Pinot Noir BC

17 Space Situational Awareness 1

Chair: Matthew Wilkins

8:00 **AAS 16-210** **Space Borne Imaging via Noise Filtering Phase Retrieval**

David Hyland, Texas A&M University

To enable ultra-fine resolution imaging with inexpensive flux collector apertures using the Brown-Twiss effect, this paper describes a phase retrieval algorithm capable of producing high quality images despite large amounts of noise in the coherence magnitude measurement data. Previously the problem was conceived as two distinct steps: coherence magnitude estimation, followed by image construction. The present unified formulation accepts highly noisy data and estimates both the measurement noise and the image using the numerous constraints on the coherence data, the image, and their interrelations. The technique is shown to reduce the necessary imaging time by many orders of magnitude.

8:20 **AAS 16-241** **Approaches to Evaluate Probability of Collision Uncertainty**

Matthew Hejduk, Astrorum Consulting LLC

In satellite conjunction assessment, the probability of collision (Pc) calculation is generally treated as a point estimate, without accompanying uncertainty statements. The present effort attempts to quantify and follow actual uncertainties in covariance and satellite sizing through the calculation, as well as consider the native miss distance distribution through a resampling technique, in order to present a distribution of Pc values, represented as a cumulative distribution function or confidence intervals. Satellite operators can then consider how a conjunction event's entire Pc distribution aligns with their Pc thresholds for conjunction remediation in choosing a particular course of action.

8:40 **AAS 16-267** **Impact Risk Analysis of Near-Earth Asteroids with Multiple Successive Earth Encounters**

George Vardaxis, Iowa State University; Bong Wie, Iowa State University

Accurate estimation of the impact risk associated with hazardous asteroids is essential for planetary defense. Asteroids in Earth resonant orbits are particularly troublesome because of the continuous threat they pose to the Earth. The problem of analyzing the impact risk associated with NEOs on close-encounters with the Earth has been studied over the years. However, the problem of multiple, successive encounters needs to be further investigated. Incorporating methods such as analytic encounter geometry, target B-planes, analytic keyhole theory, and numerical simulations presents a new computational approach to accurately estimate the impact probability of NEOs, especially those in Earth resonant orbits.

9:00 **AAS 16-303** **Space Event Detection Via Robust Time Series Forecasting**

Pradipto Ghosh, Analytical Graphics Inc.

The ability to detect sudden and unexpected changes in the ephemerides of tracked space objects is a crucial feature of space event monitoring systems. Utilizing robust time series forecasting techniques, this paper introduces a new method for detecting sudden changes in the ephemeris of a tracked object. Test cases are presented demonstrate that the software implementation of this method is able to flag each sequentially supplied orbit-determined state as in- or out-of-family depending on whether the state is statistically typical relative to a configurable look-back interval.

9:20 **AAS 16-365** **Collision Avoidance as a Robust Reachability Problem Under Model Uncertainty**

Massimiliano Vasile, University of Strathclyde; Chiara Tardioli, University of Strathclyde; Annalisa Riccardi, University of Strathclyde; Hiroshi Yamakawa, Research Institute for Sustainable Humanosphere, Kyoto University

The paper presents an approach to the design of an optimal collision avoidance maneuver under model uncertainty. The dynamical model is assumed to be only partially known and the missing components are modeled with a polynomial expansion whose coefficients are recovered from sparse observations. The resulting optimal control problem is then translated into a robust reachability problem in which a controlled spacecraft has to avoid the region of possible collisions, in a given time, with a non-cooperative target. The paper will present solutions, for both circular and elliptical orbits, in the case in which the reachable set can be approximated

9:40 **AAS 16-453** **Direct Image-to-Likelihood for Track-Before-Detect Multi-Bernoulli Filter**

Timothy Murphy, Georgia Institute of Technology; Marcus Holzinger, Georgia Institute of Technology; Brien Flewelling, Air Force Research Laboratory

This paper applies the multi-Bernoilli filter to frame-to-frame tracking of space objects observed in electro-optical imagery for space domain awareness applications. A new likelihood function for space based imagery will be presented, based on the matched filter. A more educated birth model will be proposed which better models potential SO using observer characteristics and object dynamics. Simulation results will explore the range of trackable objects. We perform uncued detection down to a total object SNR of 5.6 and a per pixel SNR of 1.5. Inconclusive results are shown for total object SNR of 3.35 and per pixel SNR of 0.7.

10:00 **Wednesday Morning Break**

10:20 **AAS 16-457** **A class of convex optimization problems for template-based star subtraction**

Brad Sease, Virginia Polytechnic Institute and State University; Brien Flewelling, Air Force Research Laboratory; Jonathan Black, Virginia Polytechnic Institute and State University

Common approaches to star removal rely on assumptions about sensor motion, which limit the applicability of the technique, or computationally expensive nonlinear iterative signal fitting processes. This paper proposes an algorithm related to conventional point spread function fitting but with reduced computational requirements. With a prior estimate of the expected behavior of a star in an image, it is possible to build template star signals. These templates then enable a global fitting process which approximates all of the star signals in an image simultaneously. Further, this problem may be formulated as a convex linear program.

10:40 **AAS 16-510** **Preliminaries of A Space Situational Awareness Ontology**

Robert Rovetto; T.S. Kelso, Center for Space Standards and Innovation

Improving the state of Space Situational Awareness (SSA) data-sharing should improve global SSA. There is little application of ontology to the SSA and the broader space domain, despite the potential for data-sharing and interoperability. This paper takes steps toward an SSA Ontology, outlining central objectives, requirements and desiderata in the ontology development process for this domain. The purpose is to explore the potential for formal ontology and ontological engineering to (i) represent SSA general knowledge, data, and domain objects, (ii) clearly express the meaning of SSA data, and (iii) foster SSA data-sharing.

11:00 **AAS 16-518** **Space Object Classification Using Model Driven and Data Driven Methods**

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

In recent years there has been an increase in the number of inactive and debris Space Objects (SOs). This work examines both data driven and model driven SO classification. The model driven approach investigated for this work is based on the Multiple Model Adaptive Estimation (MMAE) to extract SO characteristics from observations while estimating the probability the observations belong to a given class of objects. The data driven methods are based on Principle Component Analysis (PCA) approach and Convolutional Neural Network Classification (CNNC) approaches. The performance of this strategies for SO classification is demonstrated via simulated scenarios.

11:20 **AAS 16-538** **Resident Space Object Detection using Archival THEMIS Fluxgate Magnetometer Data**

Julian Brew; Marcus Holzinger, Georgia Institute of Technology

Although the detection of space objects is generally achieved using optical and radar measurements, these methods are impaired in detecting small space objects at geosynchronous altitudes. This paper examines the use of magnetometers to address this issue by introducing a matched filter scoring approach and evaluating it using archival fluxgate magnetometer data from the NASA THEMIS mission. Preliminary matched filter scoring has been implemented and tested. From this, supporting evidence for using magnetometers to detect resident space objects is found by extracting the signal-to-noise ratio of the induced magnetic fields. Future work includes track initiation using admissible regions.

11:40 **AAS 16-395** **Parallel Implicit Runge-Kutta Methods Applied to Coupled Orbit/Attitude Propagation**

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

A variable-step Gauss-Legendre implicit Runge-Kutta (GLIRK) propagator is applied to coupled orbit/attitude propagation. Concepts previously shown to improve efficiency in 3DOF propagation are modified and extended to the 6DOF problem. The impact of computing the stage dynamics of a single step in parallel is examined. Efficiency is found to peak for typical examples when using approximately 8 to 12 stages for both serial and parallel implementations. Accuracy and efficiency compare favorably to explicit Runge-Kutta and linear-multistep solvers for representative scenarios. However, linear-multistep methods are found to be more efficient for some applications, particularly in a serial computing environment.

Feb 17, 2016 - Cabernet

18 Asteroid and non-Earth Orbiting Missions 2

Chair: Paul Thompson

8:00 **AAS 16-229** **Development of a Tool for Analyzing Orbits around Asteroids**

Julian Niedling; David Gaylor, University of Arizona; Marcus Hallmann, DLR

The project deals with the theory and practice of dynamics about asteroids. Motion around asteroids is analyzed, influencing factors are gathered and their effects are demonstrated. In order to show and compare the importance of satellite and asteroid properties, the theory of asteroid dynamics is applied on asteroid Eros and Itokawa. Special orbits are analyzed by creating a tool in MATLAB, which allows to parametrically study orbits around asteroids. The tool is capable of analyzing stability of orbits around asteroids in general, designing frozen terminator orbits and determining costs for hovering.

8:20 **AAS 16-250** **Analysis of Solar Radiation Pressure Effects on the OSIRIS-REx Spacecraft in orbit around Bennu**

Siamak Hesar, University of Colorado Boulder; Daniel Scheeres, University of Colorado; Jay McMahon, University of Colorado

This study presents an analysis of the solar radiation pressure (SRP) effects on the OSIRIS-REx spacecraft in orbit about the asteroid Bennu. It utilizes a Fourier series expansion to represent the solar radiation force that is imparted on the spacecraft. We identify a set of dominant Fourier coefficients that account for a majority of the SRP effect and its uncertainty. Analytical solutions are derived to shed light on the secular effects of the SRP on the orbit of the spacecraft around the asteroid. Finally, we implement a set of covariance analyses to evaluate the expected level of estimation precision possible for the dominant coefficients.

8:40 **AAS 16-281** **Study on Impact Experience of Hayabusa2 Mission**

Takanao Saiki, JAXA / ISAS; Hiroshi Imamura; Yuya Mimasu, Japan Aerospace Exploration Agency; Yuichi Tsuda, Japan Aerospace Exploration Agency

Hayabusa2 is a current sample return mission of JAXA and it was launched on 3 December 2014. Hayabusa2 is the successor of Hayabusa, however, it is equipped with some new components. Small carry-on impactor (SCI) is one of the new components of Hayabusa2. SCI is a compact kinetic impactor and in the latter half of the proximity operation phase of Hayabusa2, the impact experiment will be performed. Because SCI has no attitude and orbit control functions, its impact accuracy depends on the separation accuracy. In this study, the results of the impact accuracy analysis are shown.

9:00 **AAS 16-293** **Delta-V Assisted Periodic Orbits around Small Bodies**

Shota Kikuchi, The University of Tokyo; Yuichi Tsuda, Japan Aerospace Exploration Agency; Jun'ichiro Kawaguchi, Japan Aerospace Exploration Agency

Delta-V assisted periodic orbits (DVAPOs) are introduced as a new type of periodic orbit around small bodies subject to strong solar radiation pressure. DVAPOs are made periodic by including a small deterministic delta-V within each period. This type of orbit has a simpler shape and provides higher flexibility than other periodic orbits, thus enabling missions with higher scientific value. In this research, the general theory on DVAPOs is described, such as the orbit design methodology, solution space analysis, and stability analysis. This paper clarifies that DVAPOs are useful and feasible options for small body missions, and have unique dynamic characteristics.

9:20 **AAS 16-286** **Performance Characterization of a Landmark Measurement System for ARRM Terrain Relative Navigation**

Michael Shoemaker; Cinnamon Wright; Andrew Liounis; Kenneth Getzandanner; John Van Eepoel; Keith DeWeese

This paper describes the landmark measurement system being developed for terrain relative navigation on NASA's Asteroid Redirect Robotic Mission (ARRM), and the results of a performance characterization study given realistic navigational and model errors. The system is called Retina, and is derived from the stereophotoclinometry methods widely used on other small-body missions. The system is simulated using synthetic imagery of the asteroid surface and discussion is given on various algorithmic design choices. Unlike other missions, ARRM's Retina is the first planned autonomous use of these methods during the close-proximity and descent phase of the mission.

9:40 **AAS 16-370** **The Analytical Study of Particle Swarm Optimization and Multiple Agent Path Planner Approaches for Extraterrestrial Surface Searches**

Michael Johnson, University of New Hampshire; May-Win Thein, University of New Hampshire

In previous work, the authors examined an autonomous methodology for the generic search mission on extraterrestrial surfaces via Particle Swarm Optimization (PSO). In this paper, this previous work is expanded to include an examination of a decentralized Multiple Agent Path Planner (MAPP) and its effects on the quality of the PSO search results. This path planning algorithm allows the swarm to navigate about obstacles in a search space, and other rovers in the swarm, so long as their locations are known a priori. It is found that these obstacles and MAPP restrict the locations in which PSO search is unbiased.

10:00 **Wednesday Morning Break**

10:20 **AAS 16-376** **Surfing the L2 gradient with the Starshade in search of extraterrestrial life**

Carlos Marc Alberto Deccia, CCAR - University of Colorado Boulder; Eduardo Villalba, University of Colorado Boulder; Jeff Parker, University of Colorado Boulder; Webster Cash, University of Colorado Boulder; Ron Noomen, Delft University of Technology

This paper discusses a preliminary observation campaign design for the New Worlds Observer (NWO) mission concept. NWO seeks to collect direct observations of exoplanets using two vehicles: a telescope and a starshade occulter, located thousands of kilometers apart. In this concept, the two NWO spacecraft are positioned in halo orbits about the Earth-Moon L2 point. This study demonstrates a method that may be used to redirect NWO′s observation vector from one star to another using dynamical systems theory, taking advantage of the non-linear dynamics around L2.

10:40 **AAS 16-449** **USING SOLAR RADIATION PRESSURE TO MANEUVER A SPACECRAFT IN THE TRIPLE ASTEROID 2001SN263**

José Silva Neto, National Institute for Space Research (INPE); Diogo Sanchez, National Institute for Space Research - INPE; Antonio Fernando Bertachini Prado, INPE

Asteroids are ideal targets for space missions because they possibly carry information about the origin of the solar system. This work aims to study the de-orbiting of a spacecraft in the direction of the central body of the triple asteroid 2001NS263 (target of the Brazilian mission called Aster) using only solar radiation pressure. The solar radiation pressure is controlled by changing physical characteristics of the spacecraft, like the ratio area-to-mass and the coefficient of reflectivity. The impact of the spacecraft, at the end of the mission, could reveal details about the composition of this asteroid.

11:00 **AAS 16-464** **Lunar Advanced Radar Orbiter for Subsurface Sounding (LAROSS): Lava Tube Exploration Mission**

Rohan Sood, Purdue University; Henry Melosh, Purdue University; Kathleen Howell, Purdue University

With the goal of expanding human presence beyond Earth, lava tubes form ideal candidates for creating a permanent habitation environment safe from cosmic radiation, micrometeorite impacts and temperature extremes. In a step towards Mars exploration, the Moon provides the most favorable pathway for lava tube exploration. In-depth analysis of GRAIL gravity data has revealed several candidate empty lava tubes within the lunar maria. The goal of this investigation is to propose a subsurface radar sounding mission to explore the regions of interest and confirm the presence and size of buried empty lava tubes under the lunar surface.

11:20 AAS 16-409 Consolidated phase A design of Asteroid Impact Mission: MASCOT-2 landing on binary asteroid Didymos.

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

The paper presents a potential and effective strategy to release MASCOT-2 lander, part of the Asteroid Impact Mission (AIM), on the secondary of the Didymos binary system. Suitable landing solutions are investigated with a three-body approach, exploited to model the gravity field in the proximity of Didymos binary asteroid. Compared to classical Keplerian solutions, three-body dynamics is shown to be effective to lower the risk of lander rebounding on the binary smaller asteroid surface after a purely ballistic landing,and to make safer the overall release maneuver to be performed by AIM orbiter.

11:40 AAS 16-235 Ground-Based Navigation and Dispersion Analysis for the Orion Exploration Mission 1

Christopher DSouza, NASA/JSC; Greg Holt; Brandon Wood; Renato Zanetti, NASA JSC

This paper will present the navigation and dispersion analysis for the Orion Exploration Mission 1. In addition to the navigation and dispersion statistics throughout the trajectory, but particularly at the Earth and Moon encounters, the Delta-V statistics will be presented. A great deal of effort has gone into modeling the expected vehicle disturbances, including attitude maneuvers, attitude deadbanding, CO_2 venting, and ammonia sublimator venting. In addition, the maneuver execution errors are modeled, both due to both the IMUs (gyros and accelerometers) and thruster/controller effects.

12:00 AAS 16-390 Trajectory design and detection path optimization of asteroid mission

Yu Shi, Beihang University; Hao Peng, Beihang University; Yue Wang, Technion – Israel Institute of Technology; Shijie Xu

This paper, also as a solution of Chinese Space Trajectory Design Competition, suggests a detection strategy of the asteroid Eros. Three robots released from a spacecraft are supposed to perform the exploration mission to detect as many target points as possible using less fuel within a given period. Detection path optimization is converted to a maximum clique problem in graph theory and solved with an approximate optimization algorithm. Transfer orbit and release orbit are optimized in consideration of both the time and fuel using sequence quadratic program algorithm. Also, the gravity equation is modified to accelerate the calculation speed.

Feb 17, 2016 - Sauvignon

19 Guidance and Control 2

Chair: Roberto Furfaro

8:00 **AAS 16-205** **The Control Strategy of Terminal Correction Projectile Based on the Track of Laser Spot**

xinglong LI, Nanjing University of Science and Technolog; Wen-jin YAO; Xiao-ming WANG; xinglong LI, Nanjing University of Science and Technolog

For the problem of the control strategy of semi-active laser terminal trajectory correction projectile, a strategy based on track of laser spot is proposed. By comparing the position error between the actual spot in non-rolling imaging plane and the reference spot, the missing distance between the target and the uncontrolled trajectory impact point is derived, and the control strategy is obtained. With the Monte-Carlo simulation, the correction effect of a certain type of terminal correction projectile under the strategy is researched. The results indicate that, the proposed strategy can effectively reduce the miss distance.

8:20 **AAS 16-318** **Finite-time Control for Flight Close to Asteroids via Terminal Sliding-mode Guidance**

Hongwei Yang, Tsinghua University; Rutgers University; Xiaoli Bai, Rutgers; Hexi Baoyin, Tsinghua University

Closed-loop guidance method is beneficial for flight close to an asteroid due to the highly irregular gravity and uncertainties in the dynamical environment. A terminal sliding guidance method is proposed to obtain continuous finite-time control. With this guidance, no reference trajectories are required and a spacecraft can achieve its target position and velocity in finite-time. The stability and finite-time convergence is proven for the dynamical system with uncertainties. A parametric approach is used to analyze the effects of the parameters in the guidance. Simulations of both hovering and landing are presented to show the performance of the proposed method.

8:40 **AAS 16-345** **Precision ZEM/ZEV Guidance Algorithm Utilizing Vinti's Analytic Solution of Perturbed Kepler Problem**

Jaemyung Ahn, Korea Advanced Institute of Science and Technology; Yanning Guo, Harbin Institute of Technology; Bong Wie, Iowa State University

The zero-effort-miss/zero-effort-velocity (ZEM/ZEV) feedback guidance algorithm is in general not an optimal solution. However, the ZEM/ZEV algorithm can even compete with corresponding open-loop optimal solutions of various practical problems, while its feedback characteristics make it more suitable to deal with uncertainties and perturbations. In this paper, the robust performance and effectiveness of the ZEM/ZEV feedback guidance algorithm, employing Vinti's analytic solution of perturbed Kepler problem, is further evaluated by considering high-fidelity gravitational field models with the J2, J3 and J4 terms for a ballistic missile intercept problem as well as an optimal orbital transfer problem.

9:00 **AAS 16-388** **A Study on Decentralized and Parallel Control Scheme in Formation Flight and Spacecraft Systems**

Jun'ichiro Kawaguchi, Japan Aerospace Exploration Agency

Current control schemes usually assume mutual exchange of information among whole members in a control system. This common strategy sometimes requests extremely heavy communication load, and the response tends to become very slow. The author devised a special type of decentralized approach excluding servers in the system. The method has only to share limited information in the system, and leaves the actuation to each entity. This paper shows a typical example of the application to the formation flying that maintains relative distance uniformly. And the paper presents a few more applications to the spacecraft power and data management systems.

9:20 **AAS 16-411** **Hypervelocity Terminal Guidance of a Multiple Kinetic-Energy Impactor Vehicle (MKIV)**

Joshua Lyzhoft; Bong Wie, Iowa State University

This paper presents preliminary study results for developing a hypervelocity terminal guidance scheme, employing visual/infrared sensors, for a new non-nuclear MKIV (Multiple Kinetic-Energy Impactor Vehicle) system that can pulverize small asteroids (<150m) with short mission lead times (<10years). The proposed MKIV system is comprised of a carrier vehicle (CV) and kinetic-energy impactors (KEIs). This paper focuses on developing an image processing algorithm for coordinated terminal guidance of multiple KEIs. GPU-based simulations are conducted to verify feasibility of impacting small asteroids using multiple KEIs. Preliminary results indicate that it is technically feasible to impact small asteroids using the proposed MKIV system.

9:40 **AAS 16-403** **Nonlinear Control and Bounded Relative Motion Design of Space Robotic Arm Actuated Microgravity Platform**

Shuquan Wang, Technology and Engineering Center for Space Utilization, CAS; Qingtang Mao; Guangheng Zhao

A novel concept of space-based microgravity platform is presented in this paper. The system is composed of a spacecraft, a robotic arm installed on the spacecraft with a shield installed at the end point of the arm and a platform floating inside the shield. The shield is used to isolate disturbances. Letting the shield to track the motion of the floating platform using the robotic arm, the floating platform assumes a pure gravitational motion. The dynamics of the system are modeled using the Lagrange's equation. A Lyapunov based nonlinear controller is developed to fulfill the tracking mission. To achieve a long

10:00 **Wednesday Morning Break**

10:20 **AAS 16-407** **Model Predictive Control of Planetary Aerocapture Using Takagi-Sugeno Fuzzy Model**

Benjamin Margolis, Santa Clara University; Mohammad Ayoubi, Santa Clara University

In this paper, we a control algorithm for a planetary entry vehicle during an aerocapture maneuver. The proposed algorithm utilizes the model predictive control (MPC) technique with a Takagi-Sugeno (T-S) fuzzy model of the vehicle to control the velocity and altitude of the entry vehicle using bank angle modulation. Finally, a Mars aerocapture case study is presented to demonstrate the stability, performance, and robustness of the proposed controller.

10:40 **AAS 16-527** **Real-Time Optimal Control and Target Assignment for Autonomous In-Orbit Satellite Assembly from a Modular Heterogeneous Swarm**

Rebecca Foust, 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 optimal guidance and control scheme to combine a heterogeneous swarm of component satellites, rods and connectors, into a large satellite structure. By expanding prior work on a decentralized auction algorithm with model predictive control using sequential convex programming (MPC-SCP) to allow for the limited type heterogeneity and docking ability required for in-orbit assembly. The assignment is performed using a distributed auction with a variable number of targets and strict bonding rules to address the heterogeneity. MPC-SCP is used to generate the collision-free trajectories, with modifications to the constraints to allow docking.

11:00 AAS 16-216 Predictive Lateral Logic for Numerical Entry Guidance Algorithms

Kelly Smith, NASA Johnson Space Center

Recent entry guidance research has focused on numerical integration of trajectories onboard in order to evaluate candidate bank profiles. Such methods enjoy benefits such as flexibility to varying mission profiles. A common element across several modern entry guidance algorithms is a reliance upon the concept of lateral error deadbands wherein bank reversals are performed when lateral error exceeds some deadband, resulting in a random number of bank reversals. This paper presents a bank reversal technique that performs a fixed number of bank reversals. This technique may enable spacecraft mass reduction by constraining propellant usage for the entry vehicle.

11:20 AAS 16-230 Atmospheric trajectory optimization of a rocket reusable first stage with turbo engines

Eric Bourgeois, CNES; Jean-Marc Bahu; Nicolas Praly

We develop a method to take into account a turbo engine in the trajectory optimization problem of a winged reusable launcher first stage, addressing both the dependence of thrust performance to flight conditions and the optimization of the thrust modulation. Two approaches are considered, one analytical derived from aeronautics and one numerical coming from advanced CNES rocket studies. Both of them are compared and combined to take benefit from their respective assets; they are used to assess the influence of initial flight conditions on the down-range. The optimization of preceding phases (vacuum and non-thrusting aerodynamic phases) is then considered.

11:40 AAS 16-273 Lunar Entry Downmode Options for Orion

Kelly Smith, NASA Johnson Space Center; Jeremy Rea, NASA

For Exploration Missions 1 and 2, the Orion capsules will be entering the Earth's atmosphere with speeds in excess of 11 km/s. In the event of a degraded GN&C system, nominal guided entry may be inadvisable due to the potential for loss of vehicle (or crew, when crew are aboard). For such a case, a method of assuring Earth capture, water landing, and observence of trajectory constraints (heating, loads) has been developed. This method is robust to large navigation uncertainty and variations in entry interface states.

Feb 17, 2016 - Chardonnay AB

20 Trajectory Optimization 2

Chair: Jon Sims

8:00 **AAS 16-417** **A Multiple-Shooting Differential Dynamic Programming Algorithm**

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

The Hybrid Differential Dynamic Programming algorithm is a second-order optimal control algorithm, which applies Bellman's Principle of Optimality for local optimization. The algorithm uses State-Transition Matrices to decouple the optimization and dynamics, and successive optimization of quadratic approximations. The present paper extends the HDDP algorithm to use a multiple-shooting structure, in order to help alleviate the problems due to the large sensitivities often encountered when optimizing modern space trajectories, to improve the algorithm's robustness to initial guesses, and to allow for a parallel implementation. The necessary theoretical developments are presented, as well as numerical results demonstrating the advantages of the multiple-shooting principles when applied to differential dynamic programming.

8:20 **AAS 16-481** **Parametric Analysis of Low-Thrust Lunar Transfers with Resonant Encounters**

Maksim Shirobokov, Keldysh Institute of Applied Mathematics, RAS; Sergey Trofimov, Keldysh Institute of Applied Mathematics

In this work, low-thrust transfers to a halo orbit around the Earth–Moon L1 point using the resonant encounters are considered. The goal is to examine the relationship between different transfer variables and parameters: the injection point in the halo orbit, the sequence of resonances etc. For that purpose, the calculated trajectories are grouped in correspondence with chosen values of variables and parameters forming tables that contain the numerical description of the best trajectories. The tables constructed for all possible values of the parameters, provide a global picture of solutions and can help mission designers to conduct feasibility mission analysis.

8:40 **AAS 16-523** **The Shadow Trajectory Model for Fast Low-Thrust Indirect Optimization**

Ricardo Restrepo, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin

Preliminary design of low-thrust trajectories generally benefits from broad searches. Despite convergence issues and the expense of numerically integrating the state and costate, indirect methods are generally faster than direct methods, and therefore well-suited for such searches. Based on a physical interpretation of the primer vector, a fast model that approximates thrust arcs with a series of ballistic arcs and impulsive maneuvers is introduced for any dynamics. A low order series solution is used for the ballistic propagation and a Sundman-transformation provides efficient discretization. The model is evaluated for speed and accuracy and order of magnitude speedups are achieved

9:00 **AAS 16-526** **Hybrid Differential Dynamic Programming with Stochastic Search**

Jonathan Aziz, University of Colorado Boulder; Jeff Parker, University of Colorado Boulder; Jacob Englander, NASA Goddard Space Flight Center

Differential dynamic programming has been demonstrated as a viable approach to low-thrust trajectory optimization, namely with the success of NASA's Dawn mission. In this study a recent algorithm, Hybrid Differential Dynamic Programming (HDDP), is augmented with monotonic basin hopping (MBH) as a stochastic search step to further explore the solution space. Results are presented for an example Earth-Mars rendezvous with variable departure and arrival dates. MBH successfully guides HDDP through large steps in the time variables and across synodic periods. An additional benefit of the stochastic step is found in reducing the user effort to manually tune the parameters of HDDP.

9:20 **AAS 16-212** **Approximate Analytical Solution of the Multiple Revolution Lambert´s Problem**

Claudio Bombardelli, Technical University of Madrid (UPM); Javier Roa, Technical University of Madrid (UPM); Juan Luis Gonzalo, Technical University of Madrid (UPM)

An approximate analytical solution of the multiple revolution Lambert's targeting problem is presented. The solution is obtained starting from Battin's optimum single-impulse transfer and a linear phasing correction and offers remarkable accuracy near minimum delta-V transfer conditions. Consequently, the method is useful for rapidly obtaining low delta-V solutions for interplanetary trajectory optimization. The solution is easy to program and non-iterative, which makes it ideal for GPU implementation. In addition, the method can be employed to provide a fast first guess solution for enhancing the convergence speed of an accurate numerical multi-revolution Lambert solver.

9:40 **AAS 16-239** **Global Optimization of Low-Thrust Interplanetary Trajectories Subject to Operational Constraints**

Jacob Englander, NASA Goddard Space Flight Center; Matthew Vavrina, a.i. solutions; David Hinckley

While several techniques exist to search for globally optimal solutions to low-thrust trajectory design problems, they are typically limited to unconstrained trajectories. The operational design community has avoided such techniques and has focused on constrained local optimization combined with grid searches and intuitive design at the expense of efficient exploration of the global design space. This work bridges the gap between the global optimization and operational design communities by presenting a mathematical framework for global optimization of low-thrust trajectories subject to complex constraints including minimum solar range, targeting of planetary landing sites, and operation of a real-world multi-thruster electric propulsion.

10:00 **Wednesday Morning Break**

10:20 **AAS 16-300** **Stochastic Differential Dynamic Programming for Low-Thrust Trajectory Design with State Uncertainty**

Naoya Ozaki, The University of Tokyo; Ryu Funase, The University of Tokyo; Stefano Campagnola, Japan Aerospace Exploration Agency; Chit Hong Yam, Japan Aerospace Exploration Agency

This paper proposes a robust-optimal trajectory design method by Stochastic Differential Dynamic Programming (SDDP) for uncertain system to minimize the expected value of objective function. Most recent studies have focused on the trajectory optimization assuming that the spacecraft can control their trajectory exactly as planed; however, the assumption is violated in the realistic operations where uncertain events, such as navigation error or dynamical system error, perturb the predetermined trajectory. A proposed SDDP autonomously provides "margin" in optimization for future feedback. Numerical result by V-infinity leveraging problem shows that SDDP has better performance than the conventional method.

10:40 AAS 16-479 On the Application of Extended Logarithmic Smoothing Technique for Indirect Optimization of Minimum-Fuel Trajectories

Ehsan Taheri, University of Michigan; Ilya Kolmanovsky, University of Michigan; Ella Atkins, University of Michigan

In this paper, the indirect method equiped with the extended logarithmic smoothing technique is applied to equations of motion formulated in the equinoctial, spherical and Cartesian coordinate systems for optimization of the minimum-fuel low-thrust trajectories. It is shown that by exploiting the extended logarithmic smoothing technique and by formulating the problem in the equinoctial coordinate system the problem is more amenable to solution with fewer number of iterations even if a single shooting technique is invoked with a poor initial guess.The results are also compared in terms of the convergence rate and the number of iterations.

11:00 AAS 16-446 A Nonlinear Controller for Low Thrust Stabilization of Spacecraft on CRTBP Orbits

Dimitrios Pylorof, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin; Efstathios Bakolas, The University of Texas at Austin

The problem of stabilizing a spacecraft on Circular Restricted Three Body Problem orbits with a nonlinear, feedback controller subject to input constraints is studied in this paper. The proposed solutions are based on Lyapunov methods, which are fused with results from convex optimization. The control inputs are calculated online, through a pointwise Quadratic Programming optimization problem, while the neighborhood around the orbit where stabilization is possible is calculated offline, using Semidefinite Programming techniques with sum of squares constraints. The results can be used for the design and execution of low thrust spacecraft missions in multi-body environments.

11:20 AAS 16-316 Spiral Lambert's problem with generalized logarithmic spirals

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

We solve the problem of connecting two points in a given time of flight using the family of generalized logarithmic spirals. The availability of analytic expressions for the trajectory and time of flight reduces the problem to solving two equations with two unknowns. A minimum energy spiral exists and pairs of conjugate spirals bifurcate from that point. Surprising connections with the Keplerian case are found, together with resonant transfers. The maximum acceleration along the trajectory is solved analytically. The algorithm results in a tool for designing low-thrust transfers very rapidly. We show its versatility by designing an asteroid tour and exploring launch opportunities to Mars.

11:40 AAS 16-206 MULTIPLE AGILE EARTH OBSERVATION SATELLITES SCHEDULING ALGORITHM ON AREA TARGETS

Xinwei Wang, Beihang University; Hongguang Yang; Chao Han, Beihang University

Limited to the time windows, it is hard for the ordinary satellite to accomplish the observation mission on the large-scale area target. However, the agile satellite with more attitude freedom could complete the task in a short period. In this paper, a division method is utilized to decompose the area target into several point targets. Then a decomposition optimization algorithm, which consists of a novel multiple satellites assignment method and the graph theory, is adopted to obtain the scheduling results. Furthermore, two typical observing modes are defined according to the practical requirements. Simulations indicate the observation missions have been completed.

Feb 17, 2016 - Pinot Noir BC

21 Dynamics and Perturbations 2

Chair: Felix Hoots

13:30 AAS 16-382 A constant, radial, low-thrust problem including first order effects of J2

Hodei Urrutxua, University of Southampton; Martin Lara

Perturbation effects due to the Earth's oblateness are incorporated to the constant radial thrust problem. It is demonstrated that if the thrust remains small, and up to first order of J2, these effects do not modify the integrability of the problem. The accuracy of the method is tested upon practical application scenarios and engineering examples are presented.

13:50 AAS 16-315 DEVELOPMENT OF A HIGH PRECISION SIMULATION TOOL FOR GRAVITY RECOVERY MISSIONS LIKE GRACE

Florian Wöske, ZARM (Center of Applied Space Technology and Microgravity), University of Bremen; Takahiro Kato, ZARM, University of Bremen; Benny Rievers, ZARM (Center of Applied Space Technology and Microgravity), University of Bremen; Meike List, ZARM (Center of Applied Space Technology and Microgravity), University of Bremen

Simulating orbit and system data for gravimetry missions using satellite-to-satellite tracking sets very high precision requirements to numerics. The standard double data type is a limiting factor for the purpose of high precision orbit modeling. It is shown that the accuracy limit of the double data type can be overcome using enhanced precision data types. Commonly used Runge-Kutta and Adams-Bashforth-Moulton multistep integration methods are investigated and compared for simple Keplerian case as well as for high fidelity gravity models, utilizing a GRACE orbit. The influence of order and step size with respect to accuracy, efficiency and data type are shown.

14:10 AAS 16-353 Impact of the Integration Stop-Condition on the Accuracy of Regularized Orbit Formulations

Hodei Urrutxua, University of Southampton; Jesus Pelaez, Technical University of Madrid (UPM); Claudio Bombardelli, Technical University of Madrid (UPM)

The tight relationship between the stop-condition of a numerical integrator and the resulting accuracy of regularized orbit propagators is addressed. It is noted that the use of events as a means to halt the numerical orbit propagation introduces timing or phasing errors in formulations involving a Sundman transformation. The fundamentals of this timing error are described, along with the mechanisms that produce this apparent loss in the achievable accuracy. Examples are provided to support that the purely geometrical description provided by regularized methods is typically orders of magnitude more accurate than when the timing error is taken into account.

14:30 AAS 16-394 Modelling and Stability Analysis of Solar Sail Heliocentric Elliptic Displaced Orbits with a Constant Displacement

Jianlin Chen; Jianping Yuan; zhanxia zhu; Chuan Ma

In this paper, a new family of heliocentric elliptic displaced orbits with the constant displacement is proposed. Solar sails in these non-keplerian orbits can levitate above the pole of a planet in a highly elliptical orbit. The dynamics of a solar sail with reflection control device in these non-keplerian orbits is investigated in the pulsating rotating frame. The heliocentric elliptic displaced orbits are achieved by seeking stationary solutions of the dynamical equations and their local stability characteristics are derived using Floquet theory.The simulation results indicate that the equilibria are stable if the reflectivity rate and pitch angle follow the reference values.

14:50 AAS 16-420 Improving the Accuracy of Orbit Lifetime Analysis using Enhanced General Perturbations Methods

Emma Kerr, University of Strathclyde; Malcolm Macdonald, University of Strathclyde

A general perturbations method for orbit lifetime analysis developed by the authors is presented and shown to produce reliable orbit lifetime predictions when compared to historical mission data. The method is then improved further using initial decay data to inform future orbit lifetime predictions. This initial decay data is used to inform the estimates of initial parameters affecting the orbit lifetime prediction such as the atmospheric density model and spacecraft characteristics. These improved estimates are then used to generate more accurate predictions while still maintaining the speed of the original method.

15:10 AAS 16-438 B-plane visualisation tool for uncertainty evaluation

Camilla Colombo, University of Southampton; Francesca Letizia, University of Southampton; Jeroen P.J.P. Van den Eynde, University of Southampton; Rüdiger Jehn

Launchers used for interplanetary missions may be inserted into orbits in resonance with the Earth or able to cross other planets' orbits. To verify the compliance with planetary protection requirements, the impact of the uncertainty on the trajectory evolution is assessed through two visualisations. The first one is the common representation of the trajectory distribution on the Earth b-plane, highlighting also areas of interactions with other bodies. The second one represents a colour map of different states (i.e. impact with the Earth, resonances, interaction with other planets) on the grid of velocity variation used to define the initial conditions.

15:30 Wednesday Afternoon Break

15:50 AAS 16-497 Adaptive Two-Point Boundary Value Problem Tool for Accurate and Efficient Computation of Perturbed Orbit Transfers

Robyn Woollands; Julie Read, Texas A&M University; John Junkins, Texas A&M University; Austin Probe

We have developed a parallel compiled code tool that combines several of our recently developed methods for solving the perturbed Lambert problem using Modified Chebyshev Picard Iteration (MCPI). This tool consists of five individual algorithms, each of which is unique and better suited for solving a particular type of orbit transfer than the others. First the Keplerian solution is computed using p-iteration and based on this our tool selects the best method of the five for solving the perturbed Lambert problem. We anticipate that this user friendly tool will be extremely useful for mission planning and development in many space applications.

16:10 AAS 16-528 Revisiting the DSST Standalone Orbit propagator – Short-Periodic Motion Model, Partial Derivative capabilites, and Standalone Orbit Determination

Paul Cefola, University at Buffalo, State University of New York

Since 2011, three projects have significantly improved the F77 DSST Standalone Orbit Propagator. These projects are: (1) the establishment of web access, (2) the implementation of the DSST in the open source, object-oriented, java-based Orekit flight dynamics library, and (3) the detailed evaluation of the accuracy and computation time characteristics. In this paper, we focus on four topics:

1. Inclusion of the DSST short-periodic motion models in the Orekit DSST flight dynamics library
2. Inclusion of the remaining un-modeled short periodic motion terms
3. Activation of the partial derivative capabilities
4. Development of a F77 DSST Standalone Orbit Determination program

16:30 AAS 16-542 Analytic Continuation Power Series Solution for the Two-Body Problem with Atmospheric Drag

Kevin Hernandez, Texas A&M University; Tarek Elgohary, Texas A&M University; James Turner, Khalifa University, Abu Dhabi; John Junkins, Texas A&M University

In this paper the two-body problem with atmospheric drag is considered. A canon-ball drag model is utilized and the problem is solved with the analytic continuation power series technique. Recent developments of the method has made it possible to sum the series to arbitrary order enabling machine precision power series solutions for the two-body problem and the zonal gravitational perturbations. Based on these recent development a simple drag model is considered and the same recursion formulas are derived and presented. The method will be evaluated in terms of computational cost and accuracy including a sensitivity analysis to the method parameters.

16:50 AAS 16-333 Analytic High-Order Reversion of Series Solution Algorithm for Solving Lambert's Problem

James Turner, Texas A&M University; James Turner, Khalifa University, Abu Dhabi

A classic celestial mechanics challenge is concerned with solving two-point boundary-value problems (TPBVP) for two-body problems. This problem was first stated by Johann Heinrich Lambert (1728-1779) 1-4. The goal is to find an orbit that connects two points in space with a given flight time. Typical applications include controlling and targeting spacecraft or directing missiles in an inverse-square gravity field. As presented in Schaub and Junkins4, the geometry of Lambert's problem is presented in Figure 1. The initial position vector is given by r1 and the final position vector is given by r2. All position vectors are measured relative to

17:10 AAS 16-263 RE-ENTRY PREDICTION AND ANALYSIS USING TAYLOR DIFFERENTIAL ALGEBRA

Vincent Morand, CNES

Taylor Differential Algebra (TDA) is one of many uncertainty propagation techniques an engineer can use in order to understand how the result of its computation is sensitive to initial conditions or parameters.CNES conducted a two-year research and technology action to study the benefits of using TDA in two specific cases: long term orbit propagation for lifetime estimation and re-entry trajectory computation for casualty-risk evaluation. The papers gives the results of this R&T action, experience feedback as well are concrete examples are detailed

Feb 17, 2016 - Cabernet

22 Mission Design 3

Chair: David Spencer

13:30 AAS 16-244 LUNAR NEAR RECTILINEAR ORBITS AND CIS-LUNAR TRANSFER TRAJECTORIES IN SUPPORT OF THE DEEP SPACE PROVING GROUND

Michel Loucks, Space Exploration Engineering; John Carrico, Google

The NASA Evolvable Mars Campaign (EMC) contains the Deep Space Proving Ground (DSPG) in the near-Lunar vicinity as one of the major elements of a sustainable human spaceflight architecture. Recent NASA studies have indicated that Lunar Near Rectilinear Orbits or NROs, could be a useful staging location for human-tended cis-lunar operations in the DSPG away from the Lunar Distant Retrograde Orbit.In this paper, we describe a method for the simple creation and analysis of these orbits and provide and describe their fundamental characteristics.

13:50 AAS 16-234 BEPICOLOMBO TRAJECTORY OPTIONS TO MERCURY IN 2018 AND 2019

Rüdiger Jehn; Yves Langevin, IAS

BepiColombo is a cornerstone mission of the ESA Science Programme consisting of a Magnetospheric Orbiter (JAXA) in a highly elliptic orbit and a Planetary Orbiter (ESA) in a 480 x 1500 km orbit. A survey of solar-electric propulsion trajectories combined with planetary flybys was performed covering launches in the year 2018 and 2019. The best opportunity is an Ariane 5 launch in April 2018 with 2 Venus flybys and 4 Mercury flybys before a gravitational capture in December 2024. The total delta-V spent during the 6.7-year travel is 4 km/s. Cheaper but even longer options exists in October 2018 and

14:10 AAS 16-251 MULTIPLE DESIGN OPTIONS FOR INTERPLANETARY ORBITER MISSIONS USING PSEUDOSTATE TECHNIQUE

Parvathi SP, Indian Institute of Space science and Technology; Ramanan R V, Indian Institute of Space Science and Technology

We develop an iterative process based on pseudostate technique to identify the four distinct transfer trajectory options in the context of interplanetary transfer. This new process reduces the deviations in the closest approach altitude (upto 98%) and the related time (upto 95%) on numerical propagation compared to patched conic design. This technique is useful for quick mission design and analysis of orbiter missions. Also, it serves as a better initial guess for numerical refinements under extended force models including other perturbations. For illustration, a typical 2018 Type I minimum energy opportunity is analysed using patched conic and pseudostate techniques.

14:30 AAS 16-456 STUDY OF PERTURBATION INTEGRALS APPLIED TO THE DYNAMICS OF SPACECRAFTS AROUND GALILEAN MOONS

Josué Cardoso dos Santos, Universidade Estadual Paulista (UNESP) and University of Colorado Boulder (UCB); Antonio Fernando Bertachini Prado, INPE; Rodolpho Moraes, UNIFESP; Jean Paulo S. Carvalho, UNIFESP - Instituto de Ciéncia e Tecnologia

Several scientific missions have been proposed for a deeper exploration of planetary systems. These missions require a lot of specialized techniques in order to reach a better understanding of the dynamics involved in their planning. In order to help to get important features about each system under study, the present study proposes to use different definitions of integrals of the perturbing forces received by spacecrafts for a specific system. These computations present important information about the energy given and/or removed from the spacecraft due to the effects of each perturbation considered in the system and they also help to understand

14:50 AAS 16-473 TROJAN ASTEROID MISSION DESIGN: TARGET SELECTION AND SEQUENCING OPTIMIZATION

Owen Blough, Western Michigan University; Tyler Farrington, Western Michigan University; Jennifer Hudson, Western Michigan University

The Trojan Asteroids, which reside in the L4 and L5 Lagrange points of Jupiter's orbit, hold significant scientific interest. A mission to these asteroids requires large amounts of propellant, due to their distance and location. Identification of the most fuel-efficient paths between asteroids would improve mission feasibility. The selection of asteroids and the sequence of visitation is a complex trajectory optimization problem akin to the ``Moving Target Traveling Salesman Problem". A Genetic Algorithm is developed that identifies asteroid sequences that significantly reduces fuel cost. The solution uses assumptions regarding starting point, flight times, and loiter time at each asteroid.

15:10 AAS 16-550 Synchronized Lunar Pole Impact and Plume Sample Return Trajectory Design

Anthony Genova, NASA; Cyrus Foster, Planet Labs; Tony Colaprete, NASA Ames Research Center

The presented trajectory design enables a secondary and tertiary spacecraft on the same trans-lunar injection (TLI) to target different lunar flyby conditions to coordinate an impact of and sample return from a lunar pole. To demonstrate this design, the lunar north pole is impacted by the centaur upper stage of the launch vehicle at a steep angle, as done in the LCROSS mission. However, instead of the plume-sampling spacecraft impacting the lunar surface, the presented design allows the spacecraft to avoid a lunar impact and return an aero-gel captured sample to Earth without permanent capture by the Moon.

15:30 Wednesday Afternoon Break

15:50 **AAS 16-529** **Trajectory Characteristics of Spacecraft Propelled by Ground-based Photonic Laser Propulsion System**

Fu-Yuen Hsiao, Tamkang University

This paper studies the trajectory characteristics of the spacecraft propelled by a ground-based photonic laser propulsion (PLP) system. An spaceborne PLP system was studied in the past years, but a ground-based PLP system may also helpful in space missions. In this paper, a PLP sytem is assumed to be installed in the surface of a celestial body. The equations of motion of the spacecraft in the body-fixed frame is derived,and the corresponded Jocobi integral is found. Contours of zero-velocity lines are presented and trajectories of example missions will be provided as potential applications in the final paper.

16:10 **AAS 16-255** **End-to-End Trajectory for Conjunction Class Mars Missions Using Hybrid Solar-Electric/Chemical Transportation System**

Patrick Chai, NASA Langley Research Center; Min Qu, AMA; Raymond Merrill, NASA Langley Research Center

NASA's Human Spaceflight Architecture Team is developing a reusable hybrid transportation architecture in which both chemical and solar-electric propulsion systems are used to deliver crew and cargo to exploration destinations. For the hybrid transportation system, a series of trajectories was designed to minimize the propulsive energy required. This paper presents the methodology and the results of higher fidelity analysis on these trajectories and their implication on the hybrid architecture. These analyses further define the trajectory work previously published and provides refinement for the hybrid transportation architecture.

16:30 **AAS 16-466** **Multi-Body Mission Design Using the Deep Space Trajectory Explorer**

Diane Davis, a.i. solutions, Inc.; Sean Phillips; Brian McCarthy

Preliminary trajectory design in the vicinity of the smaller primary (P_2) in a three-body system is complicated by the significant gravitational influence of the distant larger primary. In this investigation, the preliminary design process is simplified by the use of periapsis Poincaré maps. By employing a custom visualization and design tool, maps are used to methodically and visually select transfers into long-term P_2-centered orbits, to design escape and impact trajectories, and to transition between libration point orbits and trajectories centered at the smaller primary.

16:50 **AAS 16-535** **Mission Design Trades For A Near Term Pluto Orbiter**

Nitin Arora, JPL; Anastassios Petropoulos, NASA / Caltech JPL; John Elliott

Mission design trades for a nuclear powered, electric propulsion (EP) based Pluto orbiter, launching between 2023 and 2030, are presented. Low-thrust EP trajectories powered by either Radioisotope Thermoelectric Generators (RTG) or a high power nuclear reactor are found to be mission enabling. Trajectories using NASA Evolutionary Xenon Thruster (NEXT) or the Xenon Ion Propulsion System (XIPS) are studied and compared. While the XIPS prefer trajectories requiring lower power and longer flight times, the NEXT enable a shorter, high-powered, mission to Pluto. Effect of using different launch vehicles (including SLS) on flight time, delivered mass and propellant throughput is also investigated.

17:10 **AAS** **Designing an Asteroid Deflection Mission using Continuous Thrust and Uncertainty**

16-435 *Stijn De Smet, University of Colorado; Jeff Parker, University of Colorado Boulder; Nathan Parrish, University of Colorado at Boulder*

This paper discusses the trajectory design for future asteroid deflection concepts that consider optimization under uncertainty to minimize the fuel requirement. The goal of this paper is to find the fuel optimal continuous thrust trajectory while constraining the allowable overlap between the resulting covariance matrix at the time of closest approach and the Earth. The covariance analysis also accounts for the uncertainty introduced by the continuous thrusting. Further, the design avoids keyholes in the state space that would inadvertently place the asteroid onto a future impact trajectory.

Feb 17, 2016 - Sauvignon

23 Spacecraft Relative Motion

Chair: Alan Lovell

13:30 **AAS 16-204** **Relative Orbit Targeting Using Artificial Potential Functions**

David Spencer, Georgia Institute of Technology

This work establishes a trajectory control methodology using artificial potential functions that are expressed in terms of relative orbital elements. Through defining a scalar potential function in terms of relative orbital elements, the resulting potential field may be shaped such that the path of steepest descent lies in the direction of the desired elements, where the natural motion of the trajectory leads to the goal. An advantage of this approach is that a specified relative orbit may be targeted, whereas prior approaches only allow targeting of dicrete Cartesian state vectors.

13:50 **AAS 16-262** **Analytic Solution for Satellite Relative Motion: The Complete Zonal Gravitational Problem**

Bharat Mahajan, Texas A&M University; Srinivas R. Vadali, Texas A&M University; Kyle T. Alfriend, Texas A&M University

A state transition matrix for satellite relative motion including the effects of an arbitrary zonal gravity harmonic is presented. The direct analytic formulae for second-order secular rates, short-period, and long-period effects for an arbitrary zonal harmonic are computed, which are completely closed-form in eccentricity. Using differential perturbations, the secular and periodic effects are included in the analytic solution of the satellite relative motion. The perturbation effects are computed in terms of the Equinoctial elements to avoid singularities for circular and equatorial reference orbits. Verification of the proposed analytic solution for perturbed relative motion is carried out using GMAT.

14:10 **AAS 16-357** **Comparison of orbit element sets for modeling perturbed satellite relative motion**

Kirk Johnson; Srinivas R. Vadali, Texas A&M University; Kyle T. Alfriend, Texas A&M University

This study will present a method for modeling the relative motion of satellites perturbed by Earth's zonal gravitational harmonics using an analytic approach based on Lie-series methods. The models will include mean secular rates and mean-to-osculating element transformation terms up to second order in J_2. The accuracy of the simulations will be compared using several candidate element sets (Hoots, equinoctial, Poincaré, and polar nodal), all nonsingular for both circular and equatorial orbits. The candidate element sets will be used in differential form to model relative motion. Separate approaches will consider the inputs as either mean or osculating initial conditions.

14:30 AAS 16-436 Developing a Harmonic-Balance Model for Spacecraft Relative Motion

Ayansola Ogundele; Andrew Sinclair, Auburn University

In this paper, the harmonic-balance method is applied to develop a new linearization of the nonlinear equations of motion for satellite relative motion. A cubic approximation of the equations of motion is evaluated along a reference linear solution for the relative motion. From this, a linear approximation which is a function of the initial-conditions used to describe the reference solution is extracted. Thus, the model takes the form of an initial-condition dependent linear system. Solutions of the harmonic-balance model can provide better approximation of the relative motion with less error than the Clohessy-Wiltshire model.

14:50 AAS 16-496 Third Order Cartesian Relative Motion Perturbation Solutions for Slightly Eccentric Chief Orbits

Eric Butcher, University of Arizona; Alan Lovell, Air Force Research Laboratory; Andrew Harris, SUNY Buffalo

A perturbation method is used to obtain third order solutions for spacecraft relative motion in Cartesian coordinates for the case of a slightly eccentric chief orbit and a large chief/deputy separation distance. Both the chief eccentricity and the normalized separation are considered to be of order ε. The solution obtained includes as subsets both second order solutions for circular chief orbits previously obtained by perturbation and quadratic Volterra theory as well as a linear solution to third order in the chief eccentricity. Simulations confirm the improved accuracy of the third order solution.

15:10 AAS 16-531 Spherical Coordinate Perturbation Solutions to Relative Motion Equations: Application to Double Transformation Spherical Solution

Eric Butcher, University of Arizona; Alan Lovell, Air Force Research Laboratory

Perturbation solutions are obtained in spherical coordinates for the spacecraft relative motion problem for the case of a slightly eccentric chief orbit. The use of spherical coordinates eliminates many of the secular terms in the Cartesian coordinate solution and extends the range of validity of these solutions to larger in-track separations. Both the chief eccentricity and the normalized separation are treated as order e. Finally, the second order solution for a circular chief is used in the "double transformation" spherical solution to improve the accuracy of the "approximate double transformation" spherical solution.

15:30 Wednesday Afternoon Break

15:50 AAS 16-537 A Satellite Relative Motion Model Including J2 and J3 via Vinti's Intermediary

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

Austin

Vinti's potential is revisited for analytical propagation of the main satellite problem, this time in the context of relative motion. A particular version of Vinti's spheroidal method is chosen that is valid for arbitrary elliptical orbits, encapsulating J2, J3, and approximately two thirds of J4 in an orbit propagation theory without resorting to perturbation methods. As a child of Vinti's solution, the proposed relative motion model inherits these properties. Furthermore, the problem is solved in oblate spheroidal coordinates, leading to large regions of validity for the linearization approximation. The proposed model is derived and evaluated against other solutions.

16:10 AAS 16-486 APPROPRIATE FIDELITY ELECTROSTATIC FORCE EVALUATION CONSIDERING A RANGE OF SPACECRAFT SEPARATIONS

Joseph Hughes; Hanspeter Schaub, University of Colorado

Charged spacecraft experience electrostatic forces and torques from both charged neighboring spacecraft and the local space environment itself. Fast numeical methods are needed to numerically approximate electrostatic forces significantly faster than realtime to simulate the complex charged astrodynamics that can occur with Coulomb tugging and detumbling operations, as well as predicting the charged debris dynamics. This paper develops reduced order elec- trostatic force models suitable for locally flat electric fields (large separations), radial fields (medium separation larger than 5-10 craft radii) and coupled electric fields (close proximity less than 5-10 craft radii). This provides faster computation and adds analytical insight.

16:30 AAS 16-375 Analysis of Ambiguous Orbits in Sequential Relative Orbit Estimation with Range-Only Measurements

Jingwei Wang, University of Arizona; Eric Butcher, University of Arizona; Alan Lovell, Air Force Research Laboratory

A classification of ambiguous spacecraft relative orbits in sequential orbit estimation is formulated based on the use of linear dynamics with continuous range-only measurements. Using relative orbit elements the ambiguous orbits are categorized into two cases: mirror orbits, which conserve the size and shape but transform the orientation of the true relative orbit, and deformed orbits, which both distort the shape and change the orientation. Furthermore, it is shown that the inclusion of nonlinearities in the filter model can help resist the tendency of an extended Kalman filter to converge to the ambiguous orbits.

16:50 AAS 16-548 Enhancements to Motion Emulation Platform for Six Degree of Freedom Proximity Operations and Contact Experiments

Austin Probe; Malak Samaan, VectorNav Technologies, LLC ; Tim Woodbury, Texas A&M Aerospace Engineering; John Hurtado, Texas A&M University; John Junkins, Texas A&M University

Future efforts for the removal of space debris will require the development of new technologies. To support this development the Texas A\&M LASR Laboratory has engineered several systems for ground based testing of technologies for space based proximity operations, rendezvous, and contact dynamics. The centrepiece of this suite is the Holonomic Omnidirectional Motion Emulation Robot (HOMER), a 6 degree of freedom platform for reproducing motion based on the input of a dynamic simulation. This paper details recent upgrades made to HOMER to support contact dynamics experiments including the integration of a load-cell and inertial measurement units.

17:10 **AAS 16-432** **Planning maneuvers between periodic relative orbits using geometric relative orbital elements**

Liam Healy, Naval Research Laboratory

Periodic relative motion about a circular orbit may be described in terms of the geometric orbital elements, constants of the linearized motion analogous to the classical orbit elements for two-body inertial motion. They describe the three-dimensional motion of the secondary spacecraft about the primary in the apocentral coordinates, which are defined by that motion and are analogous to the perifocal coordinates for inertial motion. With simple computations for relative plane change and relative orbit size change, circumnavigation and inspection planning can be done interactively with a graphical software tool on the ground or even with a low-performance flight processor.

Feb 17, 2016 - Chardonnay AB

24 Special Session: Results from GTOC8

Chair: Anastassios Petropoulos

13:30 **AAS 16-501** **GTOC8: Problem Description and Summary of the Results**

Anastassios Petropoulos, NASA / Caltech JPL

The Global Trajectory Optimisation Competition was inaugurated in 2005 by Dario Izzo of the Advanced Concepts Team, European Space Agency. GTOC2 through GTOC7 were organised by the winning teams of the preceding GTOC editions. Keeping this tradition, the Outer Planet Mission Analysis Group and Mission Design and Navigation Section of the Jet Propulsion Laboratory organised the eighth edition of the competition, GTOC8. This paper is intended as the opening paper in a GTOC8 special session. As such, this paper will describe the problem posed and will provide an overview of solutions received, as well as a listing of the rankings and description of the ranking process.

13:50 **AAS 16-362** **GTOC8: RESULTS AND METHODS OF POLIMI-UPM**

Diogene Alessandro Dei Tos, Politecnico di Milano; Francesco Topputo, Politecnico di Milano; Daniele Filippetto, Politecnico di Milano; Mauro Massari, Politecnico di Milano; Pierluigi Di Lizia, Politecnico di Milano; Juan Luis Gonzalo, Technical University of Madrid (UPM); Hodei Urrutxua, University of Southampton; Claudio Bombardelli, Technical University of Madrid (UPM); Andrea Colagrossi, Politecnico di Milano; Vincenzo Pesce; Daniel Pastor-Moreno, Technical University of Madrid; Aureliano Rivolta; Amedeo Rocchi

In this work a solution to the 8th Global Trajectory Optimisation Competition is presented. With the aim of maximising the objective function, a two-stage strategy has been devised. First, two spacecraft target selenoflybys to significantly modify their orbital parameters. Later, the formation is steered with low-thrust propulsion to see radio sources within an assigned tolerance. The latter is achieved by means of a geometrical method that minimises the orbital parameters variation, and that provides boundary condition for an indirect method. No constraints on the number of seen sources have been applied. On top of this, a genetic algorithm seeks optimal flyby parameters.

14:10 AAS 16-552 GTOC8: Results and Methods of Team 8

Yang Gao, Technology and Engineering Center for Space Utilization, Chinese Academy of Sciences; Shengmao He; Zhengfan Zhu

A set of elliptical Keplerian orbits that start from the moon and return to the moon have been proposed via unifying three typical transfers in literature: backflip orbits, resonant orbits, and consecutive collision orbits. These moon-to-moon transfers could be connected to construct a long-chain consecutive lunar-flyby trajectory. Assuming each spacecraft moves in a consecutive lunar-flyby orbit, spatial triangles with variable sizes and orientations can be established. This design idea is employed by Team 8 for solving the GTOC8's problem, in which we firstly designed large-scale, subsequently medium-scale, and finally small-scale triangular formations to fulfill repeated observations to selected targets.

14:30 AAS 16-425 Construction and Verification of the Solution of the 8th Global Trajectory Optimization Competition Problem. Team 13: GlasgowJena+

Alessandro Peloni, University of Glasgow; Dietmar Wolz, Friedrich-Schiller-Universität Jena; Matteo Ceriotti; Ingo Althöfer, Fakultät Mathematik und Informatik

This paper describes the methodology to find and verify the solution to the 8th Global Trajectory Optimization Competition (GTOC) problem, developed by Team 13, GlasgowJena+. We chose a stochastic approach to quickly assess a large number (about 10^{10}) of 3-spacecraft formations. A threshold was used to select promising solutions for further optimization. Our search algorithm (implemented in Java) is based on three C++ algorithms called via Java native interface (JNI). Our final solution has a performance index of J = 59682715.44314168 km, 40 distinct observations, and the sum of the final masses of the three spacecraft is 5846.57437691254 kg.

14:50 AAS 16-421 GTOC8: Results and Methods of Team 15 DLR

Marcus Hallmann, DLR

This paper describes the results and methods used during the 8th Global Trajectory Optimization Competition (GTOC) of the DLR team. Trajectory optimization is crucial for most of the space missions and usually can be formulated as a global optimization problem. A lot of research has been done to different type of mission problems. The most demanding ones are low thrust transfers with e.g. gravity assist sequences. In that case the optimal control problem is combined with an integer problem. In most of the GTOCs we apply a filtering of the problem based on domain knowledge.

15:10 AAS 16-377 GTOC8: Results and Methods of the University of Colorado Boulder

Jeff Parker, University of Colorado Boulder; Jonathan Aziz, University of Colorado Boulder; Daniel Case, University of Colorado Boulder; Luca Corpaccioli, Delft University of Technology; Carlos Marc Alberto Deccia, CCAR - University of Colorado Boulder; Ryan Handzo, University of Colorado - Boulder; Jonathan Herman, University of Colorado at Boulder; Nathan Parrish, University of Colorado at Boulder; Stijn De Smet, University of Colorado

The University of Colorado Boulder participated in the 8th Global Trajectory Optimisation Competition, ultimately ranking sixth place. The submitted objective function of ~76,301,536 was achieved by focusing effort on placing the three spacecraft into a very desirable final constellation, where many high-value radio sources could be observed with a very high *H*-value. The route to arrive at this constellation was designed to observe the same radio sources from lower *H*-values. The resulting mission included six radio sources observed three times each, four radio sources observed twice each, and six radio sources observed once each within the mission timeline.

15:30 **Wednesday Afternoon Break**

15:50 **AAS 16-384** **GTOC8: RESULTS AND METHODS OF STATE KEY LABORATORY OF ASTRONAUTIC DYNAMICS**

Hong-Xin Shen, Chinese Xi'an satellite control center; An-Yi Huang; Zhi-Bin Zhang; Heng-Nian Li

The paper presents the trajectory designed by the team State key laboratory of astronautic dynamics (Team10), for the 8th edition of the Global Trajectory Optimization Competition (GTOC8). The global and local optimization methods, which have been used at team10 to compute the GTOC8 trajectory, are presented. In particular, the generalities of the very-long-baseline formation configuration design strategy, the optimal maneuvers for lunar gravity-assist, the procedure for finding suitable radio sources, and the mathematics for the boundary value problem are described; the details of the solution are also given.

16:10 **AAS 16-283** **GTOC8: Results and Methods of Team 22**

Lorenzo Casalino, Politecnico di Torino; Guido Colasurdo, Università di Roma Sapienza; Alessandro Zavoli, Sapienza - Università di Roma; Marco Berga, Thales Alena Space Italy

The methods and results of team Politecnico di Torino-Università di Roma Sapienza-Thales Alenia Space Italy in the 8th Global Trajectory Optimisation Compatition (GTOC8) are decsribed.

16:30 **AAS 16-248** **GTOC8: Results and Methods of Team 3 - Tsinghua University**

Gao Tang, Tsinghua University; Hongwei Yang, Tsinghua University; Rutgers University; Fanghua Jiang; Hexi Baoyin, Tsinghua University; Li Junfeng

In this paper the methods proposed by team 3 in the 8th Global Trajectory Optimization Competition (GTOC8) are introduced. %The final formation of the three spacecraft is obtained after an analysis of the performance index. The final formation of the three spacecraft is obtained by analyzing the major factors that affect the performance index. Then the optimal trajectories to construct the final formation are generated and used as nominal trajectories through which all the possible moments when the corresponding radio sources are observed are calculated. Followed by a global search algorithm to determine the sequence of observing moments, indirect methods are applied to obtain

16:50 **AAS 16-275** **GTOC8: Results and Methods of ESA Advanced Concepts Team and JAXA-ISAS**

Dario Izzo, European Space Agency; Daniel Hennes, DFKI; Ingmar Getzner, European

Space Agency; Marcus Martens, TU Delft; Krzysztof Nowak, CERN; Anna Heffernan, European Space Agency; Stefano Campagnola, JAXA / ISAS; Chit Hong Yam, Japan Aerospace Exploration Agency; Naoya Ozaki, The University of Tokyo; Yoshihide Sugimoto, Japan Aerospace Exploration Agency

We describe the methodology that was applied in the design of "The Nephalem", i.e. the interplanetary trajectory submitted as a solution to the 8th edition of the Global Trajectory Optimization Competition by the European Space Agency's Advanced Concepts Team and JAXA's ISAS. The main mission objective, as envisioned by the organizers at Jet Propulsion Laboratory, was that of performing a high-resolution mapping of radio sources in the universe using space-based Very-Long-Baseline Interferometry. "The Nephalem" turned out to achieve the highest rank among all submitted designs.

Feb 18, 2016 - Pinot Noir BC

25 Spacecraft Rendezvous

Chair: Andrew Sinclair

8:00 **AAS 16-280** **Adaptive Guidance scheme for Spacecraft Rendezvous in Elliptical Orbits**

Anand Kumar, Indian Institute of Space Science and Technology; Ramanan R V, Indian Institute of Space Science and Technology

An adaptive guidance scheme for spacecraft rendezvous problem is developed and presented. The analytical methods: homotopy and differential transform, have been used to express the control law as a polynomial with time as the independent variable. The trajectory is split into multiple arcs and the guidance scheme for each arc is derived. The initial states are taken from navigation system and the guidance law is derived to achieve the final state. Thus, the deviations in the states are computed at the end of each arc and fed back to the system eliminating the progressive accumulation of errors in the states.

8:20 **AAS 16-350** **Autonomous Time-Optimal Spacecraft Rendezvous and Proximity Operations Using Stabilized Continuation**

Emily Kollin, The University of Texas at Austin; Maruthi Akella, The University of Texas at Austin

A spacecraft's ability to compute on-board some optimal rendezvous trajectory is becoming more desirable as engineers and operators seek to make spacecraft more autonomous. Here we consider the scenario in which two spacecraft are initialized in the same orbit separated by some phase angle. The goal is to on-board autonomously determine the chaser's thrust vector time history such that rendezvous with the target is achieved in minimum time. This optimal control problem is addressed by implementing continuation with a state feedback stabilizing input. The application of a non-iterative method which includes error stabilization makes this approach feasible for on-board use.

8:40 **AAS 16-369** **PRELIMINARY STUDY ON RELATIVE MOTION AND RENDEZVOUS BETWEEN SPACECRAFT IN THE RESTRICTED THREE-BODY PROBLEM**

Davide Conte, The Pennsylvania State University; David Spencer, The Pennsylvania State University

The focus of this paper is to present a preliminary study concerning relative motion and rendezvous in the restricted three-body problem. This paper presents full numerical simulations compared with linearized results of relative motion around well-known Lagrangian orbits such as halo orbits around Earth-Moon L_2 and Distant Retrograde Orbits. Additionally, an initial linearization study is performed and presented to understand the general dynamics of such relative motion. Previous work on this topic relies on simplifications and assumptions that constrain the results to specific spatial domains and geometries.

9:00 **AAS 16-459** **Experiments on Autonomous Spacecraft Rendezvous and Docking Using an Adaptive Artificial Potential Field Approach**

Richard Zappulla, Naval Postgraduate School; Josep Virgili llop, Naval Postgraduate School; Hyeongjun Park, Naval Postgraduate School; Marcello Romano, NPS

For rapid path-planning of autonomous rendezvous and proximity operations, an adaptive artificial potential function (AAPF) method has been developed based on the artificial potential function (APF) framework. An adaptive law is applied to choose the time-dependent weights of the attractive potential function as a modification and improves performance over the APF method. This paper focuses on experimental verification and investigation by implementing the proposed method on a floating spacecraft simulator test-bed. We validate the capability of on-board execution. It is also experimentally demonstrated that the AAPF method improves performance of rendezvous and docking maneuvers compared to the APF approach.

9:20 **AAS 16-495** **Nonlinear Analytical Equations of Relative Motion on J2-Perturbed Eccentric Orbits**

Bradley Kuiack, Carleton University; Steve Ulrich, Carleton University

Future spacecraft formation flying missions will require accurate autonomous guidance systems to calculate reference, or desired, relative motion between spacecraft during reconfiguration maneuvers. However, the efficiency in terms or propellant used for such maneuvers depends on the fidelity of the dynamics model used for calculating reference relative motion. An efficient method for calculating relative motion should have an analytical solution, be applicable to an eccentric orbit, and should take into account the J_2 perturbation. Such a solution is developed, and when compared to a numerical simulator yields error on the order of a few meters.

9:40 **AAS 16-356** **Non-Iterative Approximate Solution to the Angles-Only Initial Relative Orbit Determination Problem in Spherical Coordinates**

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

An approximate solution to the angles-only Initial Relative Orbit Determination problem is presented and evaluated in the context of two-body orbital motion. The algorithm is non-iterative and requires the singular value decomposition of a 4×4 matrix and the solution to a sixth-order polynomial. Four observations of the line-of-sight vector from a chief to a deputy in a nearby orbit are required. The position and velocity of the chief are assumed known. The development of the algorithm is based upon the Clohessy-Whiltshire equations in spherical coordinates and a second-order expansion of the nonlinear relative azimuth and elevation measurement equations.

10:00 **Thursday Morning Break**

10:20 **AAS 16-507** **Coupled Translational and Rotational Dynamics for Precise Constrained Rendezvous and Docking with Periodic Reference Governors**

Christopher Petersen, University of Michigan; Ilya Kolmanovsky, University of Michigan

This paper derives a set of spacecraft translation and rotation dynamics that are coupled and model the relative motion between an arbitrary point on a deputy spacecraft and an arbitrary point on a chief spacecraft. A periodic linear quadratic controller with a periodic reference governor for collision avoidance while docking is constructed based on the linearized system. Simulations demonstrate precise, rendezvous and docking using the coupled fully nonlinear model equations and proposed control scheme which successfully enforces constraints.

10:40 **AAS 16-513** **Approaching and Docking Maneuvers Design and Control for a Tumbling Target**

Jvxiang Ge; Jianping Yuan

The maneuvers and control problems for a chaser spacecraft to approach and dock with a tumbling target spacecraft are studied in this paper. The motions of the tumbling target are classified into two modes. It is based on the principle that whether the rotation axis of a tumbling target is perpendicular to its docking port axis. The approaching and docking maneuvers and control algorithms are designed for the two tumbling modes respectively. The simulation results show that for this two tumbling modes, the designed maneuvers and control algorithms can satisfy the requirements of the missions.

11:00 **AAS 16-261** **Relative Lambert Transfer Based On Relative Orbit Elements And The Application In Hovering Formation Control**

Huan Chen; Yinrui Rao; Chao Han, Beihang University

Motivated by Lambert transfer orbit, the relative lambert transfer orbit between two different relative positions in a reference satellite is proposed and deduced based on relative orbit elements theory. Then the relative lambert transfer strategy is proposed. Next, the relative lambert orbit is applied in the hovering formation analysis and design. And relative lambert transfer strategy is applied in the hovering formation control of initialization, maintain, movement and reconfiguration. Finally, a numerical simulation of the hovering formation design and control is shown.

11:20 **AAS 16-400** **NUMERICALLY APPROXIMATED RECEDING HORIZON CONTROL FOR UNCERTAIN PURSUIT-EVASION GAMES**

Brian Janisch, Texas A&M University; John Hurtado, Texas A&M University; Kevin Brink, Air Force Research Laboratory

A robust technique for handling parameter and strategic uncertainty in a pursuit-evasion framework is developed. The approach is an open-loop receding horizon controller which approximates the optimal Hamilton-Jacobi-Bellman feedback solution with small loss in optimality. A simple analytic game solution proves that above a certain threshold value of uncertainty, the receding horizon controller can become more effective than the game-optimal controller with an incorrect estimate. Several nonlinear examples in simulation show the controller's usefulness for uncertain systems. Nonlinear feedback solutions are computationally expensive; therefore, the approach is also cast into a nonlinear programming problem which approximates the solution and can be run in real-time.

Feb 18, 2016 - Cabernet

26 Trajectory Optimization 3

Chair: Roby Wilson

8:00 **AAS 16-304** **An Accelerated Trajectory Optimization Technique Based on Pseudospectral Methods**

Qi Gong, University of California, Santa Cruz; Isaac M. Ross

We present a propagator-agnostic trajectory optimization method based on an accelerated pseudospectral method. The acceleration is achieved by discretizing the state trajectory at a significantly lower rate than the control program such that any propagator applied to the dynamics generates feasible solutions. A new covector mapping theorem provides computational tests for checking the optimality of the feasible solution. The accelerated method supports the growing need from the industry for "good" feasible solutions that can be used either for rapid mission analysis to explore large-scale parametric studies or for unscented trajectory optimization.

8:20 **AAS 16-368** **Unscented Evolution Strategies for Solving Trajectory Optimization Problems**

Christopher McGrath, Naval Postgraduate School; Ronald Proulx, Naval Postgraduate School; Mark Karpenko, Naval Postgraduate School; Isaac M. Ross

This paper incorporates the unscented transform as part of an efficient evolution strategy for solving optimal control problems. The use of sigma points is shown to achieve superior performance when compared to an evolution strategy that uses classical random sampling as the basis for search. A suite of highly multimodal benchmark test problems is used to illustrate the performance of this new scheme which incorporates an annealing concept to further enhance performance. The new evolution strategy is then used to solve an optimal control problem from astrodynamics. The results of this paper illustrate a promising new concept in evolutionary computation

8:40 **AAS 16-385** **Interplanetary Parking Method and its Application to Dual Launch Trajectory Design**

Toshinori Ikenaga, Japan Aerospace Exploration Agency; Masayoshi Utashima, Japan Aerospace Exploration Agency; Nobuaki Ishii, Japan Aerospace Exploration Agency; Yasuhiro Kawakatsu, JAXA / ISAS; Makoto Yoshikawa, Japan Aerospace Exploration Agency; Ikkoh Funaki, Japan Aerospace Exploration Agency; Takahiro Iwata, Japan Aerospace Exploration Agency

The paper proposes a new type of low-thrust orbit design method, Interplanetary Parking Method that realizes anytime launch of deep-space explorers. The proposed method enables to make an Earth return orbit with an arbitrary time-of-flight connecting to the transfer orbit to a destination. While the time-of-flight of the transfer orbit is fixed, interplanetary parking orbit virtually eliminates the severe launch window constraint in interplanetary missions. As application of the proposed method, the paper demonstraits dual launch trajectory design of explorers to different destinations i.e., Mars and Venus. The proposed method will widen the scope of opportunity for interplanetary missions.

9:00 **AAS 16-408** **Optimal 3D Orbit Corrections in Curvilinear Coordinates**

Juan Luis Gonzalo, Technical University of Madrid (UPM); Claudio Bombardelli, Technical University of Madrid (UPM)

The minimum-time, constant-thrust orbit correction between two close non-coplanar orbits is studied using a new relative motion formulation in curvilinear coordinates. The associated optimal control problem in the thrust orientation is tackled using both direct and indirect methods. The former allows to numerically solve a diverse set of problems with changes in orbital radius, phasing and inclination, while the latter leads to a set of approximate analytical solutions for particular cases. Both analysis reveal fundamental changes in each component of the motion depending on the relation between the required displacement and the thrust magnitude.

9:20 **AAS 16-426** **From Low Thrust to Solar Sailing: a Homotopic Approach**

Nicola Sullo, University of Glasgow; Alessandro Peloni, University of Glasgow; Matteo Ceriotti

This paper describes a novel method to solve solar-sail minimum time-of-flight optimal control problem starting from a low-thrust solution. The method is based on a homotopic-continuation approach. This technique allows to link the low-thrust with the solar-sail acceleration, so that the solar-sail solution can be computed starting from the easier low-thrust one by means of a numerical iterative approach. Earth-to-Mars transfers have been studied in order to validate the proposed method. A comparison with a conventional heuristic-based approach is presented. The results show that the novel technique has advantages, in terms of accuracy of the solution and computational time.

9:40 **AAS 16-448** **Two-Impulse Evolutionary Optimization of Satellite Formations with Topological Constraints**

David Hinckley; Darren Hitt, University of Vermont

In this work we apply the evolutionary technique of Differential Evolution (DE) to topologically constrained trajectory optimization of a satellite formation limited to two-impulsive maneuvers. The motivation and constraints for the problem are drawn from NASA's Magnetospheric Multi-Scale Mission (MMS). In a previous work a DE-based optimization framework was developed for a single impulsive maneuver. This work aims to improve upon that work by expanding the search-space to include the additional degree of freedom allowed by a second maneuver. With this addition, greater adherence to the topological constraints as demanded by the scientific goals of the mission will be demonstrated.

10:00 **Thursday Morning Break**

10:20 **AAS 16-471** **Trajectory Optimization Under Uncertainty for Rendezvous in the CRTBP**

Juliana Feldhacker, University of Colorado at Boulder; Brandon Jones, The University of Texas at Austin; Alireza Doostan, University of Colorado Boulder

Polynomial regression models and polynomial chaos expansions (PCEs) are useful in the mapping of deterministic and stochastic system inputs, respectively, through complex dynamics such as nonlinear astrodynamic systems. By combining the two techniques, a single model can be developed to enable a method for trajectory optimization under uncertainty (OUU) that requires orders of magnitude fewer realizations of the full system dynamics than a Monte Carlo approach to the same problem. This paper considers OUU for the robust design of spacecraft rendezvous maneuvers in the Earth-Moon circular restricted three-body problem (CRTBP). Additional savings in the computational expense of generating the model are demonstrated through the use of compressive sampling.

10:40 AAS 16-476 Application of Modified Chebyshev Picard Iteration to Differential Correction for Improved Robustness and Computation Time

Travis Swenson, Stanford University; Robyn Woollands; John Junkins, Texas A&M University; Martin W. Lo, Caltech Department of Computing + Mathematical Sciences

A novel application of Modified Chebyshev Picard Iteration (MCPI) to differential correction is presented. By leveraging the Chebyshev basis functions of MCPI, interpolation in 1 dimension may be used to target plane crossing events, instead of integrating the 42 dimensional variational equation required for standard integrators. This results in dramatically improved performance over traditional differential correctors. MCPI was tested against Runge-Kutta 7/8 on over 45,000 halo orbits in three different three-body problems, and was found to be an order of magnitude faster, while simultaneously increasing robustness.

11:00 AAS 16-516 Orbital Element Continuous Thrust Maneuvers Using Modified Chebyshev Picard Iteration

Julie Read, Texas A&M University; Robyn Woollands; Tarek Elgohary, Texas A&M University; John Junkins, Texas A&M University

The present work solves for optimal continuous thrust (using an indirect method) and implements a set of Modified Equinoctial Orbital Elements (MEE) in place of cartesian coordinates, which has shown to converge over a much larger number of orbits using MCPI; for the IVP the convergence domain is increased from around 3 orbits to 17 orbits, for the fully spherical harmonic (40x40) gravity case. This is expected to lead to a larger convergence domain for the BVP; over 1 orbit is expected compared with about 1/3 orbit as shown previously for the cartesian case.

11:20 AAS 16-422 Global Search for Low-Thrust Transfers to the Moon in the Planar Circular Restricted Three-Body Problem

Kenta Oshima, Waseda University; Stefano Campagnola, JAXA / ISAS; Tomohiro Yanao, Waseda University

The present study globally searches low-thrust transfers to the Moon in the planar circular restricted three-body problem. For the purpose of reducing the dimensionality of parameters for efficient search, we make use of the necessary condition for optimality and the analogy with two-body dynamics on the initial orbit around the Earth within the framework of the indirect method. As a result, we obtain a wide range of Pareto solutions with respect to time of flight and mass consumption. Specifically, several solutions exploit invariant manifolds around the Lagrange point L1 and resonant lunar gravity assists to reduce fuel consumption.

11:40 AAS Global open-time optimization of fuel consumption in J2 rendezvous scenarios by the

16-226 method of interval analysis

Hongliang Ma, Beihang University

By introducing the first order solutions in J_2 developed from Lagrange's planetary equations, an open-time Lambert rendezvous problem with a parking time and a transfer time is proposed in this paper. The purpose of optimization is to determine the globally optimal parking time and transfer time and minimize the velocity increment for the orbital rendezvous. The global optimization method using interval analysis combining with gradient-based method is chosen to obtain a globally optimal solution for the discontinuous and nonconvex open-time Lambert rendezvous problem in J_2 effect with the perigee altitude and semimajor constraints of transfer orbit.

Feb 18, 2016 - Sauvignon

27 Space Situational Awareness 2

Chair: Marcus Holzinger

8:00 AAS 16-319 UCT Correlation using the Bhattacharrya Divergence

Islam Hussein, Applied Defense Solutions; ISLAM Hussein, Applied Defense Solutions; Matthew Wilkins, Applied Defense Solutions; Paul Schumacher, Air Force Research Laboratory

In this paper, we solve the UCT correlation problem, where we seek to use the Bhattacharrya divergence to associate a given set of UCTs with a given set of tracks. Both sets of UCTs and tracks are uncertain and are probabilistically described using multivariate normal distributions. This allows for a closed-form solution, based on the unscented transform and on the Bhattacharrya divergence. We demonstrate the main result in simulation for LEO, MEO, GTO, and GEO orbit regimes to show general applicability. We will also compare the performance of our proposed solution with the covariance-based track association (CBTA) algorithm.

8:20 AAS 16-266 Hardware-in-the-Loop Comparison of Space Object Detection and Tracking Methodologies

Shahzad Virani, Georgia Institute of Technology; Jared Lee, Georgia Institute of Technology; Lubna Zubair; Timothy Murphy, Georgia Institute of Technology; Marcus Holzinger, Georgia Institute of Technology; Brien Flewelling, Air Force Research Laboratory

Space Domain Awareness relies on a network of surveillance architectures to catalog passive and active space object data. This paper analyzes the performance of several detection and tracking algorithms using different hardware-in-the-loop test configurations. Several image sources are tested, including simulated images generated with the Hipparcos and Space Object catalogs, and real images taken from a Nocturn XL camera and the Georgia Tech Space Object Research Telescope. A Nearest Neighbor tracking algorithm has been implemented and tested, and future work includes implementing Multiple Hypothesis Tracking and Finite Set Statistics algorithms.

8:40 AAS 16-289 Space Object Collision Probability via Monte Carlo on the Graphics Processing Unit

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

A Graphics Processing Unit is used to reduce runtime by parallelizing a Monte Carlo (MC) collision probability computation. The MC simulation takes samples from the uncertainty distributions of the Space Objects (SOs) at any time during a time window of interest and computes the closest approaches using fixed step integration with interpolation. Any uncertainty propagation method may be used and the collision probability is automatically computed as a function of collision radius. Two orders of magnitude speedups over a serial CPU implementation are shown and improve moderately with higher fidelity dynamics, making the MC approach tractable on a single workstation.

9:00 **AAS 16-302** **FRAGMENTATION EVENT TRACKING WITH THE GM-CPHD FILTER**

Daniel Bryant, University of Colorado Boulder; Brandon Jones, The University of Texas at Austin

The tracking of space objects generated by fragmentation events has been a significant challenge for the space situational awareness community. In a multi-target framework, such events are ideally modeled as spawning processes and an implementation of the Cardinalized Probability Hypothesis Density (CPHD) filter has recently been derived for the explicit use of a spawning model. This paper presents the first application of the model to the tracking of space objects and demonstrates application of the CPHD filter to the tracking of fragmentation and similarly modeled events. Simulation results demonstrate the efficacy of the filter implementation for tracking low-Earth orbit objects.

9:20 **AAS 16-327** **Optimized Collision Avoidance of Spacecraft in Ultra Close Proximity for Failed Satellite**

Xiaoyu Chu, Beijing Institute of Technology; Jingrui Zhang; Fei Liu, School of Astronautics, Beijing Institute of Technology

This paper focuses on the trajectory planning in ultra close proximity for a failed satellite, particularly considering the configuration and dynamic state of the uncontrolled tumbling target. An algorithm is proposed for establishing a fuel-optimal path under the constraints that account for collision avoidance and boundary conditions. The optimal solution of the maneuvering problems is obtained by the Gauss Pseudospectral method (GPM). Meaningfully, a close loop control method is employed in tracking the optimal trajectory using feedback linearization to derive the truly optimal and dynamic one.

9:40 **AAS 16-366** **An Analytical Solution to Quick-Response Collision Avoidance Maneuvers in Low Earth Orbit**

Jason Reiter, The Pennsylvania State University; David Spencer, The Pennsylvania State University

Collision avoidance maneuvers are typically planned multiple days in advance. If the warning time is decreased to less than half-an-orbit in advance, the problem becomes more complex. Finite burn propagation was applied to determine the burn time required to reach a desired minimum collision probability. Determining the burn time for a wide range of orbits and spacecraft properties resulted in an analytical solution to the collision avoidance problem anywhere in low earth orbit. The speed at which this method can be applied makes it valuable when minimal time is available to perform such a maneuver.

10:00 **Thursday Morning Break**

10:20 **AAS 16-447** **Athena: A Data-Driven Anomaly Detection and Space Object Classification Tool for Space Situational Awareness**

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

We present 'Athena', a data-driven system we have developed for space object anomaly detection and classification using non-resolved photometric data (light-curves). The main techniques developed can be viewed as components of a machine learning pipeline, and include (i) feature extraction using ideas inspired by compressed sensing, (ii) unsupervised learning (via robust principal component analysis) for anomaly detection, (iii) supervised learning for object classification, and (iv) a unifying database that enables all of the above. This paper describes Athena and demonstrates several of its use cases on both real and simulated photometric data.

10:40 **AAS 16-455** **ComVecs: A Special Perturbations Covariance-Based Tool for Duplicate Orbit Identification**

Alan Segerman, Naval Research Laboratory; Aaron Hoskins, Naval Research Laboratory; Zachary Sibert, Naval Research Laboratory

In operational space situational awareness, duplicate representations of an orbit can sometimes be produced. To maintain the uniqueness of space object catalog entries, the operations centers have employed techniques for duplicate resolution that were developed prior to the widespread use of special perturbations catalog maintenance and the proliferation of closely located orbits. A new special perturbations duplicate identification tool has been developed that leverages the covariances from special perturbations orbit determination and uses the Mahalanobis distance between orbits as a metric. A full description of the tool is presented, along with test results using actual and simulated orbits.

11:00 **AAS 16-482** **Evidential Reasoning Applied to Single-Object Loss-of-Custody Scenarios for Telescope Tasking**

Andris Jaunzemis, Georgia Institute of Technology; Marcus Holzinger, Georgia Institute of Technology

Evidential reasoning and data fusion are applied to the single-object loss-of-custody scenario in ground-based tracking. Upon a missed observation, the cause of non-detection must be quickly understood to improve follow-up decision-making. Space domain awareness (SDA) sensors, including a brightness sensor and an All-Sky camera with an optical-flow-based cloud detection algorithm, are conditioned as Dempster-Shafer experts and used to assess the cause of a non-detection. Telescope re-tasking is also approached using Dempster-Shafer theory by planning the next observation to minimize an estimated lack-of-information. Results from real-world operational sensors show the algorithm's ability to adjust to changing observation conditions and re-task the primary electro-optical sensor accordingly.

11:20 **AAS 16-514** **Resident Space Object Shape Inversion via Adaptive Hamiltonian Markov Chain Monte Carlo**

Richard Linares, University of Minnesota; John Crassidis, University at Buffalo, State

University of New York

This paper presents a method to determine the shape of a space object while simultaneously recovering the observed space object's inertial orientation. This paper employs an Adaptive Hamiltonian Markov Chain Monte Carlo (AHMC) estimation approach, which uses light curve data to infer the space object's orientation, shape, and surface parameters. The AHMC approach estimates the full posterior probability distribution (pdf) by generating samples form the posterior. The AHMC estimation method is shown to work well for relatively high dimensionality of the light curve inversion problem while providing a non-Gaussian estimate of the posterior pdf.

11:40 **AAS 16-207** **Uncertain Angles-Only Track Initiation for SSA Using Different IOD Methods**

ISLAM Hussein, Applied Defense Solutions; Matthew Wilkins, Applied Defense Solutions; Islam Hussein, Applied Defense Solutions; Paul Schumacher, Air Force Research Laboratory

Uncertainty in initial orbit determination (IOD) resulting from sparse optical data is a topic of great interest in modern SSA. Uncertainty propagation has been investigated in detail for purposes of collision probability analysis, data association, and Bayesian estimation, but all of these investigations assume knowledge of the initial uncertainty. For optical observations with long arcs of data, uncertainty is usually assumed Gaussian. This paper continues previous work investigating characterization of uncertainty for short-arc data. Several examples are presented using the Gooding IOD method, with different observation geometries, measurement timings, and orbit parameters.

12:00 **AAS 16-306** **TLE Generation from Sparse Tracking Data and Its Performance**

Li Bin, Wuhan University; Sang Jizhang; Ning Jinsheng

Since TLE/SGP4 is widely used in many applications, so there is a need to generate TLE data from general orbit determination and prediction results. This paper presents a method of indirectly generating TLE which still uses SGP4 to propagate orbits. In the TLE generations, the numerically propagated positions are used as pseudo-observations. The positions residuals between the TLE-propagated orbits and numerically-propagated orbits are minimized in terms of the least-squares principle. Experiments with five satellites at different altitudes and sparse debris laser ranging data show that the two propagated orbits agree well within the expected error ranges.

Feb 18, 2016 - Chardonnay AB

28 Navigation

Chair: Kyle DeMars

8:00 **AAS 16-201** **ORION EXPLORATION FLIGHT TEST-1 (EFT-1) ABSOLUTE NAVIGATION PERFORMANCE**

Renato Zanetti, NASA JSC; Christopher D'Souza, NASA - Johnson Space Center; Greg Holt; Robert Gay, NASA JSC; Jastesh Sud, Lockheed Martin Space Systems

The Orion vehicle, being design to take men back to the Moon and beyond, successfully completed its first flight test, EFT-1 (Exploration Flight Test-1), on December 5th, 2014. The objective of this paper is to document the performance of the absolute navigation system during EFT-1 and to present its design.

8:20 **AAS 16-228** **Navigation and Statistical Delta-v Analysis for Double-satellite-aided Capture at Jupiter**

Alfred Lynam, West Virginia University; Alan Didion, West Virginia University

Double-satellite-aided capture substantially reduces a mission's deterministic delta-v by using gravity assists of two of Jupiter's massive Galilean moons in addition to a Jupiter orbit insertion (JOI) maneuver. The statistical delta-v savings of double-satellite-aided capture vs. single-satellite-aided capture is more difficult to characterize because they are strongly dependent on the specifics of navigation technologies and methodologies. In this paper, we estimate the statistical delta-v required to execute Ganymede-Io-JOI, Ganymede-Europa-JOI, and Callisto-Ganymede-JOI double-satellite-aided capture using a number of different navigation assumptions with varying degrees of conservatism.

8:40 **AAS 16-232** **Independent Navigation Team Contribution to New Horizons' Pluto System Flyby**

Paul Thompson, NASA / Caltech JPL; Shyam Bhaskaran, NASA / Caltech JPL; Dylan Boone, NASA / Caltech JPL; Stephen Broschart, NASA / Caltech JPL; Gerhard Kruizinga, NASA / Caltech JPL; William Owen, NASA / Caltech JPL; Tseng-Chan Wang, NASA / Caltech JPL

The New Horizons spacecraft made its closest approach to Pluto on July 14, 2015. The most significant challenge of this mission was that the Pluto system ephemeris was initially known with a precision of ~1000 km. This needed to be improved significantly on approach in order to meet the science requirements. During the final six months leading to the flyby, a JPL Independent Navigation (INAV) Team was included in the ephemeris knowledge update process as a cross-check on the Primary Navigation (PNAV) Team's results. This paper discusses the INAV team's experiences and challenges navigating New Horizons through the Pluto planetary

9:00 **AAS 16-401** **Extended Kalman Filter based Attitude and Drift estimation of a Lunar Lander using Star sensor and Gyroscope**

Deepana Gandhi, Team Indus; CHEERUDEEP CHINTHA, Axiom Research Labs Private Limited; Natarajan P; Karthic Balasubramanian, Team Indus

Team Indus GLXP Mission is to soft land on moon, traverse and send HD imaginary to earth. To accomplish this Team Indus strategy includes the design and realization of a lunar lander which would deliver rover to the lunar surface. The attitude is determined through star sensor and gyroscope. As time proceeds the gyroscope accumulates drift which represents major error input of Attitude Determination and Control System. This paper discusses a Multiplicative Extended Kalman Filter (MEKF) which overcomes the quaternion normalization pitfalls of Additive Extended Kalman Filter (AEKF) to estimate the gyroscope drift and attitude of the spacecraft.

9:20 **AAS 16-424** **Distributed Parameter System For Optimization and Filtering in Astrodynamic Software**

Jonathon Smith, Jet Propulsion Laboratory

The Mission Analysis, Operations, and Navigation Toolkit Environment (MONTE) is JPL's signature astrodynamic computing platform. It supports all phases of space mission development, from early stage mission design and analysis through flight navigation services. A central component of MONTE's optimization and filtering modules is its distributed parameter system, which allows partial derivatives to be computed for flexible sets of supported astrodynamic parameters on request. This paper outlines the object-oriented design MONTE uses for its parameter system, and provides concrete set of examples showing the power of this approach.

9:40 **AAS 16-441** **Parametric Covariance Model for Horizon-Based Optical Navigation**

Jacob Hikes, West Virginia University; John Christian, West Virginia University

Images of the Earth and Moon may be used to autonomously navigate a spacecraft in cislunar space. New optical navigation (OPNAV) techniques have revitalized interest in horizon-based methods. While the generation of precise OPNAV measurements is well understood, the measurement covariance can be rather cumbersome to compute in practice. This problem is addressed by developing a simple parametric covariance model that fully captures the geometry of measuring the lit horizon of an ellipsoidal. These simple models provide insight into the nature of the horizon-based OPNAV covariance that was previously obscured by long and difficult to understand equations.

10:00 **Thursday Morning Break**

10:20 **AAS 16-445** **Spacecraft Navigation using a Robust Multi-Sensor Fault Detection Scheme**

Samuel Haberberger; Kyle DeMars, Missouri University of Science and Technology

Redundant sensor networks of inertial measurement units (IMUs) provide inherent robustness and redundancy to a navigation solution obtained by dead reckoning the fused accelerations and angular velocities sensed by the IMU. However, IMUs have been known to experience faults risking catastrophic mission failure creating large financial setbacks and an increased risk of human safety. Robust on-board fault detection schemes are developed and analyzed for a multi-sensor distributed network specifically for IMUs. Simulations of a spacecraft are used to baseline several cases of sensor failure in a distributed network undergoing fusion to produce an accurate navigation solution.

10:40 **AAS 16-509** **Celestial Navigation Device for Future Autonomous Applications**

Thomas Fuller, University of New Hampshire; William Nitsch; May-Win Thein, University of New Hampshire

Determination of an extraterrestrial rover's latitude and longitude will be an essential part of the exploration of other planets. This paper presents a self contained, DSLR based celestial navigation device that is based on nautical sight reduction techniques. Also presented are simulation results for two different categories of observations, three stars sighted concurrently and a single star sighted at three different times. Finally experimental results and a calibration scheme are presented along with a discussions and analysis on possible improvements.

11:00 **AAS 16-442** **Preliminary Investigation in Interstellar Navigation Techniques**

Stoian Borissov, Texas A&M University; Daniele Mortari, Texas A&M University

The classic methods of position estimation become invalid once a spacecraft leaves the local vicinity of our solar system. Parallax starts to have an effect as near as 100 AU from Earth. In this paper we develop a new method of interstellar navigation based on identifying observed stars and measuring stellar parallax. This paper also surveys possible methods of interstellar navigation and weighs their effectiveness and feasibility. Specifically, the use of pulsars for interstellar navigation has been studied extensively and offers a baseline for comparing other position estimation methods.

11:20 **AAS 16-492** **An Optimization Based Approach to Correlation of Observations with Uncertainty**

Johnny Worthy; Marcus Holzinger, Georgia Institute of Technology; Daniel Scheeres, Colorado Center for Astrodynamics Research

If two admissible regions from disparate observations can be correlated then a initial orbit state estimate for the observation can be directly produced.
A novel measurement association method is shown which utilizes admissible regions to find a possible point of intersection for the admissible regions at a common time epoch by locating the minimum distance between the two sets.
A binary hypothesis test with selected false alarm rates is used to probabilistically determine whether an intersection exists at the point(s) of minimum distance.
An improved methodology for generating the joint distribution for several admissible region constraints is also shown.

11:40 **AAS 16-358** **Effect of Update Frequency on EKF and UKF Performance**

Paul Frontera, Naval Postgraduate School; Ronald Proulx, Naval Postgraduate School; Mark Karpenko, Naval Postgraduate School; Isaac M. Ross

Physical parameters often cannot be measured directly and must be estimated using available measurements. These measurements are often related to the unknown parameter by nonlinear kinematic equations. Nonlinear recursive estimation techniques, such as the Extended Kalman Filter (EKF) and the Unscented Kalman Filter (UKF), may be employed to estimate unmeasurable parameters using noisy measurement data. Each technique employs different approximation methods to allow the application of the linear Kalman Filter structure. This paper investigates the impact of measurement update frequency on EKF and UKF performance for parameter estimation.

12:00 **AAS 16-428** **Vision-Based Relative Navigation Using 3D Scale Space Theory**

Ashish Jagat, West Virginia University; John Christian, West Virginia University

Objects that are far away often appear small and unresolved in optical imagery. Conversely, objects appear fully resolved when closer. Thus, during an on-orbit rendezvous that begins far away and concludes with a docking, it is not uncommon for the relative navigation system to be challenged with processing unresolved, partially resolved, and fully resolved imagery. Fundamentally different techniques are used in the processing of unresolved and fully resolved objects. Therefore, this manuscript explores the use of scale space theory and multi-scale 3D modeling as a means for unifying the image processing approach across all scales during a complete spacecraft rendezvous sequence.

February 15, 2016

Session	Room	Doc. #	Presenter		Title
01 Attitude Determination	Pinot Noir BC	AAS 16-225	Tjorven Delabie	8:00 - 8:20	OPTIMIZATION OF A 3D PRINTED CUBESAT BAFFLE USING RAY TRACING
04 Spacecraft Autonomy	Chardonnay AB	AAS 16-309	Shiyuan Jia	8:00 - 8:20	MAINTAIN A LIBRATION POINT ORBIT IN THE SUN-MERCURY ELLIPTIC RESTRICTED SYSTEM
03 Spacecraft Dynamics	Sauvignon	AAS 16-299	Andrew Cox	8:00 - 8:20	TRANSFERS TO A SUN-EARTH SADDLE POINT: AN EXTENDED MISSION DESIGN OPTION FOR LISA PATHFINDER
02 Trajectory Optimization 1	Cabernet	AAS 16-247	Gao Tang	8:00 - 8:20	LOW-THRUST TRAJECTORY OPTIMIZATION OF MULTIPLE SPACECRAFT WITH COOPERATIVE MANEUVERS
01 Attitude Determination	Pinot Noir BC	AAS 16-287	Daniele Mortari	8:20 - 8:40	STAR CENTROID ON THE F-RADIUS SPHERE USING VON MISES-FISHER PROBABILITY DISTRIBUTION
04 Spacecraft Autonomy	Chardonnay AB	AAS 16-221	Joseph White	8:20 - 8:40	LDSD POST2 MODELING ENHANCEMENTS IN SUPPORT OF SFDT-2 FLIGHT OPERATIONS
03 Spacecraft Dynamics	Sauvignon	AAS 16-310	Juan Félix San-Juan	8:20 - 8:40	ALGEBRAIC MANIPULATORS: NEW PERSPECTIVES IN ANALYTICAL OR SEMI-ANALYTICAL SOLUTIONS TO ASTRODYNAMICS PROBLEMS
02 Trajectory Optimization 1	Cabernet	AAS 16-260	Mark Karpenko	8:20 - 8:40	DYNAMIC OPTIMIZATION FOR SATELLITE IMAGE COLLECTION
01 Attitude Determination	Pinot Noir BC	AAS 16-321	Marcio A. A. Fialho	8:40 - 9:00	IDEAS FOR MULTISPECTRAL CAMERAS WITH STACKED PIXELS FOR STAR TRACKING AND OPTICAL NAVIGATION

04 Spacecraft Autonomy	Chardonnay AB	AAS 16-217	Chris Karlgaard	8:40 - 9:00	SUPERSONIC FLIGHT DYNAMICS TEST 2: TRAJECTORY, ATMOSPHERE, AND AERODYNAMICS RECONSTRUCTION
03 Spacecraft Dynamics	Sauvignon	AAS 16-311	Juan Félix San-Juan	8:40 - 9:00	APPLICATION OF THE HYBRID METHODOLOGY TO SGP4
02 Trajectory Optimization 1	Cabernet	AAS 16-317	Javier Roa	8:40 - 9:00	INTRODUCING A DEGREE OF FREEDOM IN THE FAMILY OF GENERALIZED LOGARITHMIC SPIRALS
01 Attitude Determination	Pinot Noir BC	AAS 16-322	Marcio A. A. Fialho	9:00 - 9:20	THE BRAZILIAN AUTONOMOUS STAR TRACKER DEVELOPMENT.
04 Spacecraft Autonomy	Chardonnay AB	AAS 16-222	Soumyo Dutta	9:00 - 9:20	POST-FLIGHT ASSESSMENT OF LOW DENSITY SUPERSONIC DECELERATOR FLIGHT DYNAMICS TEST 2 SIMULATION
03 Spacecraft Dynamics	Sauvignon	AAS 16-332	Nicola Baresi	9:00 - 9:20	SURVEY OF NUMERICAL METHODS FOR COMPUTING QUASI-PERIODIC INVARIANT TORI IN ASTRODYNAMICS
02 Trajectory Optimization 1	Cabernet	AAS 16-323	Javier Roa	9:00 - 9:20	THREE-DIMENSIONAL GENERALIZED LOGARITHMIC SPIRALS
01 Attitude Determination	Pinot Noir BC	AAS 16-392	Ying Yang	9:20 - 9:40	ATTITUDE DETERMINATION FOR SATELLITE WITH NUTATION USING SINGLE ANTENNA GPS RECEIVER AND MEMS GYRO
04 Spacecraft Autonomy	Chardonnay AB	AAS 16-243	Sonia Hernandez	9:20 - 9:40	CASSINI MANEUVER EXPERIENCE THROUGH THE LAST ICY SATELLITE TARGETED FLYBYS OF THE MISSION
03 Spacecraft Dynamics	Sauvignon	AAS 16-484	Brian Anderson	9:20 - 9:40	DYNAMICS OF ASTEROID 2006 RH120: PRE-CAPTURE AND ESCAPE PHASES
02 Trajectory Optimization 1	Cabernet	AAS 16-427	Ahmad Bani Younes	9:20 - 9:40	AN ADAPTIVE APPROACH FOR MODIFFED CHEBYSHEV PICARD ITERATION

01 Attitude Determination	Pinot Noir BC	AAS 16-413	Sungkoo Bae	9:40 - 10:00	DISTORTION CORRECTION OF THE ICESAT STAR TRACKER DATA
04 Spacecraft Autonomy	Chardonnay AB	AAS 16-305	Sean Wagner	9:40 - 10:00	CASSINI MANEUVER PERFORMANCE ASSESSMENT AND EXECUTION-ERROR MODELING THROUGH 2015
03 Spacecraft Dynamics	Sauvignon	AAS 16-378	Kenta Oshima	9:40 - 10:00	MEDIUM-ENERGY, RETROGRADE, BALLISTIC TRANSFER TO THE MOON
02 Trajectory Optimization 1	Cabernet	AAS 16-519	Chit Hong Yam	9:40 - 10:00	FEASIBILITY REGIONS OF BOUNDARY VALUE PROBLEMS OF LOW-THRUST TRAJECTORIES

Morning Break 10:00 - 10:20

01 Attitude Determination	Pinot Noir BC	AAS 16-534	Ankit Jain	10:20 - 10:40	CHARACTERIZATION OF THE EFFECTIVE OUTPUT MAGNETIC FIELD OF A TRI-AXIAL SQUARE HELMHOLTZ CAGE
04 Spacecraft Autonomy	Chardonnay AB	AAS 16-412	David Surovik	10:20 - 10:40	REACTIVE ONLINE MISSION DESIGN AT SMALL BODIES
03 Spacecraft Dynamics	Sauvignon	AAS 16-312	Shiyuan Jia	10:20 - 10:40	MANEUVER AND VIBRATION SUPPRESSION OF FLEXIBLE MANIPULATORS FOR CAPTURING UNKNOWN OBJECTS USING VARIABLE-SPEED CONTROL MOMENT GYROS
02 Trajectory Optimization 1	Cabernet	AAS 16-227	Alfred Lynam	10:20 - 10:40	BROAD SEARCH FOR DIRECT TRAJECTORIES FROM EARTH TO DOUBLE-SATELLITE-AIDED CAPTURE AT JUPITER WITH DEEP SPACE MANEUVERS

01 Attitude Determination	Pinot Noir BC	AAS 16-543	Ajay Verma	10:40 - 11:00	SPACE BASED IR SENSOR MANAGEMENT FOR SITUATIONAL AWARENESS
04 Spacecraft Autonomy	Chardonnay AB	AAS 16-551	Erik Kroeker	10:40 - 11:00	MAGNETIC ATTITUDE CONTROL WITH AERODYNAMIC STABILIZATION FOR THE LAICE SATELLITE

03 Spacecraft Dynamics	Sauvignon	AAS 16-334	Shiyuan Jia	10:40 - 11:00	ACTIVE VIBRATION SUPPRESSION IN FLEXIBLE SPACECRAFT DURING ATTITUDE MANEUVER
02 Trajectory Optimization 1	Cabernet	AAS 16-367	Christopher McGrath	10:40 - 11:00	PARALLEL GENETIC ALGORITHMS FOR OPTIMAL CONTROL
01 Attitude Determination	Pinot Noir BC	AAS 16-348	Valdemir Carrara	11:00 - 11:20	ATTITUDE DETERMINATION AND CONTROL OF ITASAT CUBESAT
04 Spacecraft Autonomy	Chardonnay AB	AAS 16-454	Joel Mueting	11:00 - 11:20	1 OPTIMAL SLIDING GUIDANCE FOR EARTH-MOON HALO ORBIT STATION-KEEPING, TRANSFER, AND RENDEZVOUS
03 Spacecraft Dynamics	Sauvignon	AAS 16-379	Sichen Yuan	11:00 - 11:20	DESIGN AND OPTIMIZATION OF TENSION DISTRIBUTION FOR SPACE DEPLOYABLE MESH REFLECTORS
02 Trajectory Optimization 1	Cabernet	AAS 16-440	Mai Bando	11:00 - 11:20	ATTRACTIVE SET OF OPTIMAL FEEDBACK CONTROL FOR THE HILL THREE-BODY PROBLEM
01 Attitude Determination	Pinot Noir BC	AAS 16-374	Marcelino Mendes de Almeida	11:20 - 11:40	DISCRETE ADAPTIVE ANGULAR VELOCITY ESTIMATION - AN EXPERIMENTAL ANALYSIS
04 Spacecraft Autonomy	Chardonnay AB	AAS 16-329	Kenshiro Oguri	11:20 - 11:40	OPTIMAL ATTITUDE AND ORBITAL CONTROL STRATEGY OF SPINNING SOLAR SAIL SPACECRAFT VIA REFLECTIVITY CONTROL
03 Spacecraft Dynamics	Sauvignon	AAS 16-499	JoAnna Fulton	11:20 - 11:40	DYNAMICS AND CONTROL OF THE FLEXIBLE ELECTROSTATIC SAIL DEPLOYMENT
02 Trajectory Optimization 1	Cabernet	AAS 16-272	Jacob Englander	11:20 - 11:40	GLOBAL OPTIMIZATION OF N-MANEUVER, HIGH-THRUST TRAJECTORIES USING DIRECT MULTIPLE SHOOTING
01 Attitude Determination	Pinot Noir BC	AAS 16-397	Zhiqiang Zhou	11:40 - 12:00	SPACECRAFT DYNAMICS SHOULD BE CONSIDERED IN KALMAN FILTER BASED ATTITUDE ESTIMATION
04 Spacecraft Autonomy	Chardonnay AB	AAS 16-517	Robert Zidek	11:40 - 12:00	GEOSTATIONARY SATELLITE STATION KEEPING USING DRIFT COUNTERACTION OPTIMAL CONTROL

03 Spacecraft Dynamics	Sauvignon	AAS 16-547	Bo Fu	11:40 - 12:00	MECHANICS OF BOUNDED INEXTENSIBLE MEMBRANES SUBJECTED TO EXTERNAL FORCES
02 Trajectory Optimization 1	Cabernet	AAS 16-487	Joseph Eide	11:40 - 12:00	SOLVING SINGULAR ARC PROBLEMS WITH DIRECT COLLOCATION METHODS

Lunch Break 12:00 - 13:30

08 Dynamics and Perturbations 1	Chardonnay AB	AAS 16-342	Ahmad Bani Younes	13:30 - 13:50	HIGH-ORDER STATE TRANSITION TENSORS OF PERTURBED ORBITAL MOTION USING COMPUTATIONAL DIFFERENTIATION
07 Estimation	Sauvignon	AAS 16-399	Christopher Binz	13:30 - 13:50	DEVELOPMENT OF A SATELLITE GROUP TRACKING METHOD
06 Guidance and Control 1	Cabernet	AAS 16-391	Roberto Furfaro	13:30 - 13:50	ROBUSTIFICATION OF A CLASS OF GUIDANCE ALGORITHMS FOR PLANETARY LANDING: THEORY AND APPLICATIONS
05 Mission Design 1	Pinot Noir BC	AAS 16-257	Fernando Abilleira	13:30 - 13:50	FINAL MISSION AND NAVIGATION DESIGN FOR THE 2016 MARS INSIGHT MISSION

08 Dynamics and Perturbations 1	Chardonnay AB	AAS 16-461	Ahmad Bani Younes	13:50 - 14:10	HIGH-ORDER STATE TRANSITION TENSOR MODELS FOR THE UNCERTAINTY PROPAGATION OF PERTURBED ORBITAL MOTION
07 Estimation	Sauvignon	AAS 16-402	James McCabe	13:50 - 14:10	THE GAUSSIAN MIXTURE CONSIDER KALMAN FILTER
06 Guidance and Control 1	Cabernet	AAS 16-215	Kelly Smith	13:50 - 14:10	ORION ENTRY MONITOR

05 Mission Design 1	Pinot Noir BC	AAS 16-288	William Strauss	13:50 - 14:10	CONSTRUCTION OF SUPERSONIC FLIGHT DYNAMICS TEST VEHICLE MONTE CARLO SPLASHDOWN FOOTPRINTS FOR USE IN RANGE SAFETY AND RECOVERY OPERATIONS
08 Dynamics and Perturbations 1	Chardonnay AB	AAS 16-265	Mauro Massari	14:10 - 14:30	NONLINEAR UNCERTAINTY PROPAGATION IN ASTRODYNAMICS: COMPARING TAYLOR DIFFERENTIAL ALGEBRA WITH MONTE-CARLO ON GPUS
07 Estimation	Sauvignon	AAS 16-336	Trevor Bennett	14:10 - 14:30	RELATIVE MOTION ESTIMATION USING RECTILINEAR AND CURVILINEAR LINEARIZED RELATIVE ORBIT ELEMENTS
06 Guidance and Control 1	Cabernet	AAS 16-220	Jinjun Shan	14:10 - 14:30	REENTRY TRAJECTORY OPTIMIZATION UNDER THE EFFECTS OF UNCERTAIN ATMOSPHERIC DENSITY AND WIND FIELD
05 Mission Design 1	Pinot Noir BC	AAS 16-285	David Folta	14:10 - 14:30	THE LUNAR ICECUBE MISSION DESIGN: CONSTRUCTION OF FEASIBLE TRANSFER TRAJECTORIES WITH A CONSTRAINED DEPARTURE
08 Dynamics and Perturbations 1	Chardonnay AB	AAS 16-500	Patrick Kenneally	14:30 - 14:50	HIGH GEOMETRIC FIDELITY MODELING OF SOLAR RADIATION PRESSURE USING GRAPHICS PROCESSING UNIT
07 Estimation	Sauvignon	AAS 16-414	Sangjin Lee	14:30 - 14:50	ANALYTIC UNCERTAINTY PROPAGATION IN SATELLITE RELATIVE MOTION ALONG ELLIPTIC ORBITS
06 Guidance and Control 1	Cabernet	AAS 16-245	Piyush Mehta	14:30 - 14:50	SURROGATE MODEL FOR PROBABILISTIC MODELING OF ATMOSPHERIC ENTRY FOR SMALL NEOS
05 Mission Design 1	Pinot Noir BC	AAS 16-372	Makoto Horikawa	14:30 - 14:50	LOW ENERGY ESCAPE TRAJECTORY FOR THE MARS MOON SAMPLE RETURN MISSION

08 Dynamics and Perturbations 1	Chardonnay AB	AAS 16-520	Julie Read	14:50 - 15:10	MONTE CARLO PROPAGATION OF ORBITAL ELEMENTS USING MODIFIED CHEBYSHEV PICARD ITERATION
07 Estimation	Sauvignon	AAS 16-512	Laura Hebert	14:50 - 15:10	ANGLES-ONLY INITIAL RELATIVE-ORBIT DETERMINATION VIA SUCCESSIVE MANEUVERS
06 Guidance and Control 1	Cabernet	AAS 16-373	Kevin Lohan	14:50 - 15:10	MOVING-MASS ACTUATOR SYSTEM OPTIONS FOR ENTRY VEHICLES WITH DEPLOYABLE DECELERATORS
05 Mission Design 1	Pinot Noir BC	AAS 16-393	Ingo Althöfer	14:50 - 15:10	DYNAMIC STRATEGIES FOR MISSION LAUNCHES AND OTHER SCENARIOS RELATED TO SECRETARY PROBLEMS

Afternoon Break 15:10 - 15:30

08 Dynamics and Perturbations 1	Chardonnay AB	AAS 16-279	Dario Izzo	15:30 - 15:50	ON THE ASTRODYNAMICS APPLICATIONS OF WEIERSTRASS ELLIPTIC AND RELATED FUNCTIONS
07 Estimation	Sauvignon	AAS 16-530	Joshua Sullivan	15:30 - 15:50	IMPROVED MANEUVER-FREE APPROACH TO ANGLES-ONLY NAVIGATION FOR SPACE RENDEZVOUS
06 Guidance and Control 1	Cabernet	AAS 16-485	Jeremy Rea	15:30 - 15:50	ORION EXPLORATION MISSION ENTRY INTERFACE TARGET LINE
05 Mission Design 1	Pinot Noir BC	AAS 16-405	Kaori Onozaki	15:30 - 15:50	THE EARTH-MOON LOW-ENERGY TRANSFER IN THE 4-BODY PROBLEM

08 Dynamics and Perturbations 1	Chardonnay AB	AAS 16-301	Gregory Lemieux	15:50 - 16:10	SSL COMMERCIAL GEOSYNCHRONOUS SPACECRAFT ORBIT RAISING CONSIDERATIONS

07 Estimation	Sauvignon	AAS 16-341	Daniele Mortari	15:50 - 16:10	MOON AND EARTH IMAGE PROCESSING USING ASYMMETRIC 2-DIMENSIONAL FUNCTIONS ON IMAGE GRADIENT
06 Guidance and Control 1	Cabernet	AAS 16-491	Piyush Mehta	15:50 - 16:10	MULTI-FIDELITY UNCERTAINTY QUANTIFICATION FOR ATMOSPHERIC RE-ENTRY USING HIGH DIMENSIONAL MODEL REPRESENTATION
05 Mission Design 1	Pinot Noir BC	AAS 16-418	Geraldo Oliveira	15:50 - 16:10	TRANSFERS BETWEEN THE LAGRANGIAN POINTS AND THE PRIMARIES CONSIDERING RADIATION PRESSURE
08 Dynamics and Perturbations 1	Chardonnay AB	AAS 16-313	Sergei Tanygin	16:10 - 16:30	GPU-ACCELERATED COMPUTATION OF SRP AND DRAG FORCES AND TORQUES WITH GRAPHICAL ENCODING OF SURFACE NORMALS
07 Estimation	Sauvignon	AAS 16-489	Aaron Burgart	16:10 - 16:30	AN UPDATE TO THE THEMIS THERMAL GAUGING FUEL ESTIMATION PROCESS AND ITS USE IN A FUEL IMBALANCE ANOMALY
06 Guidance and Control 1	Cabernet	AAS 16-504	Paolo Lunghi	16:10 - 16:30	SEMI-ANALYTICAL ADAPTIVE GUIDANCE COMPUTATION BASED ON DIFFERENTIAL ALGEBRA FOR AUTONOMOUS PLANETARY LANDING
05 Mission Design 1	Pinot Noir BC	AAS 16-467	Rohan Sood	16:10 - 16:30	L4, L5 SOLAR SAIL TRANSFERS AND TRAJECTORY DESIGN: SOLAR OBSERVATIONS AND POTENTIAL EARTH TROJAN EXPLORATION
08 Dynamics and Perturbations 1	Chardonnay AB	AAS 16-351	Hodei Urrutxua	16:30 - 16:50	QUANTIFICATION OF THE PERFORMANCE OF NUMERICAL ORBIT PROPAGATORS
07 Estimation	Sauvignon	AAS 16-423	Daniel Lubey	16:30 - 16:50	STATE ESTIMATION AND MANEUVER RECONSTRUCTION WITH THE NONLINEAR ADAPTIVE OPTIMAL CONTROL BASED ESTIMATOR
06 Guidance and Control 1	Cabernet	AAS 16-410	Theodore Wahl	16:30 - 16:50	AUTONOMOUS GUIDANCE ALGORITHM FOR MULTIPLE SPACECRAFT AND FORMATION RECONFIGURATION MANEUVERS

05 Mission Design 1	Pinot Noir BC	AAS 16-493	Pedro J. Llanos	16:30 - 16:50	COMMERCIAL CUBESAT TECHNOLOGY TO ENHANCE SCIENCE: COMMUNICATIONS, SPACE DEBRIS IDENTIFICATION, AND MOON SURFACE RECONNAISSANCE USING LAGRANGIAN CYCLERS

February 16, 2016

February 16

Session	Room	Doc. #	Presenter		Title
09 Attitude Dyn. and Contr. 1	Pinot Noir BC	AAS 16-290	Sergei Tanygin	8:00 - 8:20	FAST AUTONOMOUS THREE-AXIS CONSTRAINED ATTITUDE PATHFINDING AND VISUALIZATION FOR BORESIGHT ALIGNMENT
11 Mission Design 2	Sauvignon	AAS 16-326	Xiaoyu Chu	8:00 - 8:20	TRAJECTORY PLANNING FOR MULTI-ARM SPACE WALKING ROBOT
10 Orbital Debris and Space Env.	Cabernet	AAS 16-233	Daniel Oltrogge	8:00 - 8:20	USING SPACE POPULATION MODELS TO GENERATE REPRESENTATIVE SPACE OBJECT CATALOGS
12 Satellite Constellations	Chardonnay AB	AAS 16-203	Thomas Lang	8:00 - 8:20	AN "ADJACENT SWATH" METHOD TO DESIGN EFFICIENT LEO CONSTELLATIONS
09 Attitude Dyn. and Contr. 1	Pinot Noir BC	AAS 16-325	Fei Liu	8:20 - 8:40	CONSTRAINT FORCE ALGORITHM FOR DYNAMICS MODELING OF MULTIBODY SPACECRAFT IN ARBITRARY TOPOLOGY
11 Mission Design 2	Sauvignon	AAS 16-488	Michele Lavagna	8:20 - 8:40	EARTH-MOON MULTIPURPOSE ORBITING INFRASTRUCTURE
10 Orbital Debris and Space Env.	Cabernet	AAS 16-240	David Gondelach	8:20 - 8:40	REENTRY PREDICTION OF SPENT ROCKET BODIES IN GTO
12 Satellite Constellations	Chardonnay AB	AAS 16-218	James Wilson	8:20 - 8:40	OPERATIONAL CONSIDERATIONS FOR SATELLITE CONSTELLATIONS IN TUNDRA ORBITS

09 Attitude Dyn. and Contr. 1	Pinot Noir BC	AAS 16-337	Joshua Baculi	8:40 - 9:00	FUZZY ATTITUDE CONTROL OF SOLAR SAIL WITH TRANSLATING CONTROL MASSES VIA LINEAR MATRIX INEQUALITIES
11 Mission Design 2	Sauvignon	AAS 16-208	Gabe D. Rogers	8:40 - 9:00	NEW HORIZONS TRAJECTORY CORRECTION MANEUVER FLIGHT IMPLEMENTATION AND PERFORMANCE
10 Orbital Debris and Space Env.	Cabernet	AAS 16-254	Eleonora Botta	8:40 - 9:00	EVALUATION OF NET CAPTURE OF SPACE DEBRIS IN MULTIPLE MISSION SCENARIOS
12 Satellite Constellations	Chardonnay AB	AAS 16-224	David Arnas	8:40 - 9:00	CORRECTIONS ON REPEATING GROUND-TRACK ORBITS AND THEIR APPLICATIONS IN SATELLITE CONSTELLATION DESIGN
09 Attitude Dyn. and Contr. 1	Pinot Noir BC	AAS 16-340	Li Jingjin	9:00 - 9:20	STRATEGY AND ALGORITHM STUDY ON EVASION OF INCIDENT LIGHT OF SUN AND MOON FOR STAR TRACKER
11 Mission Design 2	Sauvignon	AAS 16-259	Dale Stanbridge	9:00 - 9:20	NEW HORIZONS PLUTO ENCOUNTER MANEUVER PLANNING AND ANALYSIS
10 Orbital Debris and Space Env.	Cabernet	AAS 16-278	Lorenzo Casalino	9:00 - 9:20	MISSION DESIGN AND DISPOSAL METHODS COMPARISON FOR THE REMOVAL OF MULTIPLE DEBRIS
12 Satellite Constellations	Chardonnay AB	AAS 16-271	Lake Singh	9:00 - 9:20	REDUCING WALL-CLOCK TIME OF METAHEURISTIC-DRIVEN CONSTELLATION DESIGN WITH COARSE PARAMETRIC MAPPING
09 Attitude Dyn. and Contr. 1	Pinot Noir BC	AAS 16-352	Sungpil Yang	9:20 - 9:40	DYNAMICALLY SCALED IMMERSION AND INVARIANCE APPROACH FOR SPACECRAFT ATTITUDE TRACKING CONTROL

11 Mission Design 2	Sauvignon	AAS 16-419	Frederic Pelletier	9:20 - 9:40	NEW HORIZONS ORBIT DETERMINATION PERFORMANCE DURING APPROACH AND FLYBY OF THE PLUTO SYSTEM
10 Orbital Debris and Space Env.	Cabernet	AAS 16-330	Suping Zhao	9:20 - 9:40	MULTI-GOAL-BASED COLLISION AVOIDANCE PATH PLANNING FOR REDUNDANT SPACE ROBOT
12 Satellite Constellations	Chardonnay AB	AAS 16-360	Sung Wook Paek	9:20 - 9:40	SATELLITE CONSTELLATION DESIGN FOR THE SOLVE MISSION INVESTIGATING DIURNAL CYCLES OF VEGETATION PHENOMENA

09 Attitude Dyn. and Contr. 1	Pinot Noir BC	AAS 16-354	Josep Virgili llop	9:40 - 10:00	USING SHIFTING MASSES TO REJECT AERODYNAMIC PERTURBATIONS AND TO MAINTAIN A STABLE ATTITUDE IN VERY LOW EARTH ORBIT.
11 Mission Design 2	Sauvignon	AAS 16-359	Josh Freeh	9:40 - 10:00	MISSION DESIGN CONSIDERATIONS FOR MARS CARGO OF THE HAT EMC
10 Orbital Debris and Space Env.	Cabernet	AAS 16-386	Qiuyue Luo	9:40 - 10:00	ON INTERCEPTING A TUMBLING TARGET BY A SPACE ROBOT USING A DEVELOPED NAVIGATION GUIDANCE METHOD
12 Satellite Constellations	Chardonnay AB	AAS 16-469	Yury Razoumny	9:40 - 10:00	EMULATING OF THE STATIONARY OBSERVATION OF THE EARTH LOCAL REGION USING LOCALLY GEOSTATIONARY ELLIPTIC ORBITS

Morning Break 10:00 - 10:20

09 Attitude Dyn. and Contr. 1	Pinot Noir BC	AAS 16-398	Dongeun Seo	10:20 - 10:40	ATTITUDE CONTROL ACTUATOR DESIGN WITH MAGNETORHEOLOGICAL FLUID RINGS
11 Mission Design 2	Sauvignon	AAS 16-361	Arnaud Boutonnet	10:20 - 10:40	JUPITER TOUR OF THE JUPITER ICY MOON EXPLORER

10 Orbital Debris and Space Env.	Cabernet	AAS 16-406	Noble Hatten	10:20 - 10:40	A SMOOTH AND ROBUST HARRIS-PRIESTER ATMOSPHERIC DENSITY MODEL
12 Satellite Constellations	Chardonnay AB	AAS 16-490	Yury Razoumny	10:20 - 10:40	METHOD FOR CONSTELLATION DESIGN FOR EARTH PERIODIC COVERAGE USING COMPOUND SATELLITE STRUCTURES ON ORBITS WITH SYNCHRONIZED NODAL REGRESSION
09 Attitude Dyn. and Contr. 1	Pinot Noir BC	AAS 16-429	Ahmad Bani Younes	10:40 - 11:00	ATTITUDE ERROR KINEMATICS: APPLICATIONS IN CONTROL
11 Mission Design 2	Sauvignon	AAS 16-494	Kartik Kumar	10:40 - 11:00	PRELIMINARY TRAJECTORY DESIGN FOR A MULTI-TARGET ACTIVE DEBRIS REMOVAL MISSION USING THE ATOM SOLVER
10 Orbital Debris and Space Env.	Cabernet	AAS 16-416	Antonella Albuja	10:40 - 11:00	ROTATIONAL DYNAMICS OF THE GOES 8 AND GOES 10 SATELLITES DUE TO THE YORP EFFECT
12 Satellite Constellations	Chardonnay AB	AAS 16-298	Daniele Mortari	10:40 - 11:00	THE THEORY OF LATTICE FLOWER FORMATIONS AND ITS APPLICATION TO INTENSITY CORRELATION INTERFEROMETRY
09 Attitude Dyn. and Contr. 1	Pinot Noir BC	AAS 16-451	Dmitriy Rivkin	11:00 - 11:20	MINIMUM ENERGY, REACTION-WHEEL BASED, CUBESAT ATTITUDE CONTROL: A COMPARION OF COST FUNCTIONS
11 Mission Design 2	Sauvignon	AAS 16-231	Simon Tardivel	11:00 - 11:20	INTERPLANETARY NANOSPACECRAFT TRAVEL CAPABILITIES
10 Orbital Debris and Space Env.	Cabernet	AAS 16-430	Liam Healy	11:00 - 11:20	STRUCTURE AND EVOLUTION OF A DEBRIS CLOUD IN THE EARLY PHASES
12 Satellite Constellations	Chardonnay AB	AAS 16-253	Sofya Spiridonova	11:00 - 11:20	A GNC SIMULATION OF A FAR-RANGE APPROACH TOWARDS A TARGET IN NEAR-GEOSTATIONARY ORBIT
09 Attitude Dyn. and Contr. 1	Pinot Noir BC	AAS 16-472	Philip Chow	11:20 - 11:40	AUTOMATED SPHERE GEOMETRY OPTIMIZATION FOR THE VOLUME MULTI-SPHERE METHOD

11 Mission Design 2	Sauvignon	AAS 16-237	Mark Jesick	11:20 - 11:40	MAVEN NAVIGATION OVERVIEW
10 Orbital Debris and Space Env.	Cabernet	AAS 16-474	Felix Hoots	11:20 - 11:40	SATELLITE BREAKUP DEBRIS CLOUD MODEL
12 Satellite Constellations	Chardonnay AB	AAS 16-347	Mohamed Shouman	11:20 - 11:40	CONTROL OF HIGH FIDELITY LINEARIZED MODEL FOR SATELLITE FORMATION FLIGHT USING AERODYNAMIC DRAG
09 Attitude Dyn. and Contr. 1	Pinot Noir BC	AAS 16-515	Richard Linares	11:40 - 12:00	DYNAMIC OBSERVABILITY ANALYSIS FOR ATTITUDE, ANGULAR VELOCITY, SHAPE, AND SURFACE PARAMETERS
11 Mission Design 2	Sauvignon	AAS 16-277	Dario Izzo	11:40 - 12:00	REINFORCEMENT LEARNING FOR SPACECRAFT MANEUVERING NEAR SMALL BODIES
10 Orbital Debris and Space Env.	Cabernet	AAS 16-437	Christoph Bamann	11:40 - 12:00	A PARTICLE FILTER FOR ORBIT DETERMINATION OF SPACE DEBRIS BASED ON MONO- AND MULTI-STATIC LASER RANGING
12 Satellite Constellations	Chardonnay AB	AAS 16-478	Michele Lavagna	11:40 - 12:00	FORMATION FLYING CONCEPT FOR BI-STATIC SAR MAPPING OF TITAN SURFACE
10 Orbital Debris and Space Env.	Cabernet	AAS 16-465	Camilla Colombo	12:00 - 12:20	SPATIAL DENSITY APPROACH FOR MODELLING OF THE SPACE DEBRIS POPULATION
12 Satellite Constellations	Chardonnay AB	AAS 16-363	Diogene Alessandro Dei Tos	12:00 - 12:20	A NOTE ON A GEOMETRICAL METHOD TO SOLVE SPACECRAFT FORMATION FLYING CONTROL

Lunch Break 12:20 - 13:30

16 Asteroid and non-Earth Orbiting Missions 1	Chardonnay AB	AAS 16-219	Simon Tardivel	13:30 - 13:50	THE DEPLOYMENT OF MASCOT-2 TO DIDYMOON

13 Attitude Dynamics and Control 2	Pinot Noir BC	AAS 16-462	Luc Sagnières	13:30 - 13:50	STOCHASTIC MODELING OF HYPERVELOCITY IMPACTS ON ATTITUDE PROPAGATION OF SPACE DEBRIS
14 Dynamics: Models	Cabernet	AAS 16-276	Takahiro Kato	13:30 - 13:50	EXTENDED ANALYSIS ON THE FREE-MOLECULAR FLOW EFFECTS ON A GRACE-LIKE SATELLITE
15 Orbit Determination	Sauvignon	AAS 16-364	Yosuke Kawabata	13:30 - 13:50	ON-BOARD ORBIT DETERMINATION USING SUN SENSOR AND OPTICAL NAVIGATION CAMERA FOR INTERPLANETARY TRAJECTORY
16 Asteroid and non-Earth Orbiting Missions 1	Chardonnay AB	AAS 16-242	Ben Zimmerman	13:50 - 14:10	A GPU-ACCELERATED MULTIPHASE COMPUTATIONAL TOOL FOR ASTEROID PULVERIZATION AND ORBITAL DISPERSION SIMULATION
13 Attitude Dynamics and Control 2	Pinot Noir BC	AAS 16-498	Dae Young Lee	13:50 - 14:10	DEVELOPMENT OF CUBESAT ATTITUDE DETERMINATION AND CONTROL SYSTEM WITH HYBRID CONTROL STRATEGY AND ITS SIMULATOR ON SO(3)
14 Dynamics: Models	Cabernet	AAS 16-282	Benny Rievers	13:50 - 14:10	ADVANCED THERMAL RADIATION PRESSURE MODELING AND ITS BENEFITS FOR THE MICROSCOPE MISSION
15 Orbit Determination	Sauvignon	AAS 16-475	Corwin Olson	13:50 - 14:10	PRECOMPUTING PROCESS NOISE FOR ONBOARD SEQUENTIAL FILTERS
16 Asteroid and non-Earth Orbiting Missions 1	Chardonnay AB	AAS 16-274	Nickolas Sabey	14:10 - 14:30	TWO BODY FORMULATION FOR MODELING TETHER-BALLAST ASTEROID DIVERSION SYSTEMS
13 Attitude Dynamics and Control 2	Pinot Noir BC	AAS 16-458	Ahmad Bani Younes	14:10 - 14:30	ATTITUDE ERROR KINEMATICS: APPLICATIONS IN ESTIMATION

14 Dynamics: Models	Cabernet	AAS 16-308	Stefano Casotto	14:10 - 14:30	CARTESIAN DEVELOPMENT OF THE GRAVITATIONAL POTENTIAL WITHIN THE HOTINE SPHERE
15 Orbit Determination	Sauvignon	AAS 16-256	Todd Ely	14:10 - 14:30	PRELIMINARY INVESTIGATION OF ON-BOARD ORBIT DETERMINATION USING DEEP SPACE ATOMIC CLOCK BASED RADIO TRACKING

16 Asteroid and non-Earth Orbiting Missions 1	Chardonnay AB	AAS 16-320	Diogo Sanchez	14:30 - 14:50	ON THE DYNAMICS OF A SPACECRAFT IN THE IRREGULAR HAUMEA-HI’IAKA BINARY SYSTEM
13 Attitude Dynamics and Control 2	Pinot Noir BC	AAS 16-511	Pitcha Prasitmeeboom	14:30 - 14:50	REPETITIVE CONTROL USING REAL TIME FREQUENCY RESPONSE UPDATES FOR ROBUSTNESS TO PARASITIC POLES
14 Dynamics: Models	Cabernet	AAS 16-331	Satoshi Ikari	14:30 - 14:50	A NOVEL SEMI-ANALYTICAL SOLAR RADIATION PRESSURE MODEL WITH THE SHADOW EFFECT FOR SPACECRAFT OF COMPLEX SHAPE
15 Orbit Determination	Sauvignon	AAS 16-258	Jill Seubert	14:30 - 14:50	DEEP SPACE ATOMIC CLOCK TECHNOLOGY DEMONSTRATION MISSION ON-BOARD NAVIGATION ANALOG EXPERIMENT

16 Asteroid and non-Earth Orbiting Missions 1	Chardonnay AB	AAS 16-371	Stefaan Van wal	14:50 - 15:10	THE LIFT-OFF VELOCITY ON SOLAR SYSTEM SMALL BODIES
13 Attitude Dynamics and Control 2	Pinot Noir BC	AAS 16-532	Jianzhong Zhu	14:50 - 15:10	CROSS FERTILIZATION BETWEEN ITERATIVE LEARNING CONTROL AND REPETITIVE CONTROL
14 Dynamics: Models	Cabernet	AAS 16-338	James Miller	14:50 - 15:10	A NEW KINETIC THEORY OF PARTICLE COLLISIONS
15 Orbit Determination	Sauvignon	AAS 16-344	Bong Wie	14:50 - 15:10	ON SELECTING THE CORRECT ROOT OF ANGLES-ONLY INITIAL ORBIT DETERMINATION EQUATIONS OF LAPLACE AND GAUSS

Afternoon Break 15:10 - 15:30

16 Asteroid and non-Earth Orbiting Missions 1	Chardonnay AB	AAS 16-387	Bruno Sarli	15:30 - 15:50	LOW-THRUST TRAJECTORY DESIGN FOR THE DESTINY MISSION TO 3200 PHAETHON
13 Attitude Dynamics and Control 2	Pinot Noir BC	AAS 16-540	Bing Song	15:30 - 15:50	INCREASING SPEED OF TRACKING IN ITERATIVE LEARNING AND REPETITIVE CONTORL USING MARKOV PARAMETER / ADAPTIVE UPDATES
14 Dynamics: Models	Cabernet	AAS 16-483	Jules Simo	15:30 - 15:50	POTENTIAL EFFECTS OF A REALISTIC SOLAR SAIL AND COMPARISON TO AN IDEAL SAIL
15 Orbit Determination	Sauvignon	AAS 16-349	Arvind Kaushik	15:30 - 15:50	A COMPARISON BETWEEN GIBBS AND HERRICK-GIBBS ORBIT DETERMINATION METHODS

16 Asteroid and non-Earth Orbiting Missions 1	Chardonnay AB	AAS 16-439	Samantha Rieger	15:50 - 16:10	ORBITAL STABILITY REGIONS FOR HYPOTHETICAL NATURAL SATELLITES OF 101955 BENNU (1999 RQ36)
13 Attitude Dynamics and Control 2	Pinot Noir BC	AAS 16-541	Christopher Hashem	15:50 - 16:10	MODIFIED HYBRID MODELING TECHNIQUE FOR FLEXIBLE SPIN-STABILIZED SPACECRAFT APPLIED TO NASA'S MAGNETOSPHERIC MULTISCALE (MMS) MISSION TABLESAT GENERATION IC (TABLESAT IC)
14 Dynamics: Models	Cabernet	AAS 16-508	Edward Levine	15:50 - 16:10	THE EFFECT OF TIDAL FORCES ON THE EVOLUTION OF MINIMUM ENERGY CONFIGURATIONS OF THE FULL THREE-BODY PROBLEM
15 Orbit Determination	Sauvignon	AAS 16-477	Ryan Handzo	15:50 - 16:10	SATELLITE NAVIGATION IN CIS-LUNAR SPACE USING HIGH DEFINITION TELEVISION SIGNALS

16 Asteroid and non-Earth Orbiting Missions 1	Chardonnay AB	AAS 16-450	Stephanie Wood	16:10 - 16:30	POLYHEDRAL POTENTIAL MODELS FOR CLOSE PROXIMITY ORBITAL SIMULATIONS ABOUT SMALL CELESTIAL OBJECTS
13 Attitude Dynamics and Control 2	Pinot Noir BC	AAS 16-549	- Vedant	16:10 - 16:30	HARDWARE IN LOOP SIMULATION FOR ATTITUDE DETERMINATION AND CONTROL OF ILLINISAT-2 BUS
14 Dynamics: Models	Cabernet	AAS 16-314	Scott Silver	16:10 - 16:30	SEMI-ANALYTIC ELECTRODYNAMIC TETHER GUIDANCE USING ROTATING DIPOLE MODEL OF EARTH
15 Orbit Determination	Sauvignon	AAS 16-236	Roberto Armellin	16:10 - 16:30	PROBABILISTIC INITIAL ORBIT DETERMINATION
16 Asteroid and non-Earth Orbiting Missions 1	Chardonnay AB	AAS 16-502	Sumita Nandi	16:30 - 16:50	INITIAL NAVIGATION ANALYSIS FOR THE EUROPA MULTIPLE FLYBY MISSION
13 Attitude Dynamics and Control 2	Pinot Noir BC	AAS 16-503	Mohammad Abdelrahman	16:30 - 16:50	STABILIZATION OF A SATELLITE WITH A MOVING ANTENNA FOR A RELAY SATELLITE TRACKING DURING IMAGING SESSION
14 Dynamics: Models	Cabernet	AAS 16-444	Hodei Urrutxua	16:30 - 16:50	EXPLORATION OF NON-CONVENTIONAL TECHNIQUES FOR THE GENERATION OF ELEMENT-BASED ANALYTICAL EPHEMERIDES
15 Orbit Determination	Sauvignon	AAS 16-380	Tomohiro Narumi	16:30 - 16:50	ROBUST ON-ORBIT OPTICAL POSITION DETERMINATION OF NON-COOPERATIVE SPACECRAFT

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Session	Room	Doc. #	Presenter		Title
18 Asteroid and non-Earth Orbiting	Cabernet	AAS 16-229	Julian Niedling	8:00 - 8:20	DEVELOPMENT OF A TOOL FOR ANALYZING ORBITS AROUND ASTEROIDS

Missions 2					
19 Guidance and Control 2	Sauvignon	AAS 16-205	xinglong LI	8:00 - 8:20	THE CONTROL STRATEGY OF TERMINAL CORRECTION PROJECTILE BASED ON THE TRACK OF LASER SPOT
17 Space Situational Awareness 1	Pinot Noir BC	AAS 16-210	David Hyland	8:00 - 8:20	SPACE BORNE IMAGING VIA NOISE FILTERING PHASE RETRIEVAL
20 Trajectory Optimization 2	Chardonnay AB	AAS 16-417	Etienne Pellegrini	8:00 - 8:20	A MULTIPLE-SHOOTING DIFFERENTIAL DYNAMIC PROGRAMMING ALGORITHM
18 Asteroid and non-Earth Orbiting Missions 2	Cabernet	AAS 16-250	Siamak Hesar	8:20 - 8:40	ANALYSIS OF SOLAR RADIATION PRESSURE EFFECTS ON THE OSIRIS-REX SPACECRAFT IN ORBIT AROUND BENNU
19 Guidance and Control 2	Sauvignon	AAS 16-318	Hongwei Yang	8:20 - 8:40	FINITE-TIME CONTROL FOR FLIGHT CLOSE TO ASTEROIDS VIA TERMINAL SLIDING-MODE GUIDANCE
17 Space Situational Awareness 1	Pinot Noir BC	AAS 16-241	Matthew Hejduk	8:20 - 8:40	APPROACHES TO EVALUATE PROBABILITY OF COLLISION UNCERTAINTY
20 Trajectory Optimization 2	Chardonnay AB	AAS 16-481	Sergey Trofimov	8:20 - 8:40	PARAMETRIC ANALYSIS OF LOW-THRUST LUNAR TRANSFERS WITH RESONANT ENCOUNTERS
18 Asteroid and non-Earth Orbiting Missions 2	Cabernet	AAS 16-281	Takanao Saiki	8:40 - 9:00	STUDY ON IMPACT EXPERIENCE OF HAYABUSA2 MISSION
19 Guidance and Control 2	Sauvignon	AAS 16-345	Jaemyung Ahn	8:40 - 9:00	PRECISION ZEM/ZEV GUIDANCE ALGORITHM UTILIZING VINTI'S ANALYTIC SOLUTION OF PERTURBED KEPLER PROBLEM
17 Space Situational Awareness 1	Pinot Noir BC	AAS 16-267	George Vardaxis	8:40 - 9:00	IMPACT RISK ANALYSIS OF NEAR-EARTH ASTEROIDS WITH MULTIPLE SUCCESSIVE EARTH ENCOUNTERS

20 Trajectory Optimization 2	Chardonnay AB	AAS 16-523	Ricardo Restrepo	8:40 - 9:00	THE SHADOW TRAJECTORY MODEL FOR FAST LOW-THRUST INDIRECT OPTIMIZATION
18 Asteroid and non-Earth Orbiting Missions 2	Cabernet	AAS 16-293	Shota Kikuchi	9:00 - 9:20	DELTA-V ASSISTED PERIODIC ORBITS AROUND SMALL BODIES
19 Guidance and Control 2	Sauvignon	AAS 16-388	Jun'ichiro Kawaguchi	9:00 - 9:20	A STUDY ON DECENTRALIZED AND PARALLEL CONTROL SCHEME IN FORMATION FLIGHT AND SPACECRAFT SYSTEMS
17 Space Situational Awareness 1	Pinot Noir BC	AAS 16-303	Pradipto Ghosh	9:00 - 9:20	SPACE EVENT DETECTION VIA ROBUST TIME SERIES FORECASTING
20 Trajectory Optimization 2	Chardonnay AB	AAS 16-526	Jonathan Aziz	9:00 - 9:20	HYBRID DIFFERENTIAL DYNAMIC PROGRAMMING WITH STOCHASTIC SEARCH
18 Asteroid and non-Earth Orbiting Missions 2	Cabernet	AAS 16-286	Michael Shoemaker	9:20 - 9:40	PERFORMANCE CHARACTERIZATION OF A LANDMARK MEASUREMENT SYSTEM FOR ARRM TERRAIN RELATIVE NAVIGATION
19 Guidance and Control 2	Sauvignon	AAS 16-411	Joshua Lyzhoft	9:20 - 9:40	HYPERVELOCITY TERMINAL GUIDANCE OF A MULTIPLE KINETIC-ENERGY IMPACTOR VEHICLE (MKIV)
17 Space Situational Awareness 1	Pinot Noir BC	AAS 16-365	Chiara Tardioli	9:20 - 9:40	COLLISION AVOIDANCE AS A ROBUST REACHABILITY PROBLEM UNDER MODEL UNCERTAINTY
20 Trajectory Optimization 2	Chardonnay AB	AAS 16-212	Claudio Bombardelli	9:20 - 9:40	APPROXIMATE ANALYTICAL SOLUTION OF THE MULTIPLE REVOLUTION LAMBERT´S PROBLEM
18 Asteroid and non-Earth Orbiting Missions 2	Cabernet	AAS 16-370	Michael Johnson	9:40 - 10:00	THE ANALYTICAL STUDY OF PARTICLE SWARM OPTIMIZATION AND MULTIPLE AGENT PATH PLANNER APPROACHES FOR EXTRATERRESTRIAL SURFACE SEARCHES

19 Guidance and Control 2	Sauvignon	AAS 16-403	Shuquan Wang	9:40 - 10:00	NONLINEAR CONTROL AND BOUNDED RELATIVE MOTION DESIGN OF SPACE ROBOTIC ARM ACTUATED MICROGRAVITY PLATFORM
17 Space Situational Awareness 1	Pinot Noir BC	AAS 16-453	Timothy Murphy	9:40 - 10:00	DIRECT IMAGE-TO-LIKELIHOOD FOR TRACK-BEFORE-DETECT MULTI-BERNOULLI FILTER
20 Trajectory Optimization 2	Chardonnay AB	AAS 16-239	Jacob Englander	9:40 - 10:00	GLOBAL OPTIMIZATION OF LOW-THRUST INTERPLANETARY TRAJECTORIES SUBJECT TO OPERATIONAL CONSTRAINTS

Wednesday Morning Break 10:00 - 10:20

18 Asteroid and non-Earth Orbiting Missions 2	Cabernet	AAS 16-376	Carlos Marc Alberto Deccia	10:20 - 10:40	SURFING THE L2 GRADIENT WITH THE STARSHADE IN SEARCH OF EXTRATERRESTRIAL LIFE
19 Guidance and Control 2	Sauvignon	AAS 16-407	Benjamin Margolis	10:20 - 10:40	MODEL PREDICTIVE CONTROL OF PLANETARY AEROCAPTURE USING TAKAGI-SUGENO FUZZY MODEL
17 Space Situational Awareness 1	Pinot Noir BC	AAS 16-457	Brad Sease	10:20 - 10:40	A CLASS OF CONVEX OPTIMIZATION PROBLEMS FOR TEMPLATE-BASED STAR SUBTRACTION
20 Trajectory Optimization 2	Chardonnay AB	AAS 16-300	Naoya Ozaki	10:20 - 10:40	STOCHASTIC DIFFERENTIAL DYNAMIC PROGRAMMING FOR LOW-THRUST TRAJECTORY DESIGN WITH STATE UNCERTAINTY

18 Asteroid and non-Earth Orbiting Missions 2	Cabernet	AAS 16-449	Antonio Fernando Bertachini Prado	10:40 - 11:00	USING SOLAR RADIATION PRESSURE TO MANEUVER A SPACECRAFT IN THE TRIPLE ASTEROID 2001SN263

19 Guidance and Control 2	Sauvignon	AAS 16-527	Rebecca Foust	10:40 - 11:00	REAL-TIME OPTIMAL CONTROL AND TARGET ASSIGNMENT FOR AUTONOMOUS IN-ORBIT SATELLITE ASSEMBLY FROM A MODULAR HETEROGENEOUS SWARM
17 Space Situational Awareness 1	Pinot Noir BC	AAS 16-510	Robert Rovetto	10:40 - 11:00	PRELIMINARIES OF A SPACE SITUATIONAL AWARENESS ONTOLOGY
20 Trajectory Optimization 2	Chardonnay AB	AAS 16-479	Ehsan Taheri	10:40 - 11:00	ON THE APPLICATION OF EXTENDED LOGARITHMIC SMOOTHING TECHNIQUE FOR INDIRECT OPTIMIZATION OF MINIMUM-FUEL TRAJECTORIES
18 Asteroid and non-Earth Orbiting Missions 2	Cabernet	AAS 16-464	Rohan Sood	11:00 - 11:20	LUNAR ADVANCED RADAR ORBITER FOR SUBSURFACE SOUNDING (LAROSS): LAVA TUBE EXPLORATION MISSION
19 Guidance and Control 2	Sauvignon	AAS 16-216	Kelly Smith	11:00 - 11:20	PREDICTIVE LATERAL LOGIC FOR NUMERICAL ENTRY GUIDANCE ALGORITHMS
17 Space Situational Awareness 1	Pinot Noir BC	AAS 16-518	Richard Linares	11:00 - 11:20	SPACE OBJECT CLASSIFICATION USING MODEL DRIVEN AND DATA DRIVEN METHODS
20 Trajectory Optimization 2	Chardonnay AB	AAS 16-446	Dimitrios Pylorof	11:00 - 11:20	A NONLINEAR CONTROLLER FOR LOW THRUST STABILIZATION OF SPACECRAFT ON CRTBP ORBITS
18 Asteroid and non-Earth Orbiting Missions 2	Cabernet	AAS 16-409	Fabio Ferrari	11:20 - 11:40	CONSOLIDATED PHASE A DESIGN OF ASTEROID IMPACT MISSION: MASCOT-2 LANDING ON BINARY ASTEROID DIDYMOS.
19 Guidance and Control 2	Sauvignon	AAS 16-230	Eric Bourgeois	11:20 - 11:40	ATMOSPHERIC TRAJECTORY OPTIMIZATION OF A ROCKET REUSABLE FIRST STAGE WITH TURBO ENGINES
17 Space Situational Awareness 1	Pinot Noir BC	AAS 16-538	Julian Brew	11:20 - 11:40	RESIDENT SPACE OBJECT DETECTION USING ARCHIVAL THEMIS FLUXGATE MAGNETOMETER DATA

20 Trajectory Optimization 2	Chardonnay AB	AAS 16-316	Javier Roa	11:20 - 11:40	SPIRAL LAMBERT'S PROBLEM WITH GENERALIZED LOGARITHMIC SPIRALS
18 Asteroid and non-Earth Orbiting Missions 2	Cabernet	AAS 16-235	Christopher DSouza	11:40 - 12:00	GROUND-BASED NAVIGATION AND DISPERSION ANALYSIS FOR THE ORION EXPLORATION MISSION 1
19 Guidance and Control 2	Sauvignon	AAS 16-273	Kelly Smith	11:40 - 12:00	LUNAR ENTRY DOWNMODE OPTIONS FOR ORION
17 Space Situational Awareness 1	Pinot Noir BC	AAS 16-395	Noble Hatten	11:40 - 12:00	PARALLEL IMPLICIT RUNGE-KUTTA METHODS APPLIED TO COUPLED ORBIT/ATTITUDE PROPAGATION
20 Trajectory Optimization 2	Chardonnay AB	AAS 16-206	Xinwei Wang	11:40 - 12:00	MULTIPLE AGILE EARTH OBSERVATION SATELLITES SCHEDULING ALGORITHM ON AREA TARGETS
18 Asteroid and non-Earth Orbiting Missions 2	Cabernet	AAS 16-390	Yu Shi	12:00 - 12:20	TRAJECTORY DESIGN AND DETECTION PATH OPTIMIZATION OF ASTEROID MISSION

Lunch Break 12:20 - 13:30

21 Dynamics and Perturbations 2	Pinot Noir BC	AAS 16-382	Hodei Urrutxua	13:30 - 13:50	A CONSTANT, RADIAL, LOW-THRUST PROBLEM INCLUDING FIRST ORDER EFFECTS OF J2
22 Mission Design 3	Cabernet	AAS 16-244	Michel Loucks	13:30 - 13:50	LUNAR NEAR RECTILINEAR ORBITS AND CIS-LUNAR TRANSFER TRAJECTORIES IN SUPPORT OF THE DEEP SPACE PROVING GROUND
23 Spacecraft	Sauvignon	AAS 16-204	David Spencer	13:30 - 13:50	RELATIVE ORBIT TARGETING USING ARTIFICIAL

Relative Motion					POTENTIAL FUNCTIONS
24 Special Session: Results from GTOC8	Chardonnay AB	AAS 16-501	Anastassios Petropoulos	13:30 - 13:50	GTOC8: PROBLEM DESCRIPTION AND SUMMARY OF THE RESULTS
21 Dynamics and Perturbations 2	Pinot Noir BC	AAS 16-315	Florian Wöske	13:50 - 14:10	DEVELOPMENT OF A HIGH PRECISION SIMULATION TOOL FOR GRAVITY RECOVERY MISSIONS LIKE GRACE
22 Mission Design 3	Cabernet	AAS 16-234	Rüdiger Jehn	13:50 - 14:10	BEPICOLOMBO TRAJECTORY OPTIONS TO MERCURY IN 2018 AND 2019
23 Spacecraft Relative Motion	Sauvignon	AAS 16-262	Bharat Mahajan	13:50 - 14:10	ANALYTIC SOLUTION FOR SATELLITE RELATIVE MOTION: THE COMPLETE ZONAL GRAVITATIONAL PROBLEM
24 Special Session: Results from GTOC8	Chardonnay AB	AAS 16-362	Diogene Alessandro Dei Tos	13:50 - 14:10	GTOC8: RESULTS AND METHODS OF POLIMI-UPM
21 Dynamics and Perturbations 2	Pinot Noir BC	AAS 16-353	Hodei Urrutxua	14:10 - 14:30	IMPACT OF THE INTEGRATION STOP-CONDITION ON THE ACCURACY OF REGULARIZED ORBIT FORMULATIONS
22 Mission Design 3	Cabernet	AAS 16-251	Parvathi SP	14:10 - 14:30	MULTIPLE DESIGN OPTIONS FOR INTERPLANETARY ORBITER MISSIONS USING PSEUDOSTATE TECHNIQUE
23 Spacecraft	Sauvignon	AAS 16-357	Kirk Johnson	14:10 - 14:30	COMPARISON OF ORBIT ELEMENT SETS FOR

Relative Motion					MODELING PERTURBED SATELLITE RELATIVE MOTION
24 Special Session: Results from GTOC8	Chardonnay AB	AAS 16-552	Yang Gao	14:10 - 14:30	GTOC8: RESULTS AND METHODS OF TEAM 8

21 Dynamics and Perturbations 2	Pinot Noir BC	AAS 16-394	Jianlin Chen	14:30 - 14:50	MODELLING AND STABILITY ANALYSIS OF SOLAR SAIL HELIOCENTRIC ELLIPTIC DISPLACED ORBITS WITH A CONSTANT DISPLACEMENT
22 Mission Design 3	Cabernet	AAS 16-456	Josué Cardoso dos Santos	14:30 - 14:50	STUDY OF PERTURBATION INTEGRALS APPLIED TO THE DYNAMICS OF SPACECRAFTS AROUND GALILEAN MOONS
23 Spacecraft Relative Motion	Sauvignon	AAS 16-436	Andrew Sinclair	14:30 - 14:50	DEVELOPING A HARMONIC-BALANCE MODEL FOR SPACECRAFT RELATIVE MOTION
24 Special Session: Results from GTOC8	Chardonnay AB	AAS 16-425	Alessandro Peloni	14:30 - 14:50	CONSTRUCTION AND VERIFICATION OF THE SOLUTION OF THE 8TH GLOBAL TRAJECTORY OPTIMIZATION COMPETITION PROBLEM. TEAM 13: GLASGOWJENA+

21 Dynamics and Perturbations 2	Pinot Noir BC	AAS 16-420	Emma Kerr	14:50 - 15:10	IMPROVING THE ACCURACY OF ORBIT LIFETIME ANALYSIS USING ENHANCED GENERAL PERTURBATIONS METHODS
22 Mission Design 3	Cabernet	AAS 16-473	Jennifer Hudson	14:50 - 15:10	TROJAN ASTEROID MISSION DESIGN: TARGET SELECTION AND SEQUENCING OPTIMIZATION
23 Spacecraft Relative Motion	Sauvignon	AAS 16-496	Eric Butcher	14:50 - 15:10	THIRD ORDER CARTESIAN RELATIVE MOTION PERTURBATION SOLUTIONS FOR SLIGHTLY ECCENTRIC CHIEF ORBITS
24 Special Session: Results from GTOC8	Chardonnay AB	AAS 16-421	Marcus Hallmann	14:50 - 15:10	GTOC8: RESULTS AND METHODS OF TEAM 15 DLR

21 Dynamics and Perturbations 2	Pinot Noir BC	AAS 16-438	Francesca Letizia	15:10 - 15:30	B-PLANE VISUALISATION TOOL FOR UNCERTAINTY EVALUATION
22 Mission Design 3	Cabernet	AAS 16-550	Anthony Genova	15:10 - 15:30	SYNCHRONIZED LUNAR POLE IMPACT AND PLUME SAMPLE RETURN TRAJECTORY DESIGN
23 Spacecraft Relative Motion	Sauvignon	AAS 16-531	Eric Butcher	15:10 - 15:30	SPHERICAL COORDINATE PERTURBATION SOLUTIONS TO RELATIVE MOTION EQUATIONS: APPLICATION TO DOUBLE TRANSFORMATION SPHERICAL SOLUTION
24 Special Session: Results from GTOC8	Chardonnay AB	AAS 16-377	Jeff Parker	15:10 - 15:30	GTOC8: RESULTS AND METHODS OF THE UNIVERSITY OF COLORADO BOULDER

Wednesday Afternoon Break 15:30 - 15:50

21 Dynamics and Perturbations 2	Pinot Noir BC	AAS 16-497	Robyn Woollands	15:50 - 16:10	ADAPTIVE TWO-POINT BOUNDARY VALUE PROBLEM TOOL FOR ACCURATE AND EFFICIENT COMPUTATION OF PERTURBED ORBIT TRANSFERS
22 Mission Design 3	Cabernet	AAS 16-529	Fu-Yuen Hsiao	15:50 - 16:10	TRAJECTORY CHARACTERISTICS OF SPACECRAFT PROPELLED BY GROUND-BASED PHOTONIC LASER PROPULSION SYSTEM
23 Spacecraft Relative Motion	Sauvignon	AAS 16-537	Ashley Biria	15:50 - 16:10	A SATELLITE RELATIVE MOTION MODEL INCLUDING J2 AND J3 VIA VINTI'S INTERMEDIARY
24 Special Session: Results from GTOC8	Chardonnay AB	AAS 16-384	Hong-Xin Shen	15:50 - 16:10	GTOC8: RESULTS AND METHODS OF STATE KEY LABORATORY OF ASTRONAUTIC DYNAMICS

21 Dynamics and	Pinot Noir BC	AAS 16-528	Paul Cefola	16:10 - 16:30	REVISITING THE DSST STANDALONE ORBIT

Perturbations 2					PROPAGATOR – SHORT-PERIODIC MOTION MODEL, PARTIAL DERIVATIVE CAPABILITES, AND STANDALONE ORBIT DETERMINATION
22 Mission Design 3	Cabernet	AAS 16-255	Patrick Chai	16:10 - 16:30	END-TO-END TRAJECTORY FOR CONJUNCTION CLASS MARS MISSIONS USING HYBRID SOLAR-ELECTRIC/CHEMICAL TRANSPORTATION SYSTEM
23 Spacecraft Relative Motion	Sauvignon	AAS 16-486	Joseph Hughes	16:10 - 16:30	APPROPRIATE FIDELITY ELECTROSTATIC FORCE EVALUATION CONSIDERING A RANGE OF SPACECRAFT SEPARATIONS
24 Special Session: Results from GTOC8	Chardonnay AB	AAS 16-283	Lorenzo Casalino	16:10 - 16:30	GTOC8: RESULTS AND METHODS OF TEAM 22
21 Dynamics and Perturbations 2	Pinot Noir BC	AAS 16-542	Kevin Hernandez	16:30 - 16:50	ANALYTIC CONTINUATION POWER SERIES SOLUTION FOR THE TWO-BODY PROBLEM WITH ATMOSPHERIC DRAG
22 Mission Design 3	Cabernet	AAS 16-466	Diane Davis	16:30 - 16:50	MULTI-BODY MISSION DESIGN USING THE DEEP SPACE TRAJECTORY EXPLORER
23 Spacecraft Relative Motion	Sauvignon	AAS 16-375	Jingwei Wang	16:30 - 16:50	ANALYSIS OF AMBIGUOUS ORBITS IN SEQUENTIAL RELATIVE ORBIT ESTIMATION WITH RANGE-ONLY MEASUREMENTS
24 Special Session: Results from GTOC8	Chardonnay AB	AAS 16-248	Gao Tang	16:30 - 16:50	GTOC8: RESULTS AND METHODS OF TEAM 3 - TSINGHUA UNIVERSITY
21 Dynamics and Perturbations 2	Pinot Noir BC	AAS 16-333	James Turner	16:50 - 17:10	ANALYTIC HIGH-ORDER REVERSION OF SERIES SOLUTION ALGORITHM FOR SOLVING LAMBERT'S PROBLEM
22 Mission Design 3	Cabernet	AAS 16-535	Nitin Arora	16:50 - 17:10	MISSION DESIGN TRADES FOR A NEAR TERM PLUTO ORBITER
23 Spacecraft Relative Motion	Sauvignon	AAS 16-548	Austin Probe	16:50 - 17:10	ENHANCEMENTS TO MOTION EMULATION PLATFORM FOR SIX DEGREE OF FREEDOM

					PROXIMITY OPERATIONS AND CONTACT EXPERIMENTS
24 Special Session: Results from GTOC8	Chardonnay AB	AAS 16-275	Dario Izzo	16:50 - 17:10	GTOC8: RESULTS AND METHODS OF ESA ADVANCED CONCEPTS TEAM AND JAXA-ISAS
21 Dynamics and Perturbations 2	Pinot Noir BC	AAS 16-263	Vincent Morand	17:10 - 17:30	RE-ENTRY PREDICTION AND ANALYSIS USING TAYLOR DIFFERENTIAL ALGEBRA
22 Mission Design 3	Cabernet	AAS 16-435	Stijn De Smet	17:10 - 17:30	DESIGNING AN ASTEROID DEFLECTION MISSION USING CONTINUOUS THRUST AND UNCERTAINTY
23 Spacecraft Relative Motion	Sauvignon	AAS 16-432	Liam Healy	17:10 - 17:30	PLANNING MANEUVERS BETWEEN PERIODIC RELATIVE ORBITS USING GEOMETRIC RELATIVE ORBITAL ELEMENTS

February 18, 2016

Session	Room	Doc. #	Presenter		Title
28 Navigation	Chardonnay AB	AAS 16-201	Renato Zanetti	8:00 - 8:20	ORION EXPLORATION FLIGHT TEST-1 (EFT-1) ABSOLUTE NAVIGATION PERFORMANCE
27 Space Situational Awareness 2	Sauvignon	AAS 16-319	Islam Hussein	8:00 - 8:20	UCT CORRELATION USING THE BHATTACHARRYA DIVERGENCE
25 Spacecraft Rendezvous	Pinot Noir BC	AAS 16-280	Anand Kumar	8:00 - 8:20	ADAPTIVE GUIDANCE SCHEME FOR SPACECRAFT RENDEZVOUS IN ELLIPTICAL ORBITS
26 Trajectory Optimization 3	Cabernet	AAS 16-304	Isaac M. Ross	8:00 - 8:20	AN ACCELERATED TRAJECTORY OPTIMIZATION TECHNIQUE BASED ON PSEUDOSPECTRAL METHODS

28 Navigation	Chardonnay AB	AAS 16-228	Alfred Lynam	8:20 - 8:40	NAVIGATION AND STATISTICAL DELTA-V ANALYSIS FOR DOUBLE-SATELLITE-AIDED CAPTURE AT JUPITER
27 Space Situational Awareness 2	Sauvignon	AAS 16-266	Shahzad Virani	8:20 - 8:40	HARDWARE-IN-THE-LOOP COMPARISON OF SPACE OBJECT DETECTION AND TRACKING METHODOLOGIES
25 Spacecraft Rendezvous	Pinot Noir BC	AAS 16-350	Emily Kollin	8:20 - 8:40	AUTONOMOUS TIME-OPTIMAL SPACECRAFT RENDEZVOUS AND PROXIMITY OPERATIONS USING STABILIZED CONTINUATION
26 Trajectory Optimization 3	Cabernet	AAS 16-368	Christopher McGrath	8:20 - 8:40	UNSCENTED EVOLUTION STRATEGIES FOR SOLVING TRAJECTORY OPTIMIZATION PROBLEMS
28 Navigation	Chardonnay AB	AAS 16-232	Paul Thompson	8:40 - 9:00	INDEPENDENT NAVIGATION TEAM CONTRIBUTION TO NEW HORIZONS' PLUTO SYSTEM FLYBY
27 Space Situational Awareness 2	Sauvignon	AAS 16-289	Vivek Vittaldev	8:40 - 9:00	SPACE OBJECT COLLISION PROBABILITY VIA MONTE CARLO ON THE GRAPHICS PROCESSING UNIT
25 Spacecraft Rendezvous	Pinot Noir BC	AAS 16-369	Davide Conte	8:40 - 9:00	PRELIMINARY STUDY ON RELATIVE MOTION AND RENDEZVOUS BETWEEN SPACECRAFT IN THE RESTRICTED THREE-BODY PROBLEM
26 Trajectory Optimization 3	Cabernet	AAS 16-385	Toshinori Ikenaga	8:40 - 9:00	INTERPLANETARY PARKING METHOD AND ITS APPLICATION TO DUAL LAUNCH TRAJECTORY DESIGN
28 Navigation	Chardonnay AB	AAS 16-401	Deepana Gandhi	9:00 - 9:20	EXTENDED KALMAN FILTER BASED ATTITUDE AND DRIFT ESTIMATION OF A LUNAR LANDER USING

					STAR SENSOR AND GYROSCOPE
27 Space Situational Awareness 2	Sauvignon	AAS 16-302	Daniel Bryant	9:00 - 9:20	FRAGMENTATION EVENT TRACKING WITH THE GM-CPHD FILTER
25 Spacecraft Rendezvous	Pinot Noir BC	AAS 16-459	Richard Zappulla	9:00 - 9:20	EXPERIMENTS ON AUTONOMOUS SPACECRAFT RENDEZVOUS AND DOCKING USING AN ADAPTIVE ARTIFICIAL POTENTIAL FIELD Approach
26 Trajectory Optimization 3	Cabernet	AAS 16-408	Juan Luis Gonzalo	9:00 - 9:20	OPTIMAL 3D ORBIT CORRECTIONS IN CURVILINEAR COORDINATES
28 Navigation	Chardonnay AB	AAS 16-424	Jonathon Smith	9:20 - 9:40	DISTRIBUTED PARAMETER SYSTEM FOR OPTIMIZATION AND FILTERING IN ASTRODYNAMIC SOFTWARE
27 Space Situational Awareness 2	Sauvignon	AAS 16-327	Xiaoyu Chu	9:20 - 9:40	OPTIMIZED COLLISION AVOIDANCE OF SPACECRAFT IN ULTRA CLOSE PROXIMITY FOR FAILED SATELLITE
25 Spacecraft Rendezvous	Pinot Noir BC	AAS 16-495	Bradley Kuiack	9:20 - 9:40	NONLINEAR ANALYTICAL EQUATIONS OF RELATIVE MOTION ON J2-PERTURBED ECCENTRIC ORBITS
26 Trajectory Optimization 3	Cabernet	AAS 16-426	Nicola Sullo	9:20 - 9:40	FROM LOW THRUST TO SOLAR SAILING: A HOMOTOPIC APPROACH
28 Navigation	Chardonnay AB	AAS 16-441	Jacob Hikes	9:40 - 10:00	PARAMETRIC COVARIANCE MODEL FOR HORIZON-BASED OPTICAL NAVIGATION
27 Space Situational Awareness 2	Sauvignon	AAS 16-366	Jason Reiter	9:40 - 10:00	AN ANALYTICAL SOLUTION TO QUICK-RESPONSE COLLISION AVOIDANCE MANEUVERS IN LOW EARTH ORBIT
25 Spacecraft	Pinot Noir BC	AAS 16-356	David Geller	9:40 - 10:00	NON-ITERATIVE APPROXIMATE SOLUTION TO THE

Rendezvous					ANGLES-ONLY INITIAL RELATIVE ORBIT DETERMINATION PROBLEM IN SPHERICAL COORDINATES
26 Trajectory Optimization 3	Cabernet	AAS 16-448	Darren Hitt	9:40 - 10:00	TWO-IMPULSE EVOLUTIONARY OPTIMIZATION OF SATELLITE FORMATIONS WITH TOPOLOGICAL CONSTRAINTS

Thursday Morning Break 10:00 - 10:20

28 Navigation	Chardonnay AB	AAS 16-445	Samuel Haberberger	10:20 - 10:40	SPACECRAFT NAVIGATION USING A ROBUST MULTI-SENSOR FAULT DETECTION SCHEME
27 Space Situational Awareness 2	Sauvignon	AAS 16-447	Navraj Singh	10:20 - 10:40	ATHENA: A DATA-DRIVEN ANOMALY DETECTION AND SPACE OBJECT CLASSIFICATION TOOL FOR SPACE SITUATIONAL AWARENESS
25 Spacecraft Rendezvous	Pinot Noir BC	AAS 16-507	Christopher Petersen	10:20 - 10:40	COUPLED TRANSLATIONAL AND ROTATIONAL DYNAMICS FOR PRECISE CONSTRAINED RENDEZVOUS AND DOCKING WITH PERIODIC REFERENCE GOVERNORS
26 Trajectory Optimization 3	Cabernet	AAS 16-471	Juliana Feldhacker	10:20 - 10:40	TRAJECTORY OPTIMIZATION UNDER UNCERTAINTY FOR RENDEZVOUS IN THE CRTBP

28 Navigation	Chardonnay AB	AAS 16-509	Thomas Fuller	10:40 - 11:00	CELESTIAL NAVIGATION DEVICE FOR FUTURE AUTONOMOUS APPLICATIONS
27 Space Situational	Sauvignon	AAS 16-455	Alan Segerman	10:40 - 11:00	COMVECS: A SPECIAL PERTURBATIONS

Awareness 2					COVARIANCE-BASED TOOL FOR DUPLICATE ORBIT IDENTIFICATION
25 Spacecraft Rendezvous	Pinot Noir BC	AAS 16-513	Jvxiang Ge	10:40 - 11:00	APPROACHING AND DOCKING MANEUVERS DESIGN AND CONTROL FOR A TUMBLING TARGET
26 Trajectory Optimization 3	Cabernet	AAS 16-476	Travis Swenson	10:40 - 11:00	APPLICATION OF MODIFIED CHEBYSHEV PICARD ITERATION TO DIFFERENTIAL CORRECTION FOR IMPROVED ROBUSTNESS AND COMPUTATION TIME

28 Navigation	Chardonnay AB	AAS 16-442	Stoian Borissov	11:00 - 11:20	PRELIMINARY INVESTIGATION IN INTERSTELLAR NAVIGATION TECHNIQUES
27 Space Situational Awareness 2	Sauvignon	AAS 16-482	Andris Jaunzemis	11:00 - 11:20	EVIDENTIAL REASONING APPLIED TO SINGLE-OBJECT LOSS-OF-CUSTODY SCENARIOS FOR TELESCOPE TASKING
25 Spacecraft Rendezvous	Pinot Noir BC	AAS 16-261	Huan Chen	11:00 - 11:20	RELATIVE LAMBERT TRANSFER BASED ON RELATIVE ORBIT ELEMENTS AND THE APPLICATION IN HOVERING FORMATION CONTROL
26 Trajectory Optimization 3	Cabernet	AAS 16-516	Julie Read	11:00 - 11:20	ORBITAL ELEMENT CONTINUOUS THRUST MANEUVERS USING MODIFIED CHEBYSHEV PICARD ITERATION

28 Navigation	Chardonnay AB	AAS 16-492	Johnny Worthy	11:20 - 11:40	AN OPTIMIZATION BASED APPROACH TO CORRELATION OF OBSERVATIONS WITH UNCERTAINTY
27 Space Situational Awareness 2	Sauvignon	AAS 16-514	Richard Linares	11:20 - 11:40	RESIDENT SPACE OBJECT SHAPE INVERSION VIA ADAPTIVE HAMILTONIAN MARKOV CHAIN MONTE CARLO
25 Spacecraft Rendezvous	Pinot Noir BC	AAS 16-400	Brian Janisch	11:20 - 11:40	NUMERICALLY APPROXIMATED RECEDING HORIZON CONTROL FOR UNCERTAIN PURSUIT-EVASION GAMES

26 Trajectory Optimization 3	Cabernet	AAS 16-422	Kenta Oshima	11:20 - 11:40	GLOBAL SEARCH FOR LOW-THRUST TRANSFERS TO THE MOON IN THE PLANAR CIRCULAR RESTRICTED THREE-BODY PROBLEM
28 Navigation	Chardonnay AB	AAS 16-358	Paul Frontera	11:40 - 12:00	EFFECT OF UPDATE FREQUENCY ON EKF AND UKF PERFORMANCE
27 Space Situational Awareness 2	Sauvignon	AAS 16-207	ISLAM Hussein	11:40 - 12:00	UNCERTAIN ANGLES-ONLY TRACK INITIATION FOR SSA USING DIFFERENT IOD METHODS
26 Trajectory Optimization 3	Cabernet	AAS 16-226	Hongliang Ma	11:40 - 12:00	GLOBAL OPEN-TIME OPTIMIZATION OF FUEL CONSUMPTION IN J2 RENDEZVOUS SCENARIOS BY THE METHOD OF INTERVAL ANALYSIS
28 Navigation	Chardonnay AB	AAS 16-428	Ashish Jagat	12:00 - 12:20	VISION-BASED RELATIVE NAVIGATION USING 3D SCALE SPACE THEORY
27 Space Situational Awareness 2	Sauvignon	AAS 16-306	Li Bin	12:00 - 12:20	TLE GENERATION FROM SPARSE TRACKING DATA AND ITS PERFORMANCE

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