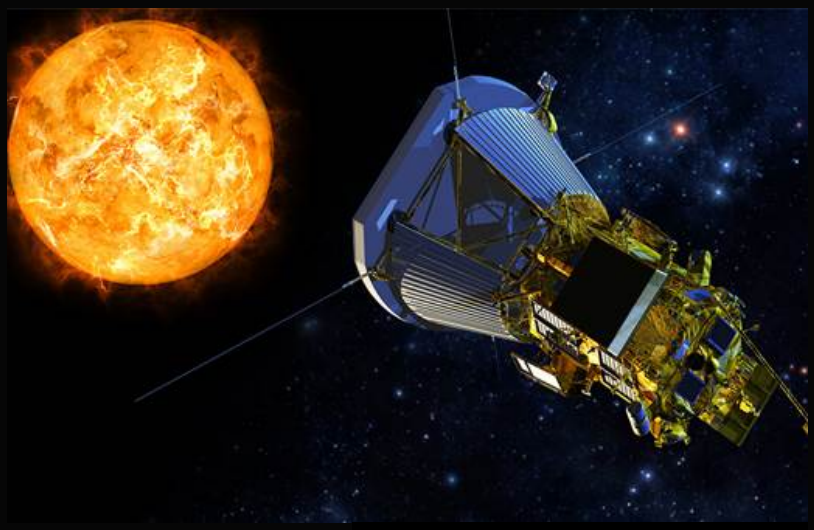
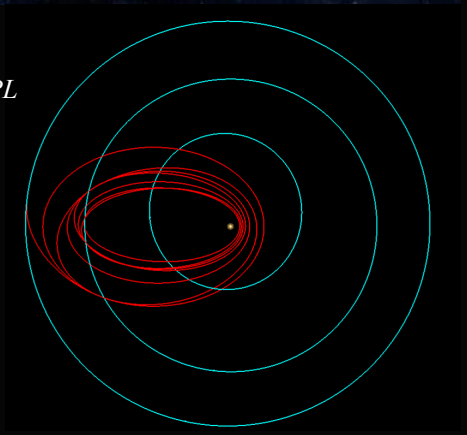
29th AAS/AIAA Space Flight Mechanics Meeting,

January 13-17

Ka'anapali, HI



Images courtesy: John Hopkins APL

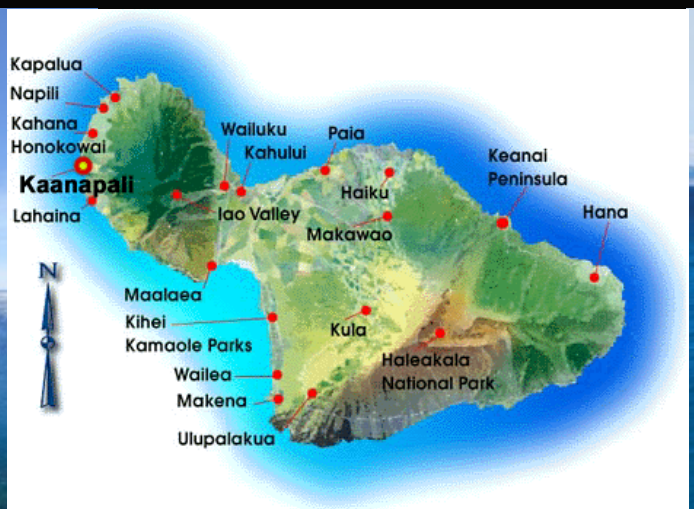


AAS General Chair
Dr. Matthew Wilkins
L3 Advanced Defense Solutions

AIAA General Chair
Dr. Renato Zanetti
The University of Texas at Austin

AAS Technical Chair
Dr. Francesco Topputo
Politecnico di Milano

AIAA Technical Chair
Dr. Andrew Sinclair
Air Force Research Laboratory



29TH AAS/AIAA SPACE FLIGHT MECHANICS MEETING

CONFERENCE INFORMATION

GENERAL INFORMATION

Welcome to the 29th Space Flight Mechanics Meeting, hosted by the American Astronautical Society (AAS) and co-hosted by the American Institute of Aeronautics and Astronautics (AIAA), January 13 – 17, 2018. This meeting is organized by the AAS Space Flight Mechanics Committee and the AIAA Astrodynamics Technical Committee, and held at the Sheraton Maui Resort and Spa, 2605 Ka'anapali, Maui, HI, (808)-661-0031, https://www.marriott.com/hotels/travel/hnmsi-sheraton-maui-resort-and-spa/.

REGISTRATION

Registration Site (https://www.xcdsystem.com/aas/attendee/index.cfm?ID=zP55GsC)

In order to encourage early registration, we have implemented the following conference registration rate structure: **Register by November 30, 2018 and save $70!**

Category	Early Registration (through Nov 30, 2018)	Registration (beginning Dec 1, 2018)	Walk-up Registration (beginning Jan 1, 2019)
Full - AAS or AIAA Member	$600	$670	$770
Full - Non-member	$700	$770	$870
Retired or Student* - Member	$250	$320	$420
Retired / Student* - Non-member	$300 / $295	$370 / $365	$470 / $465

**does not include proceedings CD*

Refunds will be issued until December 31, 2018. A 10% fee will be assessed for all refunds issued after that date and until 8:00 am EST January 13, 2018. No refunds will be issued after 8:00 am EST January 13, 2018.

Please note that only the first 279 to register and/or purchase a guest ticket will be guaranteed a ticket for admission to the Tuesday evening Old Lahina Luau. After 279 Luau ticketes are issues additional tickets will be only available contingent on the venue's seating availabiligy. The Old Lahina Luau usually sells out weeks in advance. Register Early! Bus transportation is provided from the conference hotel to the luau and back. Guest tickets for the luau may be purchased for $120. More information about the luau 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 near the session rooms of the Sheraton Maui Resort and will be staffed according to the following schedule:

- Sunday Januray 13: 3pm – 6pm
- Monday Januray 14: 7:30am – 2pm
- Tuesday Januray 15: 8am – 2pm
- Wednesday Januray 16: 8am – 2pm
- Thursday January 17: 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, 14 January, at 8 am. The last technical sessions end at 12:20 pm on Thursday, 17 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.

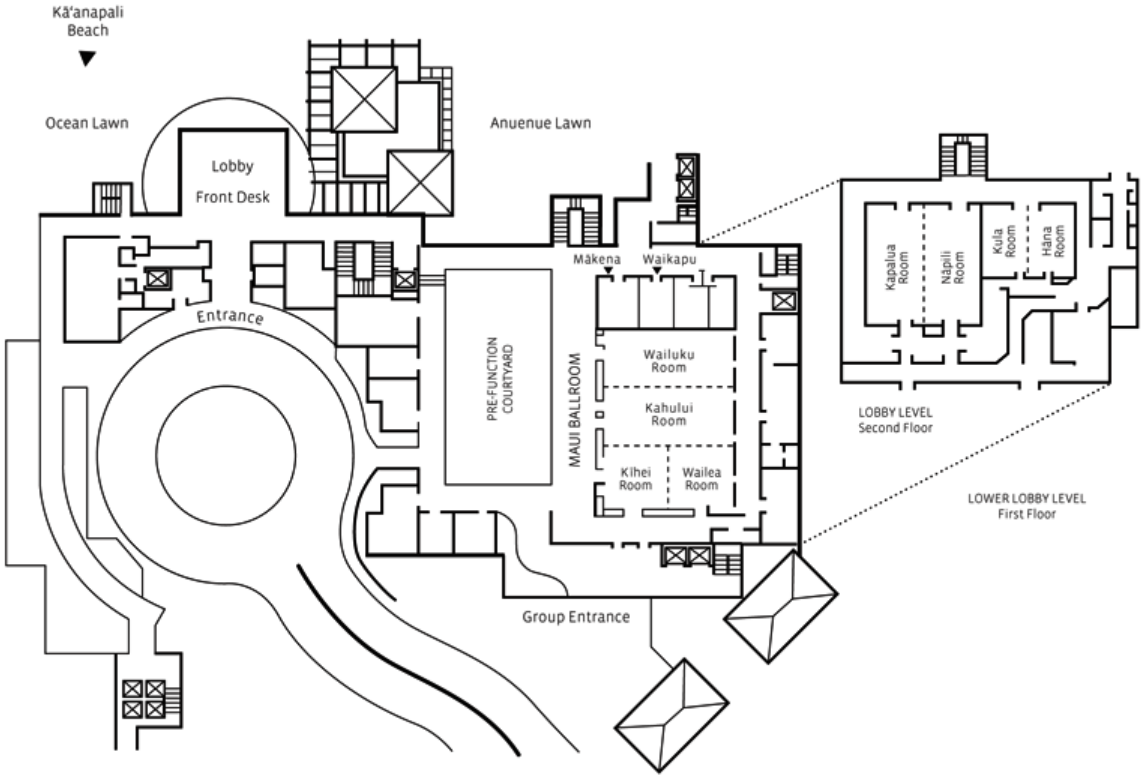
Day	Start	End	Function	Room
Sunday 13 January	3pm	6pm	Registration	Foyer/Kihei
	6pm	9pm	Early Bird Reception (Food and Hosted Bar)	Anuemue Lawn
Monday 14 January	7:30am	2pm	Registration	
	8am	12pm	Session 1: Orbit determination & space, surveillance-tracking	Kapalua
	8am	12pm	Session 2: Orbital dynamics, perturbations, and stability I	Napili
	8am	12pm	Session 3: Attitude dynamics and control I	Kula
	8am	12pm	Session 4: Trajectory Design & Optimization I	Hana
	10am	10:20am	Morning Break	
	Noon	1:30pm	Joint Technical Committee Lunch	Kihei
	1:30pm	5:30pm	Session 5: Artificial intelligence in astrodynamics	Kapalua
	1:30pm	5:30pm	Session 6: Asteroid & non-Earth orbiting missions I	Napili
	1:30pm	5:30pm	Session 7: Attitude dynamics and control II	Kula
	1:30pm	5:30pm	Session 8: Trajectory Design & Optimization II	Hana
	3:30pm	3:50pm	Afternoon Break	
	5:30pm	6:30pm	Conference Administration Subcommittee	Kapalua
	5:30pm	6:30pm	Technical Administration Subcommittee	Napili

	5:30pm	6:30pm	Website Administration Subcommittee	Kula
Day	**Start**	**End**	**Function**	**Room**
Tuesday 15 January	8am	2pm	Registration	
	8am	12pm	Session 9: Orbital debris and space environment	Kapalua
	8am	12pm	Session 10: Orbital dynamics, perturbations, and stability II	Napili
	8am	12pm	Session 11: Atmospheric re-entry & Satellite constellations	Kula
	8am	12pm	Session 12: Trajectory Design & Optimization III	Hana
	10am	10:20am	Morning Break	
	Noon	1:30pm	AIAA Technical Committee Lunch	Coral Reef
	1:30pm	4:30pm	Session 13: Large space structures and tethers	Kapalua
	1:30pm	4:30pm	Session 14: Dynamical systems theory	Napili
	1:30pm	4:30pm	Session 15: Mars InSight (Special session)	Kula
	1:30pm	4:30pm	Session 16: Mars sample return (Special session)	Hana
	3:10pm	3:30pm	Afternoon Break	
	5:15pm	8:15pm	Offsite Event: Old Lahina Luau **Buses depart the Sheraton Maui at 5:00pm**	
Wednesday 16 January	8am	2pm	Registration	
	8am	12pm	Session 17: SSA & Conjunction analysis	Kapalua
	8am	12pm	Session 18: Asteroid and non-Earth orbiting missions II	Napili
	8am	12pm	Session 19: Proximity missions, and formation flying I	Kula
	8am	12pm	Session 20: Trajectory Design & Optimization IV	Hana
	10am	10:20am	Morning Break	

	Noon	1:30pm	AAS Technical Committee Lunch	Coral Reef
	1:30pm	5:30pm	Session 21: SSA & Flight dynamics operations	Kapalua
Wednesday 16 January	1:30pm	5:30pm	Session 22: Guidance, navigation and control I	Napili
	1:30pm	5:30pm	Session 23: Proximity missions and formation flying II	Kula
	1:30pm	5:30pm	Session 24: Trajectory Design & Optimization V	Hana
	3:30pm	3:50pm	Afternoon Break	
	6:00pm	9:00pm	Awards Reception	Ocean Lawn
Thursday 17 January	8am	10am	Registration	
	8am	12pm	Session 25: Spacecraft guidance, navigation and control II	Kapalua
	8am	12pm	Session 26: Astrodynamics	Napili
	8am	12pm	Session 27: Proximity missions and formation flying III	Kula
	8am	12pm	Session 28: Trajectory Design & Optimization VI	Hana
	10am	10:20am	Morning Break	

A map of the Sheraton Maui Resort and Spa and the relevant meeting rooms appears on the next page.


Sheraton
Maui
Link @Sheraton
SHUTTLE
SHERATON FITNESS
MOANA
KA'ANAPALI POINT
GUEST ROOMS
1. 'Ohana Hale 1101-1210
2. Lahaina Hale 2101-2521
3. Anuenue Hale 3101-3631
4. Nalu Hale 4111-4611
5. Hoku Hale 5101-5111
6. Moana Hale 6101-6526
DINING
7. Black Rock Terrace
8. Black Rock Steak & Seafood
9. Teppan-yaki Dan
10. Cliff Dive Grill
11. Mai Tai Bar
12. Link@Sheraton Lounge
13. Starbucks Coffee Cart
14. Maui Nui Lu'au
15. Moana Private Dining Room
16. Hale Pilialoha*
FUNCTION AREAS
17. Maui Ballroom and Meeting Rooms
18. Courtyard/Ballroom Foyer
19. Ocean Lawn
20. Anuenue Lawn
21. Coral Reef
22. Black Rock Lawn*
23. Ka'anapali Point*
24. Moana Lawn/Lounge*
25. Ali'i Suite/Lawn*
26. Na Hoku Lounge
HOTEL SERVICES
27. Lobby
28. Concierge
29. Front Desk
30. Bell Desk/Valet
31. Fitness Center (7th floor of Hoku Hale)
32. Towel Kiosk & Poolside Concierge
33. Swimming Pool
34. Keiki Pool
35. Whirlpool
36. Gift Shop, Lamonts
37. ATM
38. Self Parking Structure
39. Self Parking Lot
40. Hoku & Moana Hale Self Parking
41. Best Buy Kiosk
42. Group Porte Cochere Shuttle Pickup
43. Wedding Showroom
44/45. Starwood Vacations Hawai'i Desk
46. Enterprise Car Rental
ACTIVITIES
47. Nightly Cliff Dive Ceremony /Entertainment
48. The Spa at Black Rock
49. Black Rock Watersports
50. Tennis Courts & Pro Shop
51 Beach Walk to Whalers Village
52. Black Rock/Pu'u Keka'a*
53. Activity Hale for Hawaiian Cultural Activities
Legend
Elevators
All restrooms are accessible facilities
Water Safety and Ocean Awareness
Respect Marine Life
Strong Current
High Surf
Dangerous Shorebreak
Beach Closed
Jellyfish
Sudden Drop-Off
Shark


Ka'anapali Beach
Ocean Lawn
Anuenue Lawn
Lobby
Front Desk
Entrance
PRE-FUNCTION COURTYARD
MAUI BALLROOM
Mākena
Waikapu
Wailuku Room
Kahului Room
Kihei Room
Wailea Room
Kapalua Room
Nāpili Room
Kula Room
Hāna Room
LOBBY LEVEL
Second Floor
LOWER LOBBY LEVEL
First Floor
Group Entrance

SPECIAL EVENTS

EARLY BIRD RECEPTION

Sunday, 13 January 6:00 – 9:00 pm

Location: Anuenue Lawn

AWARDS RECEPTION

Wednesday, 16 January 6:00 – 9:00 pm

Location: Ocean Lawn

Presentation of the 2018 AIAA/AAS Space-Flight Mechanics Meeting Best Paper Award to:

Costantinos Zagaris and Marcello Romano, for paper "Applied Reachability Analysis for Spacecraft Rendezvous and Docking with a Tumbling Object"

Presentation of the 2019 Space-Flight Mechanics Breakwell Student Travel Award to:

Ahmed Atallah, San Diego State University, for paper "Analytical Radial Adaptive Method for Spherical Harmonics Gravity Models"

Francisco Franquiz, Embry Riddle University, for paper "Optimal Range Observability Maneuvers for Angles-Only Navigation in Elliptic Orbits"

Lauren Schlenker, Massachusetts Institute of Technology, for paper "Simultaneous Localization and Mapping for Satellite Rendezvous and Proximity Operations Using Random Finite Sets"

Justin Mansell, Purdue University, for paper "Swarm Optimization of Lunar Transfers from Earth Orbit with Radiation Dose Constraints"

OLD LAHINA LUAU – TRADITIONAL HULA & FEAST

Tuesday, 15 January	5:00 pm (Buses Depart Sheraton Maui Resort for Old Lahina Luau)
	5:15 – 8:15 pm (Dinner and Entertainment)
Location	Old Lahina Luau Grounds

The Old Lahaina Lu'au takes great pride in presenting an authentic Hawaiian Lu'au. An evening of traditional Hawaiian cuisine, music, cultural dances and demonstrations. Guests will appreciate a genuine reflection of Hawaii's rich history while enjoying an ocean view and sunset.

Currently we have half of the luau grounds reserved and can accommodate the first 279 guests that register and/or purchase a guest ticket. Both full and reduced registrants will receive a luau ticket until our reserved block is full. After that, the General Chairs (GCs) will work with the luau upon space availability to accommodate additional attendees. The Old Lahaina Luau is famous and known to sell out. The sooner you register the more likely we can accommodate additional guests. Guest tickets are $120 and sales of guest tickets will be discontinued after we reach our maximum attendance.

The Old Lahaina Luau menu is included in this program (subject to change) and the Ingredients List can be found in the conference website. All ingredients for menu items are listed. If you feel that there are not menu options available to you for dietary reasons, please let the GCs know and we will do our best to accommodate you.

Luau Menu

Pua'a Kalua Pork roasted in our beachside Imu; the Hawaiian underground oven
Laulau – Lu'au leaf wrapped pork Succulent bundles of pork wrapped in taro leaf and cooked until tender.
I'a - Maui Style Fish Chef's Special Preparation with fresh seasonal ingredients
Pipi Ko'ala Grilled Beef Steak
Chicken Long Rice Shredded Chicken, Maui onions, ginger and rice bean noodles in broth
Moa – Island Style Chicken Chicken marinated with guava sauce garnished with fresh pineapples and toasted sesame seeds
Mea'ai Ola Pono Taro, Sweet Potato, and Tofu Patty served with a side of Pineapple Salsa and Garlic Chili Vinaigrette (Vegetarian / Vegan / Gluten Free)
Stir Fry Vegetables Zucchini, Maui onions, carrots, broccoli, and sugar snap peas
Local-Style Fried Rice Fried rice with green onions, peas, and sesame oil
'Uala - Sweet Potato Warm sliced Big Island sweet potatoes
Island Crab Salad Crab, shrimp and water chestnuts
Lu'au Kalo – Taro Leaf Stew Taro and Lu'au leaf combined with creamy coconut milk for an authentic island favorite.
Pohole Salad Fern shoots, Maui onions and tomatoes served in a vinaigrette sauce
LomiLomi Salmon Local tomatoes, Maui onions, and salted salmon – Lomilomi or "massaged" together with Aloha
Poke 'Ahi Fresh raw ahi (yellow fin tuna) with green onions and Maui onions
Poke He'e Marinated cooked octopus/tako
Poi Made from boiling and mashing the root of the taro plant
Fresh Island Fruit & Banana Bread Fresh seasonal fruits and banana bread
Assorted Island Desserts Passion Fruit Cake, Upcountry Lavender Lemon Shortbread Cookies, Hawaiian Chocolate Chili Pepper Brownie, and Haupia
Open Bar

CONFERENCE LOCATION

SHERATON MAUI RESORT AND SPA

2605 Kaanapali Parkway
Lahaina, Maui, HI, 96761
808-661-0031 (voice)
888-627-8114 (toll-free)




A room block with the Government Per Diem Rate (currently $259/night) was secured and available for conference attendees until soldout. We encourage all conference attendees to make your hotel reservation early!

Group Reservation Page:

https://www.marriott.com/event-reservations/reservation-link.mi?id=1808157216&key=36F014CA&app=resvlink

A deposit equal to two (2) nights is required to hold each guest's reservation. Deposits are refundable if notice is received by Hotel at least thirty (30) days prior to arrival and a cancellation number is obtained. An early departure charge of one (1) night room plus tax will apply if a Customer attendee checks out prior to the confirmed checkout date.

All rates quoted are single or double occupancy. The current rate for a third person in the room is $80.00, plus tax per night. Children seventeen (17) years of age and younger are free of charge when sharing the same room as parent(s), maximum of four (4) persons to a room. Third person charge subject to change.

Rates do not include applicable state and local taxes, currently 13.4166% or the mandatory Resort Charge of $20.00 plus tax of 4.166% per day, per room (Originally at $25.00) No automatic or mandatory charges are tips, gratuities, or services charges for employees, unless otherwise expressly stated. Resort charge, taxes and resort charge inclusions are subject to change.

Dally Resort Charge Service Inclusions (inclusions subject to change without notice):

- Unlimited wireless high-speed internet access in guest rooms
- Unlimited wireless high-speed internet access in lobby, pool bars, and Hoku Rotunda
- Valet parking on the day of arrival (first night only)
- Unlimited local telephone calls (on-island)
- Credit card and 800# access telephone calls up to 60 minutes
- Starwood Maui scheduled shuttle service to Westin Maui Resort and Spa, Westin Ka'anapali Ocean Resort Villas, and historic Lahaina town
- Adult Pool Floats
- Professional resort photo session and keepsake 4 x 8 photo
- Signature logo Hawaiian tote bag

Daily self-parking charge, starting on the 2nd night, will be $20.00 plus tax with arrival night complimentary valet parking included in the daily resort charge.

HOTEL SERVICES AND AMENITIES

Located on 23 lush oceanfront acres at legendary Pu‘u Keka‘a on Ka‘anapali Beach, Sheraton Maui Resort & Spa invites travelers to experience adventure, romance and family fun on the island of Maui. Relax at the resort’s 142-yard lagoon style pool, taste fresh island cuisine, learn indigenous Hawaiian cultural activities and play at the white sandy beach. Eighty-three percent of the resort’s 508 rooms and suites feature breathtaking views of the Pacific, and sister islands Lanai and Molokai. At sunset, the resort showcases its iconic cliff dive ceremony, a tradition since the resort first opened in 1963. Make lasting memories as you unwind during sunset, snorkel with tropical fish and honu (green sea turtles), learn ukulele with family, or rejuvenate at The Spa at Black Rock.

Hotel Dining Options

ROCKsalt *(INTERNATIONAL) Craveable, eclectic share plates with a global flair. For more information, check us out on Instagram @rocksaltmaui! Open for breakfast and dinner Phone: +1 808-921-4600*

Mai Tai Bar *(AMERICAN) Located steps away from of Kaanapali Beach, Mai Tai Bar is an ideal setting for sipping on your favorite umbrella drink and savoring tasty poolside bites. Open for lunch and dinner*

Teppan-yaki Dan *(JAPANESE) At Teppan-yaki Dan, skilled chefs expertly prepare fresh lobster, steak, and more, right before your eyes. Sakes and fine wines are the perfect complement. Reservations required, open for dinner.*

Cliff Dive Grill *(AMERICAN) This open-air hot spot serves tasty grilled fare plus a range of tempting beverages, right on Kaanapali Beach. Take in the nightly torch lighting and cliff dive ceremony, and enjoy hula dancing and live music. Open for lunch and dinner*

Hank's Haute Dogs *(AMERICAN) Inventive hot dogs, French fries and dips served poolside. Open for lunch*

OTHER HOTEL OPTIONS

Although conference rates cannot be guaranteed, suggestions for other hotel options in the area are listed below. Further information is available on VRBO and Airbnb.

- The Westin Maui Resort and Spa
- Kaanapali Alii Resort
- Hyatt Regency Maui Resort
- Royal Lahaina Resort
- Honua Kai Resort and Spa
- The Westin Kaanapali Ocean Resort Villas
- The Ritz-Carlton Kapalua
- Marriott's Maui Ocean Club Lahaina

TRANSPORTATION INFO

All flights to the conference should arrive at Kahului Airport (OGG). http://airports.hawaii.gov/ogg/

Hawaii has strict import/export rules for fresh food products, animals, meats, and plants. Please follow the following directions for travel to Hawaii:

US Mainland to Hawaii:

http://hdoa.hawaii.gov/pi/pq/travel-shipping-information/traveling-from-the-u-s-mainland-to-hawai%CA%BBi/

International Travel to Hawaii:

http://hdoa.hawaii.gov/pi/pq/travel-shipping-information/traveling-to-and-from-foreign-countries/

Several car rental companies are available at OGG. Alternatively, the following services are available:

Airport shuttle service via Roberts Hawaii, $34 each way or $68 round trip (plus tax and possible baggage fees). The booking link is: Http://www.robertshawaii.com/mauiexpress Reservations: 808-439-8800

Mercedes shuttles between OGG and the Sheraton Maui via SpeediShuttle, $35.40 one way, $67.26 round trip (10% discount on return when booked together) and includes airport greeter service. Registrants with prearranged arrival reservations will be greeted in the baggage claim area then directed to their waiting shuttles. Vehicle amenities include complimentary WiFi, 6'1" clearance, three point seat restraints. www.speedishuttle.com Phone: 808-268-2094

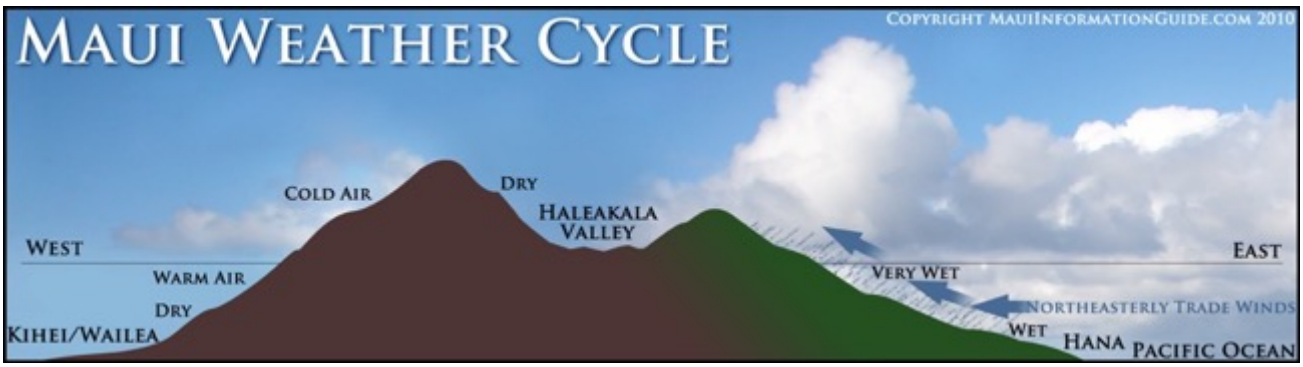
MAUI WEATHER

For more information on Maui weather, go here: https://www.mauiinformationguide.com/hawaii-weather.php

December, January, February

These months have the lowest temperatures for the year. Keep in mind that it's still plenty warm in many areas. With regular showers, these winter months are home to the wettest Maui weather of the year. In January, tradewinds only blow half as much as they do in the summer. Throughout the winter, generally from November to March, large North Swells create big surf on our North and Northwest facing beaches. The ocean temperature is approximately 75 F, and the air temperature averages between 65-80 degrees F depending on which area you're in. For Ka'anapali, the average temperature is closer to a high of 79 degrees F during the day and overnight lows of 64 degrees F with about 6 rainy days per month on average.

Maui Weather Cycle



From the crater at Haleakala's summit, you can watch Maui weather being made. On a typically warm day, trade winds carry moisture-laden air up the northeast slopes of Haleakala. As the moisture rises, it cools and condenses into the cloud layer that frequently rings the mountain. Rising warm air often pushes the clouds up through Ko'olau Gap and Kaupo Gap. As the evening air colls, the clouds drain out of the valley and the cycle begins again. Haleakala influences weather all around the volcano. Average annual rainfall varies from about 400 inches (1,000m) in the high-elevation rain forest above Hana to 10 inches (25 cm) in Kihei, only about 15 minutes apart. Because temperatures drop about 3.2F (1.3C) every 1,000 feet (305m), the summit of Haleakala is roughly 32F (13C) cooler than the beaches.

BUSINESS LUNCH OPTIONS WITHIN FIVE MILES

Hula Grill Kaanapali
$$ American (New), Hawaiian, Seafood
2435 Kaanapali Pkwy
Lahaina, HI
(808) 667-6636

Leilani's
$$ Seafood, American (New), Hawaiian
2435 Kaanapali Pkwy
Lahaina, HI
(808) 661-4495

Monkeypod Kitchen
$$ American (New), Cocktail Bars, Hawaiian

2435 Kaanapali Pkwy
Lahaina, HI
(808) 878-6763

Teppanyaki 2 Go By 808 Afternoons
$$ Teppanyaki, Food Trucks, Seafood
(808) 866-4025

Java Jazz & Soup Nutz
$$ Coffee & Tea, Breakfast & Brunch, American (New)
3350 Lower Honoapiilani Rd
Lahaina, HI
(808) 667-0787

C J's Deli & Diner
$$ Delis, Breakfast & Brunch
2580 Kekaa Dr
Lahaina, HI
(808) 667-0968

Relish Burger Bistro
$$ American (New), Breakfast & Brunch, Burgers
2365 Ka'anapali Pkwy
Lahaina, HI
(808) 667-2525

The Fish Market Maui
$$ Seafood, Hawaiian
3600 Lower Honoapiilani Rd
Lahaina, HI
(808) 665-9895

Ka'anapali Grille and Tap Room
$$ American (Traditional), Breweries
100 Nohea Kai Dr
Lahaina, HI
(808) 667-7733

Cafe Roseanne
$ Coffee & Tea, Shaved Ice, Breakfast & Brunch
2661 Kekaa Dr
Lahaina, HI
(808) 667-4215

Nikki's Pizza
$ Pizza, Italian
2435 Kaanapali Pkwy
Lahaina, HI
(808) 667-0333

Roy's Kaanapali

$$$ Hawaiian, Asian Fusion, Seafood
2290 Kaanapali Pkwy
Lahaina, HI
(808) 669-6999

Castaway Cafe
$$ American (Traditional), Diners, Breakfast & Brunch
45 Kai Ala Dr
Lahaina, HI
(808) 661-9091

Duke's Beach House
$$ Breakfast & Brunch, Hawaiian
130 Kai Malina Pkwy
Lahaina, HI
(808) 662-2900

Pizza Paradiso Mediterranean Grill
$$ Mediterranean, Middle Eastern, Greek
3350 Lower Honoapiilani Rd
Lahaina, HI
(808) 667-2929

Slappy Cakes
$$ Breakfast & Brunch
3350 Honoapiilani Rd
Lahaina, HI
(808) 419-6600

L&L Hawaiian BBQ Honokowai
$ Hawaiian, Barbeque, Seafood
3350 Lower Honoapiilani Rd
Lahaina, HI
(808) 667-7788

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 **Friday January 11th, 2019, 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 **Friday January 4th, 2019, 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)
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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

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Journal of the Astronautical Sciences
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Manuscripts can be submitted via: https://www.editorialmanager.com/jass

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

Journal of Spacecraft and Rockets
Editor-in-Chief: Dr. Hanspeter Schaub, University of Colorado Boulder
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Registrants are highly encouraged to record their level of satisfaction and conference preferences in an anonymous survey taken throughout the time of the conference. Please return the survey form given to you when you check in at the registration table to the registration table before departing from the conference.

COMMITTEE MEETINGS

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

Conference Technical Session Schedule

Last Update: 6 January 2019

The most up-to-date full schedule is at https://www.xcdsystem.com/aas/program/zKjDgfX/index.cfm

Monday, January 14

Session 1: Orbit Determination & Space-Surveillance Tracking
Monday, Kapulua
Chair: Brandon Jones, University of Texas at Austin

8:00 **AAS 19-220** **Analyzing Feasibility of Optical Communication Observables for Navigation**
Sarah Elizabeth McCandless, Jet Propulsion Laboratory; Tomas Martin-Mur, NASA/JPL; Reza Karimi

Future deep-space missions are intending to utilize optical communications and thereby take advantage of superior data delivery rates. The same laser-based links could also be used for interplanetary navigation. Two main optical tracking types could be used for this purpose: optical ranging and optical astrometry. These data types offer similar capabilities to the radiometric techniques currently used. This paper discusses the formulation of the data types and their success in meeting mission requirements for a variety of mission scenarios.

8:20 **AAS 19-231** **Navigation Accuracy at Jupiter and Saturn using Optical Observations of Planetary Satellites**
Nicholas Bradley, CalTech / Jet Propulsion Laboratory; Shyam Bhaskaran, Jet Propulsion Laboratory; Zubin Olikara, NASA Jet Propulsion Laboratory; Stephen Broschart, NASA / Caltech JPL

Optical-based deep-space autonomous navigation (AutoNav) on board a spacecraft has the potential to significantly reduce reliance on ground-based assets for navigation purposes. Continuing an investigation of AutoNav across the solar system, we assess optical-only navigation performance for Juno and Europa Clipper at Jupiter, and Cassini at Saturn, using simulated optical observations of natural satellites. We show that the use of AutoNav at these planets is feasible within current technological capabilities. Spacecraft position uncertainty can be as low as single kilometers, and statistical fuel allocation for injection and maneuvers can be quite low, depending on camera specifications.

8:40 **AAS 19-271** **ORBIT DETERMINATION SENSITIVITY ANALYSIS FOR THE EUROPA CLIPPER MISSION TOUR**
Zahi Tarzi, Jet Propulsion Laboratory; Sumita Nandi, NASA / Caltech JPL; Dylan Boone, NASA / Caltech JPL; Brian Young, Jet Propulsion Laboratory, California Institute of Technology.

The Europa Clipper mission will orbit Jupiter and investigate Europa's habitability utilizing a set of five remote sensing and five in-situ instruments. The tour phase of the current mission plan consists of forty-six low altitude Europa science flybys. Sufficiently accurate predicted and reconstructed spacecraft orbit determination (OD) is needed to support spacecraft pointing, measurement planning and interpretation of measurements. After briefly discussing expected OD capability, this paper will

assess the sensitivity of OD delivery and knowledge performance for the current Europa Mission trajectory through parametric variation of a baseline tour navigation strategy.

9:00 **AAS 19-445** **RECURSIVE POLYNOMIAL MINIMUM MEAN SQUARE ERROR ESTIMATION WITH APPLICATIONS TO ORBIT DETERMINATION**

Simone Servadio, University of Texas at Austin; Renato Zanetti, University of Texas at Austin

This paper presents a systematic generalization of the linear update structure associated with the extended Kalman filtering for high order polynomial estimation of nonlinear dynamical systems. A minimum variance criterion is used as a cost functional to determine the optimal gains required for the estimation process. The high order series representation is implemented effectively using Differential Algebra techniques.

9:20 **AAS 19-518** **INDENTIFYING SPACECRAFT CONFIGURATION USING DEEP NEURAL NETWORKS FOR PRECISE ORBIT ESTIMATION**

Madhur Tiwari, Embry-Riddle Aeronautical University; David Zuehlke, Embry-Riddle Aeronautical University; Troy Henderson, Embry-Riddle Aeronautical University

This paper proposes a method for classifying the configuration of a satellite using semantic segmentation in Deep Neural Networks. A semantic segmentation network is created and trained using MATLAB's Neural Net Toolbox based on upsampling and downsampling. The resulting network identifies features of a satellite (Panel and Bus). Images are taken with a ground based telescope, processed, then segmented before applying angles-only orbit determination (AIOD) methods with covariance. AIOD results with covariance are analyzed for centroid data of a full extended object vs. a feature of interest (i.e. central Bus). Results are shown for passes of the International Space Station.

10:00 **Morning Break**

10:20 **AAS 19-507** **GEOSTATIONARY SATELLITE ORBIT ACCURACY ANALYSIS FOR MANEVEUR EFFICIENCY CALIBRATION**

Yoola Hwang, ETRI; Byoung-Sun Lee, ETRI

Geostationary satellite keeps the position within the control box in order to conduct its missions. As geostationary satellites increase, the control box is restricted into small area. Thus the position evaluation for the maneuver becomes important factor for the next operation. In this research, we analyze the orbit determination (OD) uncertainty using covariance propagation and measurement residuals for the maneuver efficiency calibration. Both covariance error and measurement residuals depend on measurements noises. The maneuver efficiency is calibrated from the the delta velocityof the principal axis between the thruster telemetry information and the estimated OD.

10:40 **AAS 19-513** **Extended Kalman Filtering in Regularized Coordinates for Orbit Determination**

David Ciliberto, Pennsylvania State University; Puneet Singla, Pennsylvania State University; Manoranjan Majji, Texas A&M University, College Station

The linear error theory used in our previous work developing an extended Kalman filter (EKF) formulation in Burdet regularized coordinates is applied to the Kustaanheimo-Stiefel (KS) regularization for the purpose of estimating the unperturbed two-body motion of Earth-orbiting satellites. Challenges encountered in the development of the Burdet EKF, including the addition of error associated with the discrepancy between the regularized independent variable and time-tagged measurement data, are addressed. Similar strategies for dealing with these challenges are applied to the development of the KS EKF. Simulated orbit determination is conducted in the two regularized spaces and using a traditional Cartesian EKF.

11:00 AAS 19-515 INITIAL RELATIVE ORBIT DETERMINATION SOLUTIONS USING POLYNOMIAL SYSTEMS

Troy Henderson, Embry-Riddle Aeronautical University; Alex Sizemore, NRC; David Zuehlke, Embry-Riddle Aeronautical University; Kenneth Horneman, Emergent Space Technologies, Inc.; Alan Lovell, Air Force Research Laboratory

This paper presents a solution method for the initial relative orbit determination problem using a system of polynomials as measurement equations derived from the line-of-sight measurement problem. The measurements equations are cast as a set of six quadratic polynomials with the six initial conditions as variables. Solving for the roots of the polynomial equations is performed using three methods. Improved conditioning, through variable and equation scaling, is shown to increase the likelihood of finding correct solutions.

Session 2: Orbital Dynamics, Perturbations, and Stability I

Monday, Napili

Chair: Richard Linares, Massachusetts Institute of Technology

8:00 AAS 19-254 Stability and Targeting in Dawn's Final Orbit

Daniel Grebow, NASA / Caltech JPL; Nicholas Bradley, Jet Propulsion Laboratory; Brian Kennedy, Jet Propulsion Laboratory

The Dawn spacecraft conducted two extended missions at Ceres following the completion of the primary mission in June 2016. The final orbit of the second extended mission was designed to have a 35-km periapsis altitude for 10x higher-resolution science. The mission ends in this orbit when the spacecraft runs out of attitude control propellant. In this paper, we describe the final orbit and discuss the challenges of flying this low at Ceres. We also include our stability analysis showing the spacecraft will remain in orbit for more than 20 years, as stipulated by the Planetary Protection requirements.

8:20 AAS 19-270 Design and Control of Repeat Ground Track Orbit in High Fidelity Dynamical Model via High Order Poincaré Mapping

Roberto Armellin, University of Surrey; Yanchao He; Ming Xu, Beihang University

The aim of this work is to introduce a new semi-analytical technique for both the design and control of repeat ground-track (RGT) orbit in a high fidelity dynamical model, including non conservative forces and highly accurate Earth orientation parameters. The idea is based on the use of high-order expansion of Poincaré maps to propagate regions of the phase space forward in time for one, or

more, repeating cycles. This tool provides the means to efficiently study the effect that a Δv applied at the Poincaré crossing produces on the ground-track pattern, thus enabling highly accurate design and control.

8:40 **AAS 19-277** **Capture an asteroid to the Earth-Moon system via triangular libration points**
Yuying Liang; Jinjun Shan, York University; Ming Xu; Shijie Xu

This paper is devoted to the development of a new capture strategy via triangular libration points. First, the entire family of long- and short-period stable orbits at the triangular libration points will be obtained numerically by continuation. The transfer segments connecting parabolic orbits and parking orbits will then constructed by the stable manifolds of the unstable periodic orbits of L4/5, while the parking orbits are chosen from the stable members by hyper-Poincaré sections. To quantify the propellant cost and time of flight under such a control strategy, an interpolation algorithm will be implemented to provide a global view of these two key indicators. Finally, the sample capture trajectories using impulsive thrust

9:00 **AAS 19-310** **DROMO propagator for highly perturbed problems**
Virginia Raposo-Pulido; Hodei Urrutxua, Universidad Rey Juan Carlos; Jesus Pelaez, Technical University of Madrid (UPM)

DROMO is an orbital propagator developed in 2000 by the Space Dynamics Group at the Technical University of Madrid. This special perturbation method is characterized by eight ODE's. A new extension of DROMO for highly perturbed problems has been developed by introducing a new sets of variables. The formulation proposed is compared with the schemes proposed by Cowell, Kustaanheimo-Stiefel (KS) and Palacios et al. 1996 in double and quadruple precision. The results confirm the stability and reliability of the new formulation, showing a significant improvement with respect to the classic version of DROMO when the perturbation is close to unity.

9:20 **AAS 19-322** **Dedicated Mission to the Sun-Earth Saddle Point: A Feasibility Assessment**
Carmine Giordano, Politecnico di Milano; Francesco Topputo, Politecnico di Milano; Christian Trenkel

In this paper, periodic orbits through the Sun–Earth Saddle Point are sought. The periodic orbits survey is made using a systematic approach, firstly addressing it in the circular restricted three-body problem with the Sun and the Earth as main bodies: first attempt trajectories are sought through a grid search and then refined using a simple shooting, differential correction scheme. Stability is evaluated and a classification is made. Restricted four body problem adding the Moon is used as middle complexity model in order to find quasi-periodic orbits. These are refined in a full ephemeris high-fidelity n-body model. Preliminary results show different possible solutions with diverse characteristics and properties.

10:00 **Morning Break**

10:20 **AAS 19-328** **Sensitivity Analysis of Regularised Orbit Formulations with Interval Arithmetic**
Hodei Urrutxua, Universidad Rey Juan Carlos; Youssef Souied, Universidad Politécnica de

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

Regularised formulations provide a highly accurate description of the orbit as a geometric element, while the dynamical instabilities concentrate in the integration of the physical time. However, in highly perturbed problems, the geometric variables may also exhibit an important accumulation of propagation errors, where different formulations display distinctive error build-up patterns. To understand the error growth in each of the variables, in this paper *interval arithmetic* is used to perform a sensitivity analysis of the propagation error for various orbital formulations. The study considers a variety of orbital scenarios and conclusions are drawn based on the performed numerical tests.

10:40 **AAS 19-375** **Attitude Dependent Evolution of Orbits about Active Comets**
Mark Moretto, University of Colorado Boulder; Jay McMahon, CCAR (Colorado Center for Astrodynamics Research)

Spacecraft orbiting active comets are perturbed by gas drag from the coma. These gasses expand radially at about 0.5 km/s, much faster than orbital velocities that are on the order of meters per second. The resulting drag accelerations can be similar in magnitude to that of gravity and are thus important to model. Here we present an orbit averaging analysis of spacecraft motion about an active comet. The spacecraft will be modeled as a flat plate. This results in out-of-plane forces, enabling the use of natural dynamics for maneuvering. These dynamics can be leveraged for mission planning, operations, and science.

11:00 **AAS 19-379** **Stability and spin-orbit resonance analysis of low altitude Martian orbits**
Andres Dono, NASA Ames Research Center; Laura Plice, Metis Technology Solutions

The increasing interest in Mars orbiters brings the question of the likelihood of natural decay in low altitude regimes. This paper studies the change in shape of low altitude Mars orbits by carrying out large sets of numerical high fidelity simulations. Results showed that various configurations of the orbital elements gave perturbations that re- sulted in unstable orbits. The paper also studies the potential causes of the observed unstable regions. First by taking a close look at zonal and tesseral harmonics to find the implications of Mars mass concentrations, and second by computing theoretical spin-orbit resonances.

Session 3: Attitude Dynamics & Control I

Monday, Kula

Chair: Marcello Romano, Naval Postgraduate School

8:00 **AAS 19-202** **Lunar Reconnaissance Orbiter Operations Without a Gyro**
Julie Halverson, NASA GSFC; Oscar Hsu; Philip Calhoun

The Lunar Reconnaissance Orbiter, launched in 2009, has made groundbreaking discoveries of the moon. Star trackers and a miniature inertial measurement unit (MIMU) estimate attitude and bias in an extended Kalman filter (EKF). The MIMU, powered off in early 2018, is currently only used for momentum unloads; science slews are suspended, and the EKF is disabled. This paper presents a complementary filter applied to differentiated quaternions and angular acceleration derived from the attitude control torque to estimate a rate to replace the MIMU in the EKF, resulting in minimal flight software changes. Results from simulations and in-flight performance are included.

8:20 AAS 19-240 CONFIGURATION OPTIMAZATION OF 0-1 SUN SENSORS FOR SUN VECTOR DETERMINATION

Shijie Zhang; Botian Zhou; Shiqiang Wang

Sun vector is vital for the determination of satellite attitude, which can be coarsely estimated utilizing 0-1 sun sensors. However, the configuration of sun sensors varied from one to another and there is no standard theory for designing the configuration. Therefore, in this paper, the optimization model of the configuration of 0-1 sun sensors was first established, where the reliability, cost, and the precision of sun vector determination were in consideration. Then the configuration was optimized and the optimized results were presented. Finally, the sun vector determination error and its distribution were analyzed and the robustness was verified.

8:40 AAS 19-296 Rotations, Transformations, Left Quaternions, Right Quaternions?

Renato Zanetti, University of Texas at Austin

This paper surveys the two fundamental possible choices in representing the attitude of an aerospace vehicle: active and passive rotations. The consequences of the choice between the two are detailed for the two most common attitude parameterizations, a three-by-three orthogonal matrix and the quaternion. Successive rotations are also reviewed in this context and the choices as well as the attitude kinematic equations.

9:00 AAS 19-368 UNCERTAINTY QUANTIFICATION AND ANALYSIS OF INVARIANTS OF RIGID BODY ATTITUDE DYNAMICS

Anant Joshi, Indian Institute of Technology, Bombay; Kamesh Subbarao, University of Texas at Arlington

This paper considers uncertainty quantification in systems perturbed by stochastic disturbances, in particular, Gaussian white noise. The main focus of this work is on describing the time evolution of statistical moments of certain invariants (for instance total energy and magnitude of angular momentum of a spring-mass or mass-pendulum) for such systems. A case study for the attitude dynamics of a rigid body is presented where it is shown that these techniques offer a closed form representation of the evolution of the first and second moments of the states of the resulting stochastic dynamical system.

9:20 AAS 19-399 Fault Points Detection for Large Solar Panel Based on Photogrammetry

Hongwen Wang, Beihang University; Rui Zhong; Li Pengjie, Beihang University, Beijing, China

Modal analysis for a large solar panel is performed in this paper and a combined method of optical measuring points is designed with modal information. When the model is excited by pulse input, collect vibration displacement information to simulate the results from photogrammetry and add white noise to responses to correspond with real vision measurement results. When the vibration information of points is contaminated or one optical point is missing, this paper utilizes PCA to detect fault points with the statistic SPE. This research may help to modify the existing scheme of optical measuring points and identify modal parameters intelligently.

10:00 **Morning Break**

10:20 **AAS 19-460** **Removing Rate Un-observability in Sun Heading Filters Without Rate Gyros**
Thibaud Teil, University of Colorado, Boulder ; Hanspeter Schaub, University of Colorado; Scott Piggott, Laboratory for Atmospheric and Space Physics

A novel sun-heading filter is derived which estimates only the observable components of the rate vector. By switching between kinematic formulations, it provides not only better sun-heading estimates, but also a body rate that can be used for rate validation or control. One of the rate components will always remain unobservable, and therefore must be measured otherwise. Nevertheless, when using coarse sun sensors alone, this filter provides a minimal, fully observable, and non-singular state.

10:40 **AAS 19-473** **Heading and Angular Velocity Correlation Using Polynomial Chaos**
Christine Schmid; Kyle DeMars, Missouri University of Science and Technology

Polynomial chaos expresses a probability density function (pdf) as a linear combination of basis polynomials. If the density and basis polynomials are over the same field, any set of basis polynomials can describe the pdf; however, the most logical choice of polynomials is the family that is orthogonal with respect to the pdf. This problem is well-studied over the field of real numbers, and has been shown to be valid for the complex unit circle in one dimension. The current framework for circular polynomial chaos is extended to multiple angular dimensions with the inclusion of correlation terms.

11:00 **AAS 19-503** **Control of an Earth-Based Satellite Test Platform through Vision Based Position Measurement**
Sital Khatiwada, University of New Hampshire Mechanical Engineering; Andrew Masters, University of New Hampshire; Aaron Cantara, University of New Hampshire Mechanical Engineering; Michael Goulet, University of New Hampshire Computer Science; May-Win Thein, University of New Hampshire

In this paper, the authors propose using multirotor Unmanned Aerial Vehicles (UAVs) as an economical option of testing and evaluating satellite control processes on an Earth-based platform. To improve a multi-rotor's capacity to mimic satellites, a robust control scheme is designed and tested to assess its capabilities. An in-house vision system will be fabricated for state monitoring. The system will be integrated with the multirotor platform and evaluated for its accuracy and precision. It is expected that numerical and experimental results will provide meaningful qualitative data, granting insight on methods to improve multirotor capabilities to serve as low-cost spacecraft testbeds.

11:20 **AAS 19-531** **SPACECRAFT RADIATION PRESSURE USING COMPLEX BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTIONS ON GRAPHICS PROCESSING UNIT**
Patrick Kenneally; Hanspeter Schaub, University of Colorado

A description of a method for computing on the graphics processing unit the force and torque on a spacecraft due to solar radiation pressure. The method employs ray-tracing techniques, developed in

the graphics rendering discipline, to resolve spacecraft self-shadowing, self-reflections and complex surface material optical characteristics at faster than real-time computation speed. The primary algorithmic components of the ray-tracing process which contribute to the method's computational efficiency are described. Complex bidirectional reflectance distribution functions (BRDF) models are described. The modeling approach process is implemented using C++ and OpenCL and executed on a consumer grade graphics processing unit.

11:40 AAS 19-545 Attitude Control and Orbit Determination of a Crewed Spacecraft With a Lander in Near Rectilinear Halo Orbit

Clark Newman, a.i. solutions, Inc.; Diane Davis, a.i. solutions, Inc.; Ryan Whitley, NASA; Ryan Sieling, CACI NSS, INC.

NASA's Gateway program will place a crew-tended spacecraft in cislunar Near Rectilinear Halo Orbit (NRHO). The outpost will support crew arrival in the Orion spacecraft and the undocking and return of a crewed lunar lander. The impact on Gateway attitude control with the addition of a lunar lander is investigated. Perturbations from Orion and a lander's docking and undocking to the Gateway are considered. Deep Space Network (DSN) tracking is supplemented with remote Gateway measurements to lunar north pole craters to analyze the benefit in solution accuracy and/or DSN scheduling relief.

Session 4: Trajectory Design & Optimization I

Monday, Hana

Chair: Martin Ozimek, The Johns Hopkins University Applied Physics Laboratory

8:00 AAS 19-201 INDIRECT OPTIMIZATION OF LOW-THRUST TRAJECTORIES USING HOMOTOPY

Bradley Wall, Embry-Riddle Aeronautical University

In this work a homotopic approach is used to start with a simple indirect low-thrust trajectory solution and alter the boundary conditions slowly until the desired trajectory problem is solved. It is shown that the user can change the inclination, semimajor axis, eccentricity, and true anomaly of the target body as well as the transfer time of the trajectory. As previously shown in other works, the thrust acceleration of the spacecraft can then be changed to yield optimal bang-bang control trajectories.

8:20 AAS 19-203 Mars 2020 Mission Design and Navigation Overview

Fernando Abilleira, NASA Jet Propulsion Laboratory/Caltech; Seth Aaron, NASA Jet Propulsion Laboratory/Caltech; Chuck Baker, NASA Jet Propulsion Laboratory/Caltech; P. Daniel Burkhart, NASA / Caltech JPL; Gerhard Kruizinga, NASA / Caltech JPL; Julie Kangas, JPL; Mark Jesick, Jet Propulsion Laboratory; Robert Lange, NASA Jet Propulsion Laboratory/Caltech; Sarah Elizabeth McCandless, Jet Propulsion Laboratory; Mark Ryne, NASA / Caltech JPL; Jill Seubert, NASA / Caltech JPL; Sean Wagner, Jet Propulsion Laboratory; Mau C. Wong, JPL

Following the exceptionally successful Mars Science Laboratory mission which placed the Curiosity rover in the interior of Gale Crater in August 2012, NASA will launch the next rover in the 2020 Earth to Mars opportunity arriving to the Red Planet in February 2021 to explore areas suspected of

former habitability and look for evidence of past life. This paper details the mission and navigation requirements set by the Project and how the final mission design and navigation plan satisfy those requirements.

8:40 **AAS 19-206** **AL YAH 3 ORBIT TRANSFER RECOVERY DESIGN**

Chris Ranieri, The Aerospace Corporation; Marc DiPrinzio, The Aerospace Corporation; Peter Edelman, The Aerospace Corporation; Gregory Fruth, Aerospace Corporation; Jose Guzman, The Aerospace Corporation; James Gearhart, Northrop Grumman Innovation Services; John Hartmann; Rosemary Huang, The Aerospace Corporation; Demyan Lantukh, The Aerospace Corporation; Robert Markin

After an Ariane 5 ECA launch anomaly, the Al Yah 3 spacecraft required significantly more fuel to reach its desired GEO mission orbit slot. Northrop Grumman Innovation Systems and The Aerospace Corporation partnered to design an orbit transfer recovery sequence that maximized the achievable mission life. Using specialized trajectory optimization tools, a recovery sequence was found that maximized the performance of three different propulsion systems. The use of a tool to optimize the end-to-end transfer was critical and will be highlighted with comparisons to recovery options designed using experience and intuition. A mission life of >8 years was salvaged.

9:00 **AAS 19-226** **Hybrid Transportation System Integrated Trajectory Design and Optimization for Mars Landing Site Accessibility**

Patrick Chai, NASA Langley Research Center; Min Qu, AMA; Raymond Merrill, NASA Langley Research Center; Kaila Pfrang, Massachusetts Institute of Technology

This paper demonstrates the capability of the new integrated trajectory design and optimization method as it applies to the landing site accessibility problem for the Hybrid transportation architecture. A full system level analysis shows the limitations of the current basis of comparison designed vehicle in reaching higher latitudes. Sensitivity of the system mass to increased landing site accessibility across the full Earth-Mars synodic cycle is presented to show the additional performance requirements on the system given the current constraint of system power.

9:20 **AAS 19-236** **Optimization of Variable-Specific-Impulse Gravity-Assist Trajectories**

Zhemin Chi, Politecnico di Milano; Di Wu, Tsinghua University; Fanghua Jiang; Junfeng Li

This paper presents a series of optimization methods for finding fuel-optimal gravity-assist trajectories that utilize the practical solar electric propulsion with variable specific impulse. An optimization method combining the particle swarm optimization and the indirect method is proposed to optimize the variable-specific-impulse gravity-assist low-thrust trajectories. Additionally, the modified logarithmic homotopy function is applied to serve as a gateway in variable-specific-impulse case. The algorithm for optimization multiple-gravity-assist trajectories is also presented in this paper. Moreover, the experimental data of NASA's Evolutionary Xenon Thruster is employed in numerical simulations. Main-belt asteroids missions are given to substantiate the feasibility of the proposed methods.

10:00 **Morning Break**

10:20 AAS 19-242 On Alighting Daintily at Jupiter: Innovative Methods for Efficiently Achieving Jovian Orbit

Tim McElrath, JPL/Caltech; Stefano Campagnola, Jet Propulsion Laboratory; Anastassios Petropoulos, NASA / Caltech JPL; Amanda Haapala , Johns Hopkins University Applied Physics Laboratory; Fazle Siddique, The Johns Hopkins University Applied Physics Laboratory

Spacecraft bound for Jupiter orbit typically spend the majority of their delta-V in the capture process. The Galilean satellites provide myriad opportunities to use flybys to assist the capture process. In addition, the low solar range (compared to the other outer planets) and absence of significant rings add to the option space. Starting with typical single-flyby and Jupiter Orbit Insertion (JOI) maneuver sequences, the paper will walk through a range of capture options, including longer post-capture tours, double flybys (and their constraints), combined with solar-electric propulsion (SEP) usage, and concluding with the potential benefits of retrograde orbit insertion.

10:40 AAS 19-245 High Performance Interpolation of Chebyshev Ephemerides

Juan Arrieta, Nabla Zero Labs

We present the design and implementation of a software library used for high-performance interpolation of planetary and satellite ephemerides for the important case when such ephemerides are provided as Chebyshev polynomials. The need for such ephemerides arises when mission analysts and designers need to rely on ephemerides provided by SPICE (e.g., DE430 and JUP310), but need to significantly speed up the interpolation stage without sacrificing correctness. Our implementation relies on the exact same SPICE files but can deliver performance improvement between 10x and 100x.

11:00 AAS 19-248 Transfer between planar and three-dimensional Quasi Satellit Orbits in the vicinity of Phobos

Elisabet Canalias, CNES; Laurence Lorda; Enne Hekma, Thales Services (for CNES)

The peculiar dynamics of the Mars-Phobos couple results in the lack of keplerian orbits around this moon. Quasi Satellite Orbits are a type of Mars centered orbits, allowing to orbit Phobos in the sense of formation flying. JAXA's MMX probe intends to fly several different QSO trajectories to accomplish its scientific objectives in the Phobos proximity face. This paper presents the work performed at CNES concerning transfers between planar and 3D QSOs, in the frame of the cooperation with JAXA. The transfer strategy developed by the authors is described and applied to particular cases. A sensitivity analysis with respect to navigation and DV execution errors is also presented.

11:20 AAS 19-249 The Implementation of Maximum Likelihood Estimation in Space Launch System Vehicle Design

William Stein, Jacobs Technology/Jacobs ESSCA Group; Anthony Craig; Seth Thompson, Troy 7; Tamara Statham, Jacobs Space Exploration Group

The Space Launch System (SLS) uses a Maximum Likelihood Estimation (MLE) process in conjunction with Design of Experiments to develop statistically representative vehicles for the Block-1 and Block-1B configurations. These vehicles are the used to estimate maximum load

conditions for simulating stressing cases in other simulations. This paper discusses the MLE modeling process and how SLS captures manufacturing uncertainty in the launch vehicle design. It also provides an overview of the differences between Block-1 and Block-1B statistical representations. This paper also discusses proper DOE grid choice as well as which uncertainties drive the vehicle design.

11:40 AAS 19-255 Tube Stochastic Optimal Control For Nonlinear Constrained Trajectory Optimization Problems

Naoya Ozaki, ISAS, JAXA; Stefano Campagnola, Jet Propulsion Laboratory; Ryu Funase, The University of Tokyo

This paper presents a new algorithm to solve stochastic optimal control problems with nonlinear systems and constraints. The proposed algorithm uses the unscented transform to transcribe a stochastic optimal control problem into a deterministic problem, which is then solved by trajectory optimization methods such as differential dynamic programming. A numerical example that applies the proposed method to low-thrust trajectory design illustrates that it automatically introduces margins that improve robustness. Finally, Monte-Carlo simulations are used to evaluate the robustness and optimality of the solution.

Session 5: Artificial Intelligence in Astrodynamics

Monday, Kapulua

Chair: Roberto Furfaro, The University of Arizona

13:30 AAS 19-304 An Interactive Reinforcement Learning Approach to Real-Time Optimal Control for Celestial Landing Problems

Lin Cheng, Tsinghua University; Fanghua Jiang; Zhenbo Wang, University of Tennessee

An interactive reinforcement learning approach is proposed for real-time optimal control of celestial landing systems with irregular gravitational attraction, wherein an approximate indirect method with high computational efficiency is presented to generate the optimal control instructions for actor learning, and the trained actor returns good initial guesses to improve the success probability of the indirect method in finding optimal solutions. On this basis, a new control paradigm is developed to achieve the real-time optimal control for the celestial landing. Two examples of fuel-optimal landing problems respectively to the Moon and Eros are given to substantiate the effectiveness of these techniques.

13:50 AAS 19-441 Actor-Critic Reinforcement Learning Approach to Relative Motion Guidance in Near-Rectilinear Orbit

Andrea Scorsoglio, Politechnico di Milano; Roberto Furfaro, The University of Arizona; RICHARD LINARES, Massachusetts Institute of Technology; Mauro Massari, Politecnico di Milano

In this paper, we develop a novel feedback guidance algorithm for docking maneuvers in the cislunar environment. In particular, the aim is to create a guidance algorithm that is lightweight and closed-loop, suitable for on-board implementation. The problem has been solved starting from the well know Zero-Effort-Miss/Zero-Effort-Velocity (ZEM/ZEV) feedback algorithm using machine learning to improve its capabilities and widen its field of applicability.

14:10 AAS 19-447 Spacecraft Decision-Making Autonomy using Deep Reinforcement Learning

Andrew Harris, University of Colorado Boulder; Thibaud Teil, University of Colorado, Boulder ; Hanspeter Schaub, University of Colorado

The high cost of space mission operations has motivated several space agencies to prioritize the development of autonomous spacecraft control techniques. Learning agents present one manner in which autonomous spacecraft can adapt to changing hardware capabilities, environmental parameters, or mission objectives while minimizing dependence on ground intervention. This work considers the frameworks and tools of Deep Reinforcement Learning to address high-level mission planning and decision-making problems for autonomous spacecraft, under the assumption that sub-problems have been addressed through design. Simulated results show that learning agents can improve science return substantially over baseline policies.

14:30 AAS 19-462 SPACECRAFT RENDEZVOUS GUIDANCE IN CLUTTERED ENVIRONMENTS VIA REINFORCEMENT LEARNING

Jacob Broida, Massachusetts Institute of Technology; RICHARD LINARES, Massachusetts Institute of Technology

This paper investigates the use of Reinforcement Learning for controlling satellite rendezvous missions. We implement and evaluate two different reinforcement learning approaches for this problem: Proximal Policy Optimization (PPO) and Asynchronous Advantage-Actor Critic (A3C). Both of these methods use data sampled from repeated simulation to perform gradient descent on a parameterize policy. After sufficient training, we evaluate the performance of A3C and PPO developed policies and compare against traditional optimal control approaches. Our experimental results show that these RL approaches achieve comparable results to optimal control methods with minimal computational requirements, as well as prove effective in solving nonlinear problems.

14:50 AAS 19-479 INVESTIGATION OF DIFFERENT NEURAL NETWORK ARCHITECTURES FOR DYNAMIC SYSTEM IDENTIFICATION: APPLICATIONS TO ORBITAL MECHANICS

Damien GUEHO, The Pennsylvania State University; Puneet Singla, Pennsylvania State University; Robert G. Melton, Pennsylvania State University

Previous work investigated the learning capabilities of feed-forward neural networks based on the conservative unperturbed Keplerian two-body problem. It has been found that rich data set combined with a penalty term in loss function formulation corresponding to violation of constants of the motion during the training provide a good accuracy, close to integration tolerances. In this paper, we considerably improve previous work by considering brand new structures of neural networks such as Residual Neural Networks (ResNet) or Recurrent Neural Network (RNN). We also implement a new kind of optimizer to take into account hard constraints during the training phase.

15:10 AAS 19-537 ADAPTIVE CONTROL BY REINFORCEMENT LEARNING FOR SPACECRAFT ATTITUDE CONTROL

Mohammad Ramadan, San Diego State University; Ahmad Bani Younes, San Diego State University

A direct Neural Dynamic Programming (direct NDP) is utilized to develop an adaptive model-free controller using Temporal Difference (TD) methods. The Approximate Dynamic Programming

(ADP) is basically used to approximate the cost-to-go term of the Dynamic Programming (DP) to avoid the so-called curse of dimensionality. A new algorithm is proposed in this paper to the learning scheme. The proposed algorithm takes the advantage of the properties of the exponential function and its derivatives. From the preliminary results, our approach can provide a good on-line learning rate for a given dynamical system allowing sufficient time to train both critic and action

15:30 **Afternoon Break**

15:50 **AAS 19-560** **Low-Thrust Optimal Control via Reinforcement Learning**
Daniel Miller, Massachusetts Institute of Technology; RICHARD LINARES, Massachusetts Institute of Technology

This paper investigates a Reinforcement Learning (RL) based approach for real-time optimal control applied to the problem of finding solutions to the low-thrust cis-lunar problem. The Proximal Policy Optimization (PPO) method is used for developing complex policies by training neural network controllers to solve optimal control problems. Simulation demonstrations are shown which compare the proposed approach to "open-loop" optimal control methods. These include transfers to and from Near Rectilinear Halo Orbits, which have been identified as a possible orbit type for NASA's future Lunar Orbital Platform-Gateway.

16:10 **AAS 19-566** **COLLISION PREDICTION WITHIN A CUBESAT SWARM USING MACHINE LEARNING**
Patrick Doran; Navid Nakhjiri, California State Polytechnic University Pomona

This paper presents an algorithm of predicting collisions in a swarm of small satellites in orbit. The paper studies a case of dozen CubeSats in a relaxed-formation flying in low Earth orbits. A machine learning method based on classification is trained from hundreds of training sets made from simulations to predict the collision. The training sets are created from a simulation of the dozen CubeSats orbiting till a collision or completion of five orbits. The trained algorithm could predict a collision two orbits before and which satellites are involved.

16:30 **AAS 19-573** **TRAINING SET DATA OPTIMIZATION FOR ARTIFICIAL NEURAL NETWORKS FOR ORBITAL STATE SPACE TRAJECTORY PREDICTIONS**
Zachary Reinke, Western Michigan University

Demand on earth orbiting object surveillance systems is increasing as more equipment is put in to orbit. These systems rely on predictive techniques to periodically track objects. The demand on these systems may be reduced if object trajectories could be predicted farther into the future. The goal of this research is to develop techniques to analyze orbital state trajectory data to develop optimal training data sets used for teaching artificial neural networks (ANN) used for trajectory predictions. These methods use multi-variable statistics to analyze data energy content providing the ANN with scaled, information dense, training data.

16:50 **AAS 19-336** **Deep neural networks of Optimal Low-Thrust Orbit Raising**
Haiyang Li, Politecnico di Milano; Tsinghua University; Francesco Topputo, Politecnico di

Milano; Hexi Baoyin, Tsinghua University

Geostationary Earth orbit (GEO) satellites are of great significance in the space market. Low-thrust propulsion has been highly developed in the last decades because it is fuel saving. Therefore, the design of GEO satellites is rapidly changing from classic high-thrust propulsion more and more toward low-thrust propulsion. However, the transfer time will be quite long using low-thrust propulsion. It will be very expensive if the ground supports the whole orbit raising. Autonomous orbit raising is necessary. Deep neural networks are trained to learn the optimal control. Results show that DNNs can be utilized for future low-thrust orbit raising missions

17:10 AAS 19-397 Fast Estimation of Gravitational Field of Irregular Asteroids Based on Deep Learning and Its Applications

Yu Song, Tsinghua University; Lin Cheng, Tsinghua University; Shengping Gong, Tsinghua University

In this study, a novel approach is proposed to fast estimate the gravitational field of the irregular asteroid by the deep neural network (DNN), and the related orbital dynamics problems around the asteroid are studied based on the obtained gravitational field. A DNN architecture will be established and trained off-line to learn the gravitational field of irregular asteroids, and the gradient estimation of the gravitational field based on the DNN will be derived. Numerical examples are used to verify the effectiveness of the proposed approach.

Session 6: Asteroid & Non-Earth Orbiting Missions I

Monday, Napili

Chair: Donghoon Kim, Mississippi State University

13:30 AAS 19-243 Deployment analysis and trajectory reconstruction of MINERVA-II rovers on asteroid Ryugu

Stefaan Van Wal, Japan Aerospace Exploration Agency; Yuichi Tsuda, Japan Aerospace Exploration Agency; Kent Yoshikawa, Japan Aerospace Exploration Agency

In September 2018, the Hayabusa2 asteroid explorer deployed the small MINERVA-II-1A/B rovers to asteroid Ryugu. They contain small instruments and can hop across the asteroid surface. The mission geometry restricts all Hayabusa2 descent operations to a narrow region around the asteroid equator. Given the rovers' chaotic bouncing dynamics, it was challenging to design their deployment while complying with requirements from the other Hayabusa2 operations. We present the process applied to generate candidates for, and select the final, rover landing site. Using imagery from Hayabusa2, we attempt to reconstruct the rover trajectory and constrain Ryugu's mechanical surface properties.

13:50 AAS 19-253 Initial Orbit Determination about Small Bodies Using Flash LIDAR and Rigid Transform Invariants

Benjamin Bercovici, University of Colorado Boulder, Colorado Center for Astrodynamics Research (CCAR); Jay McMahon, CCAR (Colorado Center for Astrodynamics Research)

This paper proposes a novel approach based on the registration of 3D point clouds acquired by means of a LIDAR instrument to perform initial orbit determination in the vicinity of a small body. Specifically, the proposed methods provide position, velocity and standard gravitational parameter

estimates along with their consistent uncertainties. Besides the knowledge of the instrument inertial pointing, no a-priori information is required for the filter to function. Initial results featuring a point-mass gravity model and normally distributed Iterated Closest Point registration errors demonstrate the ability of the filter to quickly characterize the spacecraft orbit.

14:10 **AAS 19-260** **Multilayer Clustered Sampling Technique (MLCS) for Near-Earth Asteroid Impact Hazard Assessment**

Javier Roa, NASA / Caltech JPL; Davide Farnocchia

Because of planetary encounters, the motion of near-Earth asteroids is chaotic and small differences in the initial conditions tend to diverge exponentially. Linear approximations for propagating the orbital uncertainty can lead to inaccurate estimates of the probability of an Earth collision. We present a novel fully nonlinear strategy for estimating the probability of an asteroid impact using sequential Monte Carlo layers. The method first explores low-resolution layers to locate potentially relevant regions. Then, we conduct localized searches on deeper layers with higher resolution. The method retains the accuracy of Monte Carlo sampling while significantly reducing the computational cost.

14:30 **AAS 19-269** **Science Orbit Design with Frozen Beta angle: Theory and Application to Psyche mission**

Kenshiro Oguri, University of Colorado Boulder; Gregory Lantoine, NASA / Caltech JPL; William Hart, NASA / Caltech JPL; Jay McMahon, CCAR (Colorado Center for Astrodynamics Research)

Beta angle, an angle formed by the sunlight and a spacecraft orbital plane, is an important parameter for science orbit design at primitive bodies. This angle defines lighting conditions and eclipse occurrences, and is then used for science observation planning. Investigating evolution of the beta angle is therefore critical for science orbit design. This paper presents beta frozen solutions under the J2-perturbed dynamics using the averaged Lagrange Planetary Equations, and extends them to initially-frozen solutions for more flexible mission design. The analytical work is applied to science orbit design of the Psyche mission, a recently selected mission of the NASA's Discovery Program.

14:50 **AAS 19-339** **Curvilinear Surface-Based Gravity Model for Evolutionary Trajectory Optimization around Bennu**

Jason Pearl, University of Vermont; David Hinckley, University of Vermont; William Louisos, University of Vermont; Darren Hitt, University of Vermont

Trajectory optimization around small bodies presents interesting challenges due to their irregular shape. Often several competing objectives must simultaneously be considered in a high dimensional optimization landscape. As such population based optimization techniques have been applied. In the present study, a gravity model using numerical quadrature and a curvilinear surface mesh is developed to meet the requirements of a differential evolution trajectory optimization problem around Bennu.

15:30 **Afternoon Break**

15:50 AAS 19-385 Lagrange – Mission Analysis for the European Space Agency's Space Weather Mission to the Sun-Earth Libration Point L5

Florian Renk, European Space Agency; Michael Khan, European Space Agency; Mehdi Scoubeau, European Space Agency

In the frame of the European Space Agency's Space Situational Awareness Programme a space weather mission is currently being studied. For this mission the satellite is envisioned to be placed at the Sun-Earth Libration Point L5. Observations from the L5 point extend our view of the Sun by about 33% and would allow to see Sun activities not yet visible from Earth. The paper covers the 14 as well as the 26 months transfer options and dicusses the impact of the orbit size about L5 on the DeltaV budget. The stability under normal perturbations is investigated.

16:10 AAS 19-387 Trajectory design for LUMIO CubeSat in the cislunar space

Diogene Alessandro Dei Tos, Politecnico di Milano; Francesco Topputo, Politecnico di Milano

The Lunar Meteoroid Impacts Observer, or LUMIO, is a CubeSat mission concept awarded ex-aequo winner of ESA's SysNova Competition "Lunar CubeSats for Exploration" that shall observe, quantify, and characterize the meteoroid impacts by detecting their flashes on the lunar farside. After a study at the ESA/ESTEC concurrent design facility, LUMIO is now under consideration for future implementation by the Agency. In this paper, we propose the implementation of a sophisticated orbit design, concept of operations, and station-keeping strategy: LUMIO is placed on a quasi-halo orbit about Earth-Moon L_2. The baseline solution is presented with evidence to support the orbit design.

16:30 AAS 19-411 Mascot: flight dynamics activities in support of an asteroid landing mission

Elisabet Canalias, CNES; Laurence Lorda; Romain Garmier; Thierry Martin, Centre National d'Etudes Spatiales; Jens Biele, DLR; Aurélie Moussi, Centre National d'Etudes Spatiales

MASCOT is a German-French small lander that travelled onboard of the Japanese spacecraft Hayabusa2 to the C-type asteroid called Ryugu. The probe arrived at Ryugu in June 2018. Then, Hayabusa2 scientific teams started generating asteroid models that allowed for the selection of the landing sites of its passengers (Minerva-II and MASCOT landers), as well as the touchdown sites of the S/C itself. This paper describes the mission analysis and flight dynamics activities performed at CNES since the early stages of MASCOT development and until after the lander release, with special emphasis on the operational process implemented for its landing site

16:50 AAS 19-412 A new environment to simulate the dynamics in the close proximity of rubble-pile asteroids

Fabio Ferrari, NASA Jet Propulsion Laboratory

This paper presents a new environment to simulate close-proximity dynamics around rubble-pile asteroids. The code provides methods for modeling the asteroid's gravity field and surface through granular dynamics. It implements state-of-the-art techniques to model both gravity and contact interaction between particles: 1) mutual gravity as either direct N2 or Barnes-Hut GPU-parallel octree and 2) contact dynamics with a soft-body (force-based, smooth dynamics), hard-body (constraint-based, non-smooth dynamics), or hybrid (constraint-based with compliance and damping) approach. A very relevant feature of the code is its ability to handle complex-shaped rigid

bodies and their full 6D motion. Examples of spacecraft close-proximity scenarios and their numerical simulations are shown.

Session 7: Attitude Dynamics & Control II
Monday, Kula
Chair: Marco Ciarcia, South Dakota State University

13:30 **AAS 19-210** **Spacecraft Attitude Motion Planning on SO(3) using Gradient-based Optimization**
Fabio Celani, Sapienza University of Rome - School of Aerospace Engineering; Dennis Lucarelli, American University - Department of Physics

The purpose of the present work is to perform spacecraft attitude motion planning so that a rest-to-rest rotation while satisfying pointing constraints is achieved. Attitude is represented on the group of three dimensional rotations SO(3). The motion planning is executed in two steps. In the first step, path-planning is performed by searching for a time behavior for the angular rates through the formulation of an optimal control problem solved with a gradient-based algorithm. In the second step, the actual input torque is simply determined by the use of inverse attitude dynamics. A numerical example is included to show the effectiveness of the method.

13:50 **AAS 19-257** **Innovative Guidance and Control Design of the Versatile Orbit Transfer Space Vehicle of the Epsilon Rocket**
Yasuhiro Morita, Japan Aerospace Exploration Agency

This paper deals with the innovative guidance and control design of the versatile orbit transfer space vehicle. The vehicle acts as the upper stage vehicle of the Epsilon rocket and its objective is to place multiple small satellites into different orbits at significantly high accuracy. The primary issue is the high accuracy guidance and control under the relatively low thrust acceleration (long burn time). A novel guidance strategy, the extended long-time velocity increment cut-off guidance law (LVIC), is utilized to tackle this challenge.

14:10 **AAS 19-275** **HIGH PRECISION ATTITUDE CONTROL OF SPACECRAFT BASED ON ELECTRIC THRUSTER AND FLYWHEEL**
Ting Jin; Jian Cai

A new output torque strategy is proposed for attitude control actuators composed of electric thrusters and flywheels. At the initial time, the large-angle and fast attitude maneuver is realized by flywheels. When the attitude control is stable, the flywheels rotate at a constant speed without output torque, and the electric thrusters generate control torque. If the control torque exceeds the output range of electric thrusters, the flywheels output constant torque over a period of time, and the electric thrusters generate the residual control torque. Simulation results verify the feasibility of high precision attitude control based on electric thrusters and flywheels.

14:30 **AAS 19-283** **WAYPOINT FOLLOWING DYNAMICS OF A QUATERNION ERROR FEEDBACK ATTITUDE CONTROL SYSTEM**
Mark Karpenko, Naval Postgraduate School; Julie Halverson, NASA GSFC; Rebecca Besser, KBRwyle

Closed-loop attitude steering can be used to implement a non-standard attitude maneuver by using a conventional attitude control system to track a profile of downsampled attitude commands (waypoints) stored in a spacecraft's command buffer. In this paper, we explore the waypoint following dynamics of a quaternion error feedback control system. It is shown that using downsampled commands induces a ripple between samples that causes the satellite angular rate to significantly overshoot the desired limit. Analysis in the z-domain is carried out in order to understand the phenomenon. NASA's Lunar Reconnaissance Orbiter is used to illustrate the behavior of a practical attitude control system.

14:50 **AAS 19-287** **Attitude Maneuver Design for Planar Space Solar Power Satellites**

Michael Marshall, Graduate Aerospace Laboratories, California Institute of Technology; Ashish Goel, Jet Propulsion Laboratory; Sergio Pellegrino, Graduate Aerospace Laboratories, California Institute of Technology

This paper investigates the attitude dynamics of planar space solar power satellites (SSPSs) by formulating the power-optimal guidance problem as a nonlinear optimal control problem. The power-optimal guidance problem determines the attitude maneuvers that maximize the power transmitted to Earth. This transmitted power depends on the relative geometry between the SSPS, Sun, and receiving station. Hence, it is inherently coupled to the SSPS's attitude. We solve the power-optimal guidance problem to obtain attitude maneuver designs for various orbits. By quantifying control and propellant requirements for various orbits, we emphasize how maneuver dynamics play an important role in SSPS design.

15:30 **Afternoon Break**

15:50 **AAS 19-319** **Predicting Time-Optimal Slews Across Multiple Spacecraft with Inertia Ratios and the Agility Envelope**

Jeffery King, U.S. Naval Academy; Yash Khatavkar, U.S. Naval Academy

This paper expands the prior findings by using a normalized satellite inertia tensor and demonstrating a direct relationship between the agility envelope and the time benefit of using optimal control maneuvering. This relationship was validated by analyzing 5184 maneuvers across 4π steradian for each satellite configuration. Since the agilitoid is defined by the physical configuration (reaction wheel and spacecraft inertia), it can be easily calculated without resorting to extensive simulation. This method achieves a simple and effective estimation of the benefit of optimal control maneuvering for any spacecraft.

16:10 **AAS 19-374** **NUMERICAL RESULTS ON THE GENERAL TIME-OPTIMAL REST-TO-REST THREE-AXIS REORIENTATION OF A RIGID SPACECRAFT**

Marcello Romano, Naval Postgraduate School; Alanna Sharp, Naval Postgraduate School

The time optimal results to the rest-to-rest three-axis reorientation of a rigid spacecraft are presented as a stereographic projection with respect to the eigenvector sphere for all possible rest-to-rest reorientation maneuvers of a given slew angle. The pseudospectral method is used to obtain the numerical results over a selec- tion of azimuths and elevations within the first octant of the eigenvector sphere. The stereographic projection method used in cartography then translates the

three dimensional eigenvector coordinates to a two dimensional plane at the equator of the eigenvector sphere. These projections are applicable to inertially symmetric, axisymmetric, and asymmetic spacecraft.

16:30 AAS 19-490 Discrete-Time Iterative Learning Control for Nonlinear Systems by Feedback Linearization

Bing Song, Columbia University; Minh Phan, Dartmouth College; Richard Longman, Columbia University

Iterative learning control (ILC) learns to track a pre-defined maneuver with high accuracy through practice. It aims to approach the hardware reproducibility error level, beyond the accuracy of the system model used in the learning process. ILC can be used in spacecraft fine pointing sensors doing repeated scanning maneuvers. This paper is one of a series that extends ILC to classes of nonlinear systems, besides linearization/bilinearization-based ILC algorithms. Feedback linearization is another alternative that offers the possibility to apply linear ILC for learning in nonlinear systems. Numerical examples demonstrate the comparison of these ILC methods for nonlinear systems.

16:50 AAS 19-572 ON THE USE OF SINGULAR VALUE DECOMPOSITION BASIS FUNCTIONS TO PREVENT ERROR SIGNAL ACCUMULATION IN ITERATIVE LEARNING CONTROL

Bowen Wang, Columbia University; Richard Longman, Columbia University

Iterative Learning Control (ILC) aims to achieve zero error when performing the same finite-time task repeatedly. The learning during transients are of importance for ILC to achieve zero tracking error in a finite time, particularly when the desired trajectory is short compared to the system settling time. Using basis functions can not only decrease the computation burden, but also provides solution to obtain a bounded control action sequence. Basis functions based on system Toeplitz matrix are developed, which can prevent the accumulation of errors outside the span of output basis functions that are produced during learning processes.

Session 8: Trajectory Design & Optimization II

Monday, Hana

Chair: Sonia Hernandez, Jet Propulsion Laboratory

13:30 AAS 19-259 DESIGNING LOW-ENERGY TRANSFERS FROM LOW-EARTH ORBIT TO A TEMPORARILY-CAPTURED ORBITER

Kanta Yanagida; Naoya Ozaki, ISAS, JAXA; Ryu Funase, The University of Tokyo

Temporarily-Captured Orbiters (TCOs) are a new population of asteroids that are captured by Earth's gravity. Due to its proximity to the Earth, short-term exploration with small delta-V is expected possible. This study aims to construct low-energy transfers to 2006 RH120, one of the TCOs, from Low-Earth Orbit using an analogy with the lunar transfers. The initial guess was sought by back-propagating perturbed TCO trajectories, which was then optimized through the direct multiple shooting method. The result shows that various transfers are possible with rendezvous delta-V even below 100 m/s, and that they form family structures.

13:50 AAS 19-265 A TITAN GRAVITY-ASSIST TECHNIQUE FOR BALLISTIC TOURS SKIMMING OVER THE RINGS OF SATURN

Mar Vaquero, Jet Propulsion Laboratory; Juan Senent, Jet Propulsion Laboratory; Matthew Tiscareno, Carl Sagan Center for the Study of Life in the Universe, SETI Institute

A novel type of Titan-flyby orbits featuring passes of the Saturn rings at close range has been recently discovered. The purpose of this study is to explore the trajectory design space and assess the applicability of such orbits to the design of a Saturn Ring Tour mission concept. A set of initial conditions required to start a tour is first determined, and a ΔV sequence to maximize the science time over desired ring regions in terms of range distance, relative velocity and duration is then selected. To demonstrate the potential of this technique, two sample ballistic ring tours are detailed.

14:10 AAS 19-285 Robust Optimisation of Low-Thrust Interplanetary Transfers using Evidence Theory

Marilena Di Carlo, University of Strathclyde; Massimiliano Vasile, University of Strathclyde; Cristian Greco, University of Strathclyde; Richard Epenoy, Centre National d'Etudes Spatiales

This work presents the formulation and solution of optimal control problems under epistemic uncertainty, when the uncertainty is modelled with Dempster-Shaffer theory of evidence. The application is to the design of low-thrust interplanetary transfers with epistemic uncertainty in the performance of the propulsion system and initial launch mass. The problem is solved by transforming the exact formulation, that uses discontinuous Belief functions, into an inexact formulation that uses a new continuous statistical function that approximates the value of the Belief function. The method is applied to the design of optimal low-thrust transfers from the Earth to asteroid Apophis.

14:30 AAS 19-294 CHARTING A COURSE TO THE SUN: FLIGHT PATH CONTROL FOR PARKER SOLAR PROBE

Powtawche Valerino, NASA / Caltech JPL; Paul Frank Thompson, Jet Propulson Laboratory; Drew Jones, Jet Propulsion Laboratory, Caltech; Troy Goodson, NASA / Caltech JPL; Robert Haw, NASA / Caltech JPL; Eunice Lau, NASA / Caltech JPL; Neil Mottinger, NASA / Caltech JPL; Mark Ryne, NASA / Caltech JPL

The successful launch of the Parker Solar Probe (PSP) during the early morning of August 12, 2018 on a Delta IV rocket and Star 48BV third stage has placed the spacecraft on a 7-year trajectory to study the Sun. The goals of PSP are to better characterize the solar environment by collecting data as close as 9.86 solar radii. This paper documents the analysis of 42 planned trajectory correction maneuvers in preparation for the achieved launch date, along with the post-launch maneuver activities. Since the previous paper, two design cycles were completed; they included the analysis of refined inputs for 24 reference trajectories.

14:50 AAS 19-295 MARS GRAVITY ASSIST OPTIONS TO REDUCE MISSION ΔV FOR EUROPA LANDER

Amanda Haapala , Johns Hopkins University Applied Physics Laboratory; Tim McElrath, JPL/Caltech; Fazle Siddique, The Johns Hopkins University Applied Physics Laboratory

For the Europa Lander concept, a Carrier spacecraft transports a Lander to Jupiter's moon, Europa, to perform in-situ science aimed at detecting bio-signatures. Launch is planned for 2026 using the SLS Block-1B to accommodate the mass of the Carrier and Lander. A 2026 baseline launch offers

the opportunity for a unique set of Mars gravity assists (MGA) for both baseline and backup launch options. By exploiting MGAs during interplanetary cruise, total mission ΔV is reduced from 2.3 to 1.7 km/s, and the spacecraft wet mass is correspondingly reduced.

15:10 **AAS 19-297** **A Survey of the Methods Available for the Design of Many-Revolution Low-Thrust Planetocentric Trajectories**

Pradipto Ghosh, Analytical Graphics, Inc.

The mission use of electric propulsion (EP) systems providing continuous, low thrust has steadily increased over the past several years. As EP technology continues to mature, the upward trend in its efficient utilization is expected to persist. A particularly challenging and long-studied low-thrust trajectory design problem is Electric Orbit Raising, i.e. the design of many-revolution, long duration transfers in the planetocentric space. Numerous methods, both analytical and numerical, optimal and sub-optimal, open-and-closed-loop, and involving models of various degrees of complexity, have been proposed. This paper attempts to characterize and classify the more popular of these methods and their variants.

15:30 **Afternoon Break**

15:50 **AAS 19-298** **Julia Language 1.0 Ephemeris and Physical Constants Reader for Solar System Bodies**

Kaela Martin, Embry-Riddle Aeronautical University (ERAU); Julia Mihaylov, Embry-Riddle Aeronautical University (ERAU); Renee Spear, Embry-Riddle Aeronautical University (ERAU); Damon Landau, NASA / JPL

An ephemeris reader in the Julia Language that includes small bodies, asteroid shape modeling, and higher order spherical harmonics is presented here. The second generation of this ephemeris reader introduces shape models of known asteroids as well as spherical harmonics capabilities to support gravitational potential models. This version of the ephemeris reader is also compatible with Julia 1.0 which was released in August of 2018. This second-generation version continues to support the obtainment of critical information needed for mission and trajectory design.

16:10 **AAS 19-299** **Multi-step Optimization of Orbit Raising Trajectories for All-electric Propulsion Geostationary Satellites**

Kentaro Nishi, Japan Aerospace Exploration Agency (JAXA); Satoru Ozawa, Japan Aerospace Exploration Agency (JAXA); Saburo Matunaga

An all-electric propulsion satellite has become a major system architecture for geostationary communication satellites. To mitigate drawbacks caused by its low-thrust such as long stay in severe radiation environment, minimum-time transfer is necessary. In this paper, we propose a multi-step optimization of orbit raising trajectories for the all-electric propulsion satellites. This method splits the problem into multiple steps and optimizes thrust-vector direction in each step. It lightens the computational load and requires no initial guess. This paper describes detail of the method and evaluates optimality of the method. It also provides numerical results and a comparison with an existing method.

16:30 AAS 19-306 Reachable Domain of Continuous Low-Thrust Trajectories with Linearized Dynamic Model

Zhaowei Wang, Tsinghua University; Fanghua Jiang

An analytical method is improved for reachable domain of noncircular orbit propelled by low thrust within fixed allowable transfer time, using the linearized differential equations of relative motion. The projection of the relative reachable domain for noncircular and non-coplanar orbits can be obtained by numerical calculation of the derived analytical expressions. A geometrical construction technique based on the envelope theory of family of surfaces is developed to determine the envelope of the reachable domain. Two numerical examples demonstrate the usefulness of the proposed method and show that the reachable domains consist well with the ones obtained by indirect method.

16:50 AAS 19-308 Optimal Hyperbolic Rendezvous Trajectories for Cycler Missions

Mauro Pontani, Sapienza University of Rome

Cycler mission architectures consider the use of a large space vehicle that cycles continuously between Earth and Mars. While this large spacecraft, termed the cycler, is employed in the interplanetary arc, taxi vehicles of reduced size are sufficient for the connection between each planet and the cycler. This research provides a comprehensive analysis on optimal hyperbolic rendezvous trajectories, with reference to two classes of rendezvous problems: (i) multiple-velocity-impulse paths and (ii) low-thrust trajectories. Optimal high-thrust rendezvous trajectories include up to four velocity changes. Moreover, low-thrust propulsion is proven to possess the potentiality of outperforming high-thrust in the future.

17:10 AAS 19-311 Adjoint Estimation Method for Low-thrust Many-revolution Trajectory Optimization

Di Wu, Tsinghua University; Hexi Baoyin, Tsinghua University; Junfeng Li

This paper presents an adjoint estimation method for many revolution transfers. First the many-revolution transfer problem is formulated as a multi-rendezvous problem with the same boundary conditions. The initial guess of adjoint variables are obtained by the shape-based path technique. A transforming method of the adjoint variables is then developed to get the results of the many-revolution transfer. Then, based on the optimality analysis, an iterative optimization algorithm is proposed to ensure that the nominal trajectories approach the optimum. In this way, the initial guess is obtained by solving linearized equations analytically. Two scenarios are conducted as examples.

Tuesday, January 15

Session 9: Orbital Debris & Space Environment
Tuesday, Kapulua
Chair: Simone D'Amico, Stanford University

8:00 **AAS 19-229** **Conjunction Assessment and Risk Mitigation Automation (CARMA)**
Mark Vincent, Raytheon

The Conjunction Assessment and Risk Mitigation Automation (CARMA) process at the Jet Propulsion Laboratory was a natural response to the devolution strategy of the NASA Conjunction Assessment Risk Analysis (CARA) institution. The progress in the implementation of the distributed CARA software, any enhancements made, and preliminary test results will be described. CARMA research includes matching the NASA lifetime risk criteria to the Probability of Collision (Pc) thresholds used in operations. A new tool produces Predicted Maneuver Trade Space plots, which give a range of Pc values for a chosen maneuver given a model of *future* uncertainties from new observations.

8:20 **AAS 19-557** **Resident Space Object Proper Orbital Elements**
Aaron J. Rosengren, University of Arizona; Davide Amato, Technical University of Madrid (UPM); Claudio Bombardelli, Technical University of Madrid (UPM); Moriba K. Jah, University of Texas at Austin

Proper elements are obtained as a result of the elimination of short and long periodic perturbations from their instantaneous, osculating counterparts, and therefore represent a kind of average characteristic of motion. Projected into proper element space, asteroids tend to cluster around special values of the orbital elements leading to their classification into dynamical families. Proper elements thus appear to have application to a number of underpinning areas of SSA in terms taxonomy of RSOs and the associated of debris from breakup into its parent satellite. Here, we will work out the theory of proper orbital elements in the circumterrestrial context.

8:40 **AAS 19-268** **Mass Estimation Through Fusion of Astrometric and Photometric Data Collection with Applications to Orbital Debris Characterization**
Matthew Richardson, L3 Applied Defense Solutions; Thomas Kelecy, Applied Defense Solutions; Jason Stauch, Applied Defense Solutions; Jack Wetterer, Integrity Applications Incorporated; Channing Chow, Pacific Defense Solutions, LLC

A formulation is presented for estimating the mass of a space object from the fusion of astrometric and photometric data processed through a particle filter. The application for such a tool is to characterize the mass of an unknown debris object and quantify the mass uncertainty through the estimation method. This will facilitate understanding of unknown debris objects when characterizing such objects with quantifiable uncertainty. Observability, in conjunction with consider analysis of the states, was incorporated and shown to be a good indicator of when mass, size and attitude can be estimated.

9:00 **AAS 19-320** **Interpolation and Integration of Phase Space Density for Estimation of Fragmentation Cloud Distribution**
Stefan Frey, Politecnico di Milano; Camilla Colombo, Politecnico di Milano; Stijn

Lemmens, European Space Agency

On-orbit fragmentations potentially produce hundreds of thousands of debris. The evolution of a fragmentation cloud is modelled to estimate the consequences such events have on the space environment. Propagating the characteristics of the continuum equation can accurately estimate the density given any generic force model. However, interpolation and integration from point clouds is challenging. Here, a method is presented to estimate the underlying distribution through Delaunay triangulation. Alpha shapes are used to manage non-convex distributions. Integration is performed on individual simplexes to give consistent marginals independent of bin sizes. The method is shown to outperform others based on representative objects.

9:20 **AAS 19-438** **Data-driven investigation of thermospheric variations**

Piyush Mehta, West Virginia University; RICHARD LINARES, Massachusetts Institute of Technology

This paper presents a methodology for data-driven investigation of thermospheric variations that uses modal decomposition to extract high-dimensional basis for the correlated variation of the neutral thermospheric species and temperature. The extracted basis functions are combined with CHAMP and GRACE mass density measurements using a non-linear least squares solver. We demonstrate the methodology using the MSIS model to derive high-dimensional basis functions. We use the methodology to investigate oxygen-to-helium transition through variations of the individual species as both species have a direct impact on drag and orbit prediction through gas-surface interactions and mass density.

9:40 **AAS 19-439** **On deriving Self-Consistent, High-accuracy Mass Density Measurements**

Piyush Mehta, West Virginia University

High-accuracy thermospheric mass densities derived from measurements of orbital drag on-board the CHAMP and GRACE satellites have been the workhorse of upper atmospheric research for more than a decade. These estimates use drag coefficients (C_D) computed with neutral species composition from some empirical model that provides global estimates by combining diffusive equilibrium profiles with lower boundary number density estimates that can contain errors. Recent work on self-consistent calibration of empirical models provide insight into the errors in lower boundary estimates and temperature profiles and this paper investigates its impact on the derivation of the measurements used to calibrate them.

10:00 **Morning Break**

10:20 **AAS 19-465** **Robustness of Targeting Regions of Chaos In the GNSS Regime**

Marielle Pellegrino, University of Colorado Boulder; Daniel Scheeres, University of Colorado at Boulder

This paper investigates the sensitivity of resonant and chaotic orbital dynamics proximate to GNSS satellites. These regions are caused by luni-solar resonances and are defined by the semimajor axis, eccentricity, and inclination. However, they are dependent on the position of the sun, moon, and other orbital parameters. This work will describe how sensitive the system is based on the different orbital parameters in an effort to determine the feasibility of targeting these regions for debris

disposal.

10:40 AAS 19-502 Koopman Operator Theory for Thermospheric Density Modeling

RICHARD LINARES, Massachusetts Institute of Technology; Piyush Mehta, West Virginia University; Humberto C. Godinez, Los Alamos National Laboratory; David Gondelach, University of Surrey, UK

Low-Earth orbiting (LEO) satellites are heavily influenced by atmospheric drag, which is very difficult to model accurately. This paper demonstrates the Koopman Operator (KO)-theory applied to the TIE-GCM model. The goal of this work is to use a physics-based atmospheric density model for obtaining a Reduced-Order Model (ROM) for density forecasting. It is shown that Koopman/Extended Dynamic Model Decomposition (DMD) approach can reduce propagation error while using fewer modes as compared to the DMD approach which assumes a linear model.

11:00 AAS 19-409 A density-based approach to the propagation of re-entry uncertainties

Mirko Trisolini, Politecnico di Milano; Camilla Colombo, Politecnico di Milano

The proposed study aims at implementing a density-based approach for the propagation of uncertainties in the initial conditions and parameters for the analysis and prediction of spacecraft re-entries. Using the continuity equation together with the re-entry dynamics, the joint probability distribution function of the uncertainties is propagated and the final uncertainties in the re-entry corridor, impact location, and casualty area are quantified. The paper considers uncertainties in the initial conditions at re-entry and in the ballistic coefficient of the satellite for different types of re-entry scenarios, studying the effects that such uncertainties have on the impact location and entry corridor.

11:20 AAS 19-480 Large Constellation De-Orbiting with Low-Thrust Propulsion

Simeng Huang, Politecnico di Milano; Camilla Colombo, Politecnico di Milano; Elisa Maria Alessi, IFAC-CNR; Zhili Hou, Tsinghua univercity

This paper deals with the de-orbiting of large constellations using low-thrust propulsion. The objective is to de-orbit all satellites without any inner-constellation collision. Two de-orbit strategies are considered — the first is lowering the perigee and the second is reaching a natural de-orbiting highway. The research will be conducted via two layers — the first layer is designing the trajectories for a single satellite and the second layer is minimizing the risk of inner-constellation collision. For the first layer, three different control methods are investigated; the orbital averaging technique and the direct apporach are used.

Session 10: Orbital Dynamics, Perturbations, and Stability II

Tuesday, Napili

Chair: Thomas Kelecy, L3 - Applied Defense Solutions

8:00 AAS 19-390 SECULAR ORBITAL ELEMENT VARIATIONS DUE TO CONTINUOUS LOW-THRUST CONTROL AND THIRD-BODY PERTURBATIONS

Xiaoyu Liu, University of Glasgow; Colin McInnes, University of Glasgow; Matteo Ceriotti, University of Glasgow

An analytical method is investigated to evaluate the orbital element variations of a massless particle in orbit about a central body, under the influence of continuous low-thrust control and third-body perturbations. The third-body disturbing function is expanded in the form of Legendre polynomials and truncated up to the second-order term. The components of continuous low-thrust control are then represented as Fourier series in eccentric anomaly. Finally, the variational equations for the particle orbital elements are averaged over the period of the particle to yield the secular effects. Numerical simulation verifies the efficiency of the methodology.

8:20 AAS 19-396 Trajectory Design in the Circular Restricted Three-body Problem Using Artificial Invariant Manifolds

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

This paper generalizes invariant manifolds of unstable libration point orbits through the application of constant thrust acceleration. First, artificial periodic orbits and their associated invariant manifolds are introduced. It is shown that heteroclinic connections between an artificial periodic orbit and an unforced periodic orbit with the same Jacobi constant are realized by detecting intersections of manifolds on the Poincare section. Second, new Jacobi constant incorporating the constant acceleration is defined. By utilizing the new Jacobi constant, zero-velocity curves for the motion under constant thrust are shown and revealed that there exist transit orbits which connect different regions in the CRTBP.

8:40 AAS 19-401 VERY LONG ARC TIMING COEFFICIENT AND SOLAR LUNAR PLANETARY EPHEMERIS FILES AND APPLICATIONS

Zachary Folcik, MIT Lincoln Laboratory; Paul J. Cefola, University at Buffalo (SUNY)

Precision orbit determination programs require time difference, polar motion parameter, solar, lunar, and planetary (SLP) ephemeris, and rotation matrix data. A single set of Timing Coefficient and SLP files valid from 1973 to 2169 is developed. The start date is dictated by the IERS data. The end date is dictated by the DE 200 file. DE 200 provides information referred to the dynamical equator and equinox of 2000. The 196 year Timing Coefficient file requires consideration of the transition from observed to extrapolated data. Cumulative Distribution Function (CDF) plots are given. The performance of the 196 year files is explored.

9:00 AAS 19-512 A HIGH ORDER ANALYTIC CONTINUATION TECHNIQUE FOR THE PERTURBED TWO-BODY PROBLEM STATE TRANSITION MATRIX

Tahsinul Haque Tasif, University of Central Florida; Tarek Elgohary, University of Central Florida

In this work, the analytic continuation technique is used to derive the State Transition Matrix for the perturbed two body problem resulting in a fast, high precision solution that outperforms state of the art numerical methods. Analytic Continuation is a Taylor series based technique where two scalar Lagrange like invariants are defined and differentiated to an arbitrary order by using Leibniz product rule. These derivatives are used in the Taylor series expansion to obtain the solution. Previously, this method has been applied to several trajectory calculations, which gave high precision solutions with a comparatively lower computational cost.

9:20 AAS 19-470 Identification of Families of Periodic Orbits Above/Below the Solar Sail Earth-Moon Libration Points

Jules Simo, University of Central Lancashire

This paper addresses the problem of finding periodic solutions in the circular restricted three- body problem (CRTBP) with the Earth and Moon as the two primaries and the third massless body a solar sail. Based upon the first-order approximation, an analytical formulation of the periodic orbits at linear order is presented. The approximate analytical solutions found are utilized in a numerical search to determine displaced periodic orbits in the full nonlinear model. In order to illustrate the near term and possible future orbits that can be achieved, we have generated the results for several values of the characteristic acceleration.

9:40 **AAS 19-510** **Feasibility study of near-frozen, near-circular, near-polar and extremely low altitude lunar orbits**

Sandeep Singh, Texas A&M University; Robyn Woollands, Jet Propulsion Laboratory; John L. Junkins, Texas A&M University

Designing long duration lunar orbiter missions is challenging due to Moon's nonlinear gravity field and third body perturbations. The absence of a lunar atmosphere, has encouraged mission designers to search for extremely low altitude, stable lunar orbits as they present an opportunity for unique scientific studies such as high resolution imaging of polar ice deposits in deep craters. Inaccuracy in gravity models severely impacted duration of several past lunar orbiters. In this paper, we perform a station keeping feasibility study for near-frozen, near-circular, near-polar and extrememly low altitude orbits around the Moon. We study the trade-space between mission duration and corrective impulses.

10:00 **Morning Break**

10:20 **AAS 19-526** **ANALYSIS OF DISTURBANCE ANOMALY OF INTERPLANETARY MICRO-SPACECRAFT PROCYON**

Satoshi Ikari, The University of Tokyo; Takaya Inamori, Nagoya University; Takahiro Ito, Japan Aerospace Eploration Agency; Ryu Funase, The University of Tokyo

Drugin the operation of the first 50-kg class interplanetary micro-spacecraft PROCYON,it's gradient of the angular momentum on Z-axis was suddenly changed without any external torque generation from propulsion system and attitude maneuver. In other words, disturbances acting on the spacecraft was suddenly increased by 10^{-8} Nm oder at the point. In order to reveal the cause of the disturbance anomaly, we investigated accurate solar radiation pressure, thermal radiation pressure, interplanetary magnetic field torque, and collision with proton particle. These detailed investigations of minor disturbances with real flight data will contribute for future accurate navigation of interplanetary spacecraft.

10:40 **AAS 19-544** **Analytical Radial Adaptive Method for Spherical Harmonics Gravity Models**

Ahmed Atallah, San Diego State University; Robyn Woollands, Jet Propulsion Laboratory; Ahmad Bani Younes, San Diego State University; John L. Junkins, Texas A&M University

High precision propagation for satellites orbiting the Earth require accurate computation of the gravitational acceleration at each integration step. This is a computationally expensive operation that depends on the orbit geometry and the accuracy to which the solution is required. High accuracy

solutions require a large degree and order in the spherical harmonic series which increases the computation time. In this paper we present an analytic method for which the degree of the spherical harmonic series is automatically selected based on the desired solution accuracy and the radial distance of the satellite from the Earth.

11:00 AAS 19-554 Retrograde Teardrop Orbits about Asteroids: Application to the Hayabusa2 Mission

Shota Kikuchi, Japan Aerospace Exploration Agency; Yusuke Oki, The University of Tokyo; Takanao Saiki, JAXA / ISAS; Yuto Takei; Hiroshi Takeuchi, Japan Aerospace Exploration Agency; Go Ono, Japan Aerospace Exploration Agency; Hitoshi Ikeda, Japan Aerospace Exploration Agency; Yuichi Tsuda, Japan Aerospace Exploration Agency

This research investigates retrograde teardrop orbits (RTOs) about asteroids subject to strong solar radiation pressure (SRP). RTOs are closed orbits that are made periodic by introducing a deterministic impulsive delta-V within each period. This type of artificial periodic orbit provides high flexibility in the orbit design compared with natural periodic orbits. RTOs are promising options for asteroid missions because of their stability and small delta-V values (on the order of 10 cm/s or less). This paper presents the dynamical theories of RTOs and possible applications for the Hayabusa2 mission.

11:20 AAS 19-564 ANALYTIC PROBABILITY DENSITY MODEL OF SATELLITE SWARMS

Yupeng Gong

A probability density model is developed to calculate the spatial distribution and coverage performance of satellite swarms on various orbits. Probability density function describes the probably location of the satellites and considers the evolution under the effect of gravitational perturbations, solar radiation pressure and drag. Since the satellite quantities can be represented by the distribution of the sum of satellite probability density functions, the coverage property of swarms can be calculated. Remarkably, the probability distribution of coverage property can be calculated by interval and distribution of orbit elements without need for precise orbital parameters.

Session 11: Atmospheric Re-entry & Satellite Constellations

Tuesday, Kula

Chair: Kamesh Subbarao, University of Texas at Arlington

8:00 AAS 19-212 Investigation of Direct Force Control for Planetary Aerocapture at Neptune

Rohan Deshmukh, Purdue University; Soumyo Dutta, NASA Langley Research Center; David A. Spencer, Purdue University

In this work, a direct force control (DFC) numerical predictor-corrector guidance architecture is developed to enable Neptune aerocapture using low-L/D blunt body aeroshells. Optimal control theory is applied to obtain the angle of attack and side-slip angle guidance laws for a Mars Science Laboratory-derived aeroshell. Robustness testing and performance analysis are performed in a Monte Carlo setting using the Program to Optimize Simulated Trajectories II. The simulated trajectories are demonstrated to be both robust to the modeled dispersions and at a low total delta-v cost. DFC guidance is shown to be an enabling and enhancing technology for low-L/D planetary aerocapture.

8:20 AAS 19-301 Autopilot for Near-Space Hypersonic Vehicle Controlled by Aerodynamic Lift and Divert Thrusters with Off-Centered Seeker Window

Penglei Zhao; Wanchun Chen; Wenbin Yu

This paper presents the design of an autopilot of the near-space hypersonic vehicle that is controlled by aerodynamic lift and divert thrusters and has an off-centered seeker window. To decouple the control of attitude and trajectory, a command allocation algorithm following the aerodynamic-divert-first principle is proposed to coordinate the divert and attitude control systems. Thereafter, a high-order sliding mode controller using nonlinear dynamic sliding manifold technique is designed for the control of the attitude control system, and a pulse-width pulse-frequency modulator is designed for the control of the divert control system. Simulations demonstrate the effectiveness and robustness of the autopilot.

8:40 AAS 19-463 PARKING ORBIT SELECTION FOR MARS AEROCAPTURE-ENTRY SYSTEMS

Evan Zinner, University of Illinois at Urbana-Champaign; Zachary Putnam, University of Illinois at Urbana-Champaign

This study explores parking orbit selection for an aerocapture-entry system at Mars and assesses the impact on vehicle design. This study explores the effect of parking orbit selection on the total entry system mass. The effect of non-virgin thermal protection system during entry, descent, and landing is considered. The analysis finds that the mass from the thermal protection system does not vary significantly depending on orbit selection. The larger driver of entry system mass is the propellant needed to stabilize the parking orbit. This leads to longer period parking orbits having less entry system mass

9:00 AAS 19-468 STOCHASTIC REACHABILITY ANALYSIS FOR THE HYPERSONIC RE-ENTRY PROBLEM

Amit Jain, Penn State University; Damien GUEHO, The Pennsylvania State University; Puneet Singla, Pennsylvania State University; Maruthi R. Akella, University of Texas at Austin

In this paper, a computationally efficient approach will be presented to enable on- board computation of reachability sets for the hypersonic re-entry problem. The main idea of the presented approach is to consider the bounded control variables as random variables and represent the reachability sets as the level sets of the state probability density function. A main advantage of such an approach is that it provide not only the boundary of the reachability set but it also characterizes the probability distribution of state variable due to variation in control input. The computation of state density function due to variation in

9:20 AAS 19-499 Mid-Lift-to-Drag ratio Rigid Vehicle 6-DoF EDL Performance Using Tunable Apollo Powered Guidance

Breanna Johnson, NASA; Ping Lu, San Diego State University; Christopher Cerimele, NASA Johnson Space Center

The Mid-Lift-to-Drag ratio Rigid Vehicle (MRV) is a candidate in the NASA multi-center effort to determine the most cost effective vehicle to deliver a large-mass payload to the surface of Mars for a human mission. Products of this effort include six-degree-of-freedom (6DoF) entry-to-descent trajectory performance studies for each candidate vehicle. These high fidelity analyses help determine the best guidance and control (G&C) strategies for a feasible, robust trajectory. This

paper presents an analysis of the MRV's G&C design by applying common entry and descent associated uncertainties using a Fully Numerical Predictor-corrector Entry Guidance (FNPEG) and tunable Apollo powered descent guidance.

10:00 **Morning Break**

10:20 **AAS 19-491** **Neural Network Trained Controller for Atmospheric Entry in Mars Missions**
Hao Wang, University of Central Florida; Dillon Martin, University of Central Florida; Tarek Elgohary, University of Central Florida

We will present a new method to design the controller of Mars capsule atmospheric entry using neural networks. Compared to Apollo controller as a baseline, the simulation of neural network controller reproduced the classical Apollo results over a wide variation of initial conditions and system parameters, e.g. atmospheric drag. This leads to the potential of achieving requirements of future manned Mars missions. The data from Earth and Mars models are used for neural networks training. The neural network for Earth reentry is evaluated with Apollo real data and then adapted for the Mars environment.

10:40 **AAS 19-508** **Guidance and Control System Design for Mars Aerocapture**
Larissa Balestrero Machado, Florida Institute of Technology; Brian Kaplinger, Florida Institute of Technology; Markus Wilde, Florida Institute of Technology; Robert Moses, NASA Langley Research Center

This paper presents a control system and guidance algorithm for an aerocapture maneuver to transfer a Crew Transfer Vehicle (CTV) from an Earth-Mars Cycler into a Low Mars Orbit (LMO). The guidance algorithm guides the spacecraft through the Martian atmosphere targeting the atmospheric exit conditions necessary for the vehicle to reach the desired post-aerocapture orbit apoapsis. The reference trajectory is also optimized such that the maximum deceleration and heat loads tolerable by the crew and vehicle are not violated.

11:00 **AAS 19-402** **DESIGN OF A RESILIENT RIDESHARE-BASED SMALL SATELLITE CONSTELLATION USING A GENETIC ALGORITHM**
Katherine Mott, Virginia Tech; Jonathan Black

Responsive and resilient space-based systems are needed to satisfy changing mission requirements and react to unforeseen challenges. This paper studies the ability of a constellation constructed from commercial-off-the-shelf parts and launched using rideshare to provide imaging coverage over a small region in the event of a disaster, such as an outbreak of wildfires. A genetic algorithm is used to evaluate rideshare constellations through coverage metrics in both the nominal case and the case in which some satellites have failed. Novel methods for determining reachability between two orbits and for determining revisit metrics for degraded constellations are presented.

11:20 **AAS 19-431** **Differential Lift and Drag Based Constellation Control Using Trimmed Attitude**
Andrew Harris, University of Colorado Boulder; Hanspeter Schaub, University of Colorado

Spacecraft operating in Low Earth Orbit can leverage atmospheric forces to reduce fuel consumption and improve robustness to hardware failure. This work extends prior work in differential-drag formation flight to the constellation domain through the use of differential orbital elements. Additionally, a gas-surface interaction model is incorporated into the control dynamics to enable out-of-plane maneuvers using atmospheric lift Small variations to attitude about a reference attitude–referred to as "trimmed attitude" in this work–are considered as the control input, allowing for the construction of a system that is affine in control.

Session 12: Trajectory Design & Optimization III
Tuesday, Hana
Chair: Ryan Russell, The University of Texas at Austin

8:00 **AAS 19-316** **Low-Energy Trajectories as Staging Points for Landing on the Secondary Body in the CR3BP**
Luke Bury, University of Colorado Boulder; Jay McMahon, CCAR (Colorado Center for Astrodynamics Research)

Many scientifically interesting moons orbit the gas giants, but without atmospheres to soften the landing (excluding Titan), sending a lander to the surface becomes a very difficult problem for which a low-energy trajectory is required. In this paper, a grid-search is utilized to study all possible landing regions for given Jacobi constants in the CR3BP, and various systems are compared. Impact angles and location of Lagrange-point-neck crossings are carefully observed. Additionally, zonal harmonics are included to study whether they allow new surface regions to be reached when accounted for.

8:20 **AAS 19-323** **Modeling and Optimization of Aero-Ballistic Capture**
Carmine Giordano, Politecnico di Milano; Francesco Topputo, Politecnico di Milano

In this paper a novel paradigm for Mars missions is modeled and optimized. This concept consists in a maneuver that combines aerocapture and ballistic capture upon Mars arrival, and is labelled aero-ballistic capture. The idea is reducing the final mass by exploiting the interaction with the planet atmosphere as well as the Sun--Mars gravitational field. The aero-ballistic capture paradigm is formulated. Then the problem is stated by using optimal control theory, and optimal solutions are sought. An assessment of aero-ballistic capture shows the superiority compared to classical maneuvers when medium-to-high final orbits are wanted.

8:40 **AAS 19-356** **A Two-Level Differential Corrections Algorithm for Low-Thrust Spacecraft Trajectory Targeting**
Collin York, Purdue University; Kathleen C. Howell, Purdue University

Applications of low-thrust propulsion to spaceflight in multi-body environments require a targeting algorithm to produce suitable trajectories on the ground and on board spacecraft. The two-level targeter with low thrust (TLT-LT) provides a framework to implement differential corrections in both computationally-limited autonomous spacecraft applications and the larger design space of pre-mission planning. Extending existing two-level corrections algorithms, applications of the TLT-LT to spacecraft with a range of propulsive capabilities, from nearly-impulsive to low-thrust, are explored. The process of determining partial derivatives is generalized, allowing for reduced logical

complexity and increased flexibility in designing sequences of thrusting and ballistic segments.

9:00 **AAS 19-327** **Europa Lander trajectory design: case studies for the Direct-To-Earth architecture**
Stefano Campagnola, Jet Propulsion Laboratory; Tim McElrath, JPL/Caltech; Aline K. Zimmer, Jet Propulsion Laboratory; Damon Landau, NASA / JPL

This paper presents two interesting phasing problems that came up in support of design studies for a potential Europa Lander mission. Recent system trades were performed after the Mission Concept Review in fall 2017, when the NASA board recommended the Europa Lander project design a Direct-to-Earth architecture. In the first study, which considered a bi-propellant system for the lander, we designed an ultra-low-radiation endgame with separate Europa orbit insertion and de-orbiting maneuvers for the Descent Vehicle, and a ballistic Ganymede-impact transfer for the carrier. In the second study, we analyzed trajectories to use Clipper as a data-relay spacecraft during landing.

9:20 **AAS 19-329** **Trajectory Design Using Quasi-Periodic Orbits in the Multi-Body Problem**
Brian McCarthy, Purdue University; Kathleen C. Howell, Purdue University

Incorporating quasi-periodic orbits (QPOs) into the preliminary design process offers a wider range of options to meet mission constraints and address the challenges in a complex trade space. In this investigation, QPO stability and alternative QPO family continuation schemes are examined to meet various types of trajectory constraints. Additionally, trajectory arcs from QPOs can be exploited to generate transfers between periodic orbits. By leveraging the natural dynamical structures associated with QPOs, novel low cost transfers may emerge.

9:40 **AAS 19-330** **Mission Design for the Lunar Pallet Lander**
Anthony Craig; James Holt; Mike Hannan; Juan Orphee

Marshall Space Flight Center is developing a small lunar lander capable of delivering up to 300 kg of payload to the lunar surface near the North or South Pole. Originally designed as a lander for small rover, the Lunar Pallet Lander, has seen several design iterations over the last couple of years. This paper will cover how the vehicle and mission design evolved from starting as a Space Launch System co-manifested payload up to the current design that could be launched with an EELV class vehicle.

10:00 **Morning Break**

10:20 **AAS 19-331** **NASA Exploration Mission 2 Mission Design**
Anthony Craig; Christopher Berry, NASA; Eric Christiansen; Gerald Condon, NASA; Adam Harden; Christopher Foster; Jeffery Little; Trey Perryman; Seth Thompson, Troy 7; Michael D. Bjorkman, Jacobs Technology

Exploration Mission 2 (EM-2) will be NASA's first manned flight on the Space Launch System (SLS) and Orion Spacecraft. The mission has been changed from an SLS Block 1B configuration to Block 1. This change has necessitated a reexamination of the flight profile to determine what changes must be made in order to accommodate the reduced launch vehicle performance on the

Block 1. Launch availability and Orbital Debris risk will be traded to find the best flight profile for both SLS and Orion.

10:40 AAS 19-333 Fuel-Optimal Convex Trajectory Optimization of Rendezvous on Elliptical Orbits
Mauro Massari, Politecnico di Milano; Paolo Massioni, Laboratoire Ampere, INSA Lyon, Universitè de Lyon

In this paper a new approach to constrained low-thrust trajectory optimization for rendezvous on elliptical orbits is presented. The approach is derived from a technique developed in the control engineering community, known as Sum Of Squares. Approximating the solution as a polynomial with respect to time, the constraints are reduced to bounds on polynomials. The polynomial bounding problem is then formulated as a convex optimization problem which does not require an initial guess for the solution. This approach is well suited for problems under linear dynamic equations, therefore perfectly fitting the case of spacecraft relative motion.

11:00 AAS 19-334 New Horizons 2014MU69 Flyby Design and Operation
Yanping Guo, JHUAPL; Wayne Schlei, JHUAPL

After the Pluto flyby in July 2015, the New Horizons spacecraft continued its journey to the outermost region of solar system to explore the Kuiper Belt. New Horizons will fly by a Kuiper Belt Object (KBO), designated 2014MU69, on January 1, 2019 for the closest observations of a KBO ever by a spacecraft. The design plan includes both prime and alternate flyby trajectories at closest approach distances of 3,500 km and 10,000 km, respectively. Seven trajectory correction maneuvers are scheduled during the final approach phase for flight path refinement and final targeting of the MU69 flyby.

11:20 AAS 19-348 The Low-Thrust Interplanetary Explorer: A Medium-Fidelity Algorithm for Multi-Gravity Assist Low-Thrust Trajectory Optimization
Martin Ozimek, The Johns Hopkins University Applied Physics Laboratory; Jack Riley, Johns Hopkins Applied Physics Laboratory; Juan Arrieta, Nabla Zero Labs

The Johns Hopkins University Applied Physics Laboratory and Nabla Zero Labs have developed a multi-gravity assist, low-thrust trajectory optimization software tool known as LInX: the Low-thrust Interplanetary eXplorer. LInX relies on the well-known Sims-Flanagan transcription and nonlinear programming. The tool features fully analytical partial derivatives with accurate hardware models and is well-suited for medium-fidelity applications. There are many novel aspects to LInX, including a modular implementation based on the latest C++ standard; an efficient parallel ephemeris implementation of SPICE; and support for deployment in heterogeneous computing environments for large-scale applicatins. Results against established trajectory optimization benchmark problems exhibit favorable convergence and performance.

Session 13: Large Space Structures & Tethers
Tuesday, Kapulua
Chair: Islam Hussein, Applied Defense Solutions

13:30 AAS Identification of Stiffness and Damping Matrices of High Degree-of-Freedom

19-238 Structural Models

Dong-Huei Tseng; Minh Phan, Dartmouth College; Richard Longman, Columbia University

A method to identify the stiffness and damping matrices of high degree-of-freedom structural models is described. The number of degrees of freedom is considered high if the state-space model of the correct dimension from force inputs to measured outputs becomes uncontrollable and cannot be identified from input-output measurements, thus preventing the structure mass, stiffness, and damping matrices from being recovered. This difficulty is overcome by identifying the physical parameters associated with each individual degree of freedom, where controllability is not compromised. These parameters are aggregated to form the stiffness and damping matrices of the entire structure.

13:50 AAS 19-239 Partial System Identification of Stiffness and Damping Matrices From Output Measurements Only

Minh Phan, Dartmouth College; Dong-Huei Tseng; Richard Longman, Columbia University

This paper deals with the partial system identification of stiffness and damping matrices of a structure from output measurements only. The input forces that excite the structure are unknown and not necessarily white. This is a common scenario in practice where a structure is richly instrumented with accelerometers that provide a wealth of output measurements, yet the forces that excite the structure are unknown or unmeasured. This paper shows that if the mass matrix is known then the rows of the stiffness and damping matrices associated with the degrees of freedoms that are not directly actuated can still be recovered.

14:10 AAS 19-247 Optimal Control of Space Debris Deorbit Using Space Tethered Satellite System

Li Pengjie, Beihang University, Beijing, China; Rui Zhong; Hongwen Wang, Beihang University

This paper proposes an optimal control scheme for space debris deorbit by a space tethered satellite (STS) system with minimal fuel consumption. The scheme includes two phases, the open-loop control trajectory optimization and the closed-loop optimal control. The first phase, the open-loop control trajectory optimization, is derived by solving a STS system optimal deorbit problem using a direct collocation method based on Gauss pseudospectral method. The second phase concerns the closed-loop optimal control for tracking the optimal states reference trajectory using the model predictive control method. Numerical results showed that the proposed scheme can achieve space debris deorbiting to graveyard safely, economically and efficiently.

14:30 AAS 19-363 HIGH-FIDELITY DYNAMIC MODELLING OF PARTIAL SPACE ELEVATOR WITH DEPOYMENT OR RETRIEVAL OF TETHER

George Zhu, York University; Gangqiang Li, York University

This paper presents a high-fidelity model for the partial space elevator system. The partial space elevator system is modeled by nodal position finite element method in arbitrary Lagrangian-Euler description, where a material coordinate is introduced as the state variable to represent the climbers moving along the tether. A dividing/emerging of element process is developed to model the climbers' motion by changing the length of variable-length elements. The simulation results show that the proposed method can be easily extended to multiple-climber case by assigning the moving

nodes and variable-length elements.

14:50 AAS 19-365 FLIGHT DYNAMIC AND CONTROL STRATEGY OF FLEXIBLE ELECTRIC SOLAR WIND SAIL

George Zhu, York University; Gangqiang Li, York University; Chonggang Du, York University

A high-fidelity multiphysics model of an electric solar wind sail is developed by the nodal position finite element method. The coupling effects between the orbital and self-spinning motion are analyzed when the system subjects to the gravitational force only, and major coupling terms are identified and examined. The numerical simulations also show that the coupling effect between the orbital and self-spinning motions causes a periodic variation of the self-spin rate of E-sail and the tether tension.

15:10 AAS 19-369 PARALLEL OPTIMIZAL CONTROL FOR PARTIAL SPACE ELEVATOR

George Zhu, York University

A new piecewise parallel optimal control scheme to suppress the libration of a partial space elevator is developed. The libration is controlled by regulating tether length. The original optimal control scheme is split into two parallel phases on a dual-CPU system to reduce computational burden. CPU I predicts an optimal reference state trajectory for the next time interval piecewise by an open-loop optimization with a grossly simplified three-body tethered system model. CPU II tracks the predicted reference trajectory at the current time interval simultaneously by a closed-loop receding horizon control using a full dynamic model. The simulation results reveal that

15:30 AAS 19-370 NANOSATELLITE MISSION FOR SPACE DEBRIS DEORBIT DEMONSTRATION BY ELECTRODYNAMIC TETHER

George Zhu, York University

Electrodynamic space tethers (EDT) have unique capabilities to provide cost-effective demonstrations of innovative concepts and acquire science data which would otherwise not be achievable on Earth. Over the past four decades, the development of space tether technology has witnessed 26 suborbital and orbital flights. These missions demonstrated that space tether technology has the near-term potential to meet a broad range of scientific and engineering demands. This paper will cover the mission concept study, mission objectives, nanosatellite design, hardware selection, and operation.

15:50 AAS 19-251 A Multidisciplinary Performance Analysis for the Cygnus Cargo Resupply Mission to the ISS

Virgil Hutchinson, Northrop Grumman

The Cygnus propellant is a critical flight resource and consumption analysis is performed for every CRS mission to determine the propellant load required to complete the mission with adequate propellant contingency and margin. An integrated analysis model involving several coupled analyses is used to generate the propellant budget by calculating the propellant usage for each maneuver during the CRS mission. Mission and configuration parameters within the integrated analysis model were varied probabilistically by performing a Monte Carlo analysis. Statistical distributions for the propellant usage from the Monte Carlo analysis are used to determine the

recommended propellant load for the mission.

Session 14: Dynamical Systems Theory
Tuesday, Napili
Chair: Diane Davis, a.i. solutions, Inc.

13:30 AAS 19-266 Designing Low-Thrust Enabled Trajectories for A Heliophysics SmallSat Mission to Sun-Earth L5

Ian Elliott, University of Colorado Boulder; Christopher Sullivan, University of Colorado Boulder; Natasha Bosanac, University of Colorado, Boulder; Farah Alibay; Jeffrey Stuart, Jet Propulsion Laboratory

A small satellite deployed to Sun-Earth L5 could serve as a low-cost platform to observe solar phenomena such as coronal mass ejections. However, the small satellite platform introduces significant challenges in the trajectory design process via limited thrusting capabilities, power and operational constraints, and fixed deployment conditions. To address these challenges, a strategy employing dynamical systems theory is used to design a low-thrust-enabled trajectory for a small satellite to reach the Sun-Earth L5 region. This procedure is demonstrated for a small satellite that launches as a secondary payload with a larger spacecraft destined for a Sun-Earth L2 halo orbit.

13:50 AAS 19-267 Exploring the Low-Thrust Trajectory Design Space for SmallSat Missions to the Sun-Earth Triangular Equilibrium Points

Christopher Sullivan, University of Colorado Boulder; Ian Elliott, University of Colorado Boulder; Natasha Bosanac, University of Colorado, Boulder; Farah Alibay; Jeffrey Stuart, Jet Propulsion Laboratory

With the increasing availability of upcoming rideshare opportunities, low-thrust-enabled small satellites could be leveraged as a platform for targeted heliophysics investigations conducted from the Sun-Earth L4 or L5 regions. In the early stages of mission concept development for small satellites, understanding the trajectory trade space – and the influence of the spacecraft hardware configuration and scientific objectives – is crucial. Fundamental dynamical structures within the Sun-Earth system are examined and used to extract insight into the properties of the trajectory design space for low-thrust-enabled small satellites to visit Sun-Earth L4 or L5 from several fixed deployment conditions.

14:10 AAS 19-280 Transit and Capture in the Planar Three-Body Problem Leveraging Low-Thrust Dynamical Structures

Andrew Cox, Purdue University; Kathleen C. Howell, Purdue University; David Folta, NASA Goddard Space Flight Center

Path planning in the circular restricted 3-body problem (CR3BP) is frequently guided by the forbidden regions and manifold arcs. However, when low-thrust is employed to modify the spacecraft trajectory, these dynamical structures pulsate with the varying Hamiltonian value. In a combined CR3BP, low-thrust (CR3BP-LT) model, an additional low-thrust Hamiltonian is available that remains constant along low-thrust arcs. Accordingly, the analogous low-thrust forbidden regions and manifolds are static and are useful guides for low-thrust trajectory design. Strategies leveraging these structures and other insights from the CR3BP-LT are explored to construct transit

and capture itineraries.

14:30 AAS 19-366 GLOBAL SEARCH OF RESONANT TRANSFERS FOR EUROPA LANDER TO CLIPPER DATA RELAY

Damon Landau, Jet Propulsion Laboratory; Stefano Campagnola, Jet Propulsion Laboratory

Following its prime mission Europa Clipper becomes a potential asset to relay data from Europa Lander back to Earth. To this end, we propose an efficient method to globally search for trajectories that repeatedly fly over the same location on Europa. Different families of trajectories emerge with different flyby geometries that satisfy a convoluted set of landing constraints. Here, the landing location and local solar time must match a limited set derived from expected Clipper observations, while providing multiple opportunities to land in a given season. We include estimates for data volume and radiation dose associated with these resonant trajectories.

14:50 AAS 19-342 Attitude Dynamics of a Rigid Body in Circular Orbit

Francisco Crespo, Universidad del Bio-Bio; Jorge Luis Zapata, Universidad del Bío-Bío; Sebastian Ferrer, Universidad de Murcia; Molero Francisco Javier, Universidad de Murcia

We address the attitude dynamics of a triaxial rigid body in a circular orbit. This task is done by means of a 1-DOF approximation dubbed as the intermediary system. Our study is carried out in global non-canonical variables. The key role played by the moments of inertia and the magnitude of the angular momentum modulus in the different types of relative equilibria and bifurcations is shown in detail. Precisely, the classic dynamics of the free rigid body is modified for slow rotation regime: several bifurcations with changes of stability are displayed. Moreover, the precession of the angular momentum plane circulates.

15:10 AAS 19-359 Sparse Optimal Trajectory Design in Three-Body Problem

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

A structure of the optimal trajectory for minimizing fuel consumption in an unstable dynamical environment such as the three-body problem is not revealed. Recently, it has been found that a sparse solution structure appears also in an optimization of a dynamical system. This concept explains the property that sections the minimum fuel trajectory corresponds to the trajectory which minimizes the total thrusting time. In this paper we propose a numerical method to obtain the minimum-fuel sparse optimal trajectory in the unstable dynamical system. As an example, proposed method applies to the transfer between halo orbits in the Sun-Earth system.

15:30 AAS 19-372 Applications to Space Flight of new results on minimum-time Control of Linear Systems between Two Arbitrary States

Marcello Romano, Naval Postgraduate School; Fabio Curti, School of Aerospace Engineering

A new general solution method, recently developed by the authors, is presented here which is solving for the first time to the best knowledge of the author the general problem of minimum-time control of a linear time-invariant normal system evolving from an arbitrary initial state to an arbitrary desired final state subjected to a cubic-constrained control. The method and its

demonstration are here summarized. Furthermore, new solutions are presented for this optimal control problem for widely used dynamic models used in space flight dynamics, including the double integrator system, the undamped harmonic oscillator system and other cases.

15:50 AAS 19-543 Finding Symmetric Halo Orbits Framed as a Global Optimization problem Using Monotonic Basin Hopping

David Hinckley, University of Vermont; Darren Hitt, University of Vermont

In this work we use the stochastic optimization algorithm Monotonic Basin Hopping to find symmetric halo orbits of a prescribed amplitude in the Sun-Earth and Earth-Moon systems through posing the search as an optimization problem. Stochastic methods are well suited for this problem due to its highly multi-modal nature. Monotonic Basin Hopping is proposed here since it can take advantage of the clustering of sub-optima around an orbit of desired precision. The result is a fast means of finding halo orbits of a desired amplitude which are symmetric within a prescribed tolerance.

Session 15: Special Session - Mars Insight

Tuesday, Kula

Chair: Eric Gustafson, NASA / JPL Caltech

13:30 AAS 19-204 2018 Mars InSight Trajectory Reconstruction and Performance from Launch through Landing

Fernando Abilleira, NASA Jet Propulsion Laboratory/Caltech; Allen Halsell, JPL/Caltech; Min-Kun Chung, NASA/JPL; Ken Fujii; Eric Gustafson, NASA / JPL Caltech; Yungsun Hahn, Jet Propulsion Laboratory; Mark Johnson; Thomas Kennedy, Lockheed Martin Corporation; Julim Lee, NASA JPL; Sarah Elizabeth McCandless, Jet Propulsion Laboratory; Neil Mottinger, NASA / Caltech JPL; Jill Seubert, NASA / Caltech JPL; Gina Signori, Lockheed Martin Corporation; Evgeniy Sklyanskiy, NASA / Caltech JPL; Mark Wallace, Jet Propulsion Laboratory, California Institute of Technology

The InSight mission successfully launched on an Atlas V 401 launch vehicle from the Western Test Range (WTR) at Vandenberg Air Force Base (VAFB) at 11:05:00 UTC on May 5th, 2018. At 12:38:41 UTC, 20 sec after the InSight spacecraft separated from the Centaur upper stage, the spacecraft transmitter was turned on and in about 8 sec spacecraft carrier lock was achieved at the Goldstone tracking station. This paper summarizes in detail the actual vs. predicted trajectory performance in terms of launch vehicle events, injection performance, actual DSN performance, trajectory correction maneuver performance, and Entry, Descent, and Landing events.

13:50 AAS 19-209 Mars Reconnaissance Orbiter Navigation Strategy for Support of InSight Lander's Entry, Descent and Landing Sequence

Premkumar Menon, NASA/JPL; Sean Wagner, Jet Propulsion Laboratory; David Jefferson, NASA / Caltech JPL; Eric Graat, NASA/JPL; Kyong Lee, NASA/JPL; William Schulze, NASA/JPL; Robyn Woollands, Jet Propulsion Laboratory; Kevin Criddle, NASA / Caltech JPL

The Mars Reconnaissance Orbiter (MRO) provided primary relay support for the InSight mission's Entry, Descent and Landing (EDL) on November 26, 2018 and after its landing on Mars. To

position MRO for relay support during InSight EDL, two propulsive maneuvers were performed: the first on August 22, 2018 and the second on October 24, 2018. This paper documents the phasing strategy employed by the MRO Navigation Team to support the InSight EDL sequence.

14:10 AAS 19-213 InSight Orbit Determination

Eric Gustafson, NASA / JPL Caltech; Allen Halsell, Jet Propulsion Laboratory, California Institute of Technology; David Jefferson, NASA / Caltech JPL; Eunice Lau, NASA / Caltech JPL; Julim Lee, NASA JPL; Sarah Elizabeth McCandless, Jet Propulsion Laboratory; Neil Mottinger, NASA / Caltech JPL; Jill Seubert, NASA / Caltech JPL

The InSight mission depends on accurate deep-space navigation for a successful Mars landing. In this paper, we discuss the role of the cruise Orbit Determination team, whose responsibility included determining the spacecraft state, predicting the future trajectory, and quantifying the uncertainty associated with those estimates. In particular, we will focus on spacecraft dynamic modeling, small forces due to attitude control, radiometric tracking data, filter strategies, uncertainty quantification, and responses to unexpected flight situations. We will also provide a full analysis of reconstructed maneuvers, small forces, and delivery accuracy at Mars arrival.

14:30 AAS 19-222 InSight Attitude Control System Thruster Characterization and Calibration for Successful Navigation to Mars

Jill Seubert, NASA / Caltech JPL; Eric Gustafson, NASA / JPL Caltech; Allen Halsell, Jet Propulsion Laboratory, California Institute of Technology; Sarah Elizabeth McCandless, Jet Propulsion Laboratory; Julim Lee, NASA JPL

In order for the InSight spacecraft to execute a safe Mars landing, it is crucial that the navigation team accurately predict the trajectory and deliver the spacecraft to the targeted atmospheric entry point. One of the primary challenges faced by the Navigation Team was the accurate reconstruction and prediction of small but frequent velocity changes imparted by the spacecraft's Attitude Control System thrusters. This paper discusses the in-flight thruster calibration campaign, the reconstruction and prediction of thruster accelerations throughout various phases of cruise (including compensating for significant outgassing post-launch and -attitude-transition), and the subsequent impact on atmospheric entry point delivery.

14:50 AAS 19-228 Navigation Performance of the 2018 InSight Mars Lander Mission

Allen Halsell, JPL/Caltech; Min-Kun Chung, Jet Propulsion Laboratory; Eric Gustafson, NASA / JPL Caltech; Yungsun Hahn, Jet Propulsion Laboratory; David Jefferson, NASA / Caltech JPL; Eunice Lau, NASA / Caltech JPL; Julim Lee, NASA JPL; Sarah Elizabeth McCandless, Jet Propulsion Laboratory; Neil Mottinger, NASA / Caltech JPL; Jill Seubert, NASA / Caltech JPL; Evgeniy Sklyanskiy, NASA / Caltech JPL; Mark Wallace, Jet Propulsion Laboratory, California Institute of Technology

The Mars InSight mission was launched on May 5th, 2018. The spacecraft trajectory had to be controlled to a set of precise atmospheric entry and landing conditions to land safely on the surface of Mars. The two corresponding critical components of the atmospheric entry conditions are the entry flight path angle (to allow for successful descent to the surface) and the entry time (to ensure that real-time data could be seen). This paper will describe how the InSight Navigation team met this difficult task.

15:10 AAS 19-232 Maneuver Design Overview of the 2018 InSight Mars Lander Mission

Min-Kun Chung, Jet Propulsion Laboratory; Yungsun Hahn, Jet Propulsion Laboratory; Allen Halsell, Jet Propulsion Laboratory, California Institute of Technology; Sarah Elizabeth McCandless, Jet Propulsion Laboratory; Evgeniy Sklyanskiy, NASA / Caltech JPL; Mark Wallace, Jet Propulsion Laboratory, California Institute of Technology

Launched on May 5, 2018, the InSight spacecraft is scheduled for Mars landing on November 26, 2018. To ensure a safe and accurate landing, six nominal trajectory correction maneuvers (TCMs) are planned along the reference trajectory from Earth launch to Mars arrival with two contingency TCMs. There are also twenty pre-designed menu TCMs available for execution at the time of the last contingency TCM, 8 hours before the Mars entry, descent, and landing phase begins. This navigation paper will describe the purpose and design strategy of each TCM as well as how each one actually performed during the flight.

15:30 AAS 19-233 Mars Reconnaissance Orbiter Maneuver Plan for Mars 2020 Entry, Descent, and Landing Support and Beyond

Sean Wagner, Jet Propulsion Laboratory; Premkumar Menon, NASA/JPL

The Mars Reconnaissance Orbiter (MRO) spacecraft continues to perform valuable science observations at Mars, provide telecommunication relay for surface assets, and characterize landing sites for future missions. MRO provided primary relay support for the InSight mission during Entry, Descent, and Landing (EDL) on November 26, 2018. This paper discusses the current maneuver plan to support Mars 2020 EDL and maintain MRO's orbit for science operations through 2028.

15:50 AAS 19-264 Atmospheric Impacts on EDL Maneuver Targeting for the Insight Mission and Unguided Mars Landers

Eugene Bonfiglio, Jet Propulsion Laboratory; Mark Wallace, Jet Propulsion Laboratory, California Institute of Technology; Eric Gustafson, NASA / JPL Caltech; Min-Kun Chung, Jet Propulsion Laboratory; Evgeniy Sklyanskiy, NASA / Caltech JPL; Devin Kipp, Jet Propulsion Laboratory

During operational testing for the InSight mission to Mars, it was discovered that the final maneuvers to target the atmosphere were unexpectedly sensitive to planned atmosphere model updates that would be based on real-time MRO measurements of Mars. The team realized that the Phoenix mission also discovered this sensitivity during operational testing. An investigation identified the cause and revealed that any unguided Mars EDL mission would be impacted by this sensitivity if it used 'real-time' atmosphere observations to model the atmosphere used for maneuver targeting. This paper discusses the investigation results, potential mitigations, and the consequences of ignoring the sensitivity.

16:10 AAS 19-291 Orbiters, Cubesats, and Radio Telescopes, Oh My; Entry, Descent, and Landing Communications for the 2018 InSight Mars Lander Mission

Mark Wallace, Jet Propulsion Laboratory, California Institute of Technology; Daniel Litton, NASA; Tomas Martin-Mur, NASA/JPL; Sean Wagner, Jet Propulsion Laboratory

The Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight) Mars lander mission was launched on May 5th, 2018 and its November 26, 2018 entry, descent, and landing sequence was observed by no less than five separate assets. The Mars Reconnaissance

Orbiter (MRO) in orbit about Mars, the two Mars Cube One (MarCO) spacecraft flying by, and two radio telescopes back on Earth were all used for this critical event communication coverage. These many paths of communication were enabled via the InSight launch/arrival strategy design, MRO orbital phasing selection, and MarCO trajectory design.

Special Session - Mars Sample Return
Tuesday, Hana
Chair: Ryan Woolley, NASA / Caltech JPL

13:30 AAS 19-225 End to End Optimization of a Mars Hybrid Transportation Architecture
Min Qu, AMA; Raymond Merrill, NASA Langley Research Center; Patrick Chai, NASA Langley Research Center

NASA's Mars Study Capability Team (MSCT) is developing a reusable Mars hybrid transportation architecture in which both chemical and solar electric propulsion systems are used in a single vehicle design to send crew and cargo to Mars. This paper presents a new integrated framework that combines Earth departure/arrival, heliocentric trajectory, Mars orbit reorientation, and vehicle sizing into a single environment and solves the entire mission from beginning to end in an effort to find a globally optimized solution for the hybrid architecture.

13:50 AAS 19-230 Mars Sample Return -- ORBITAL RENDEZVOUS DETECTION METHODS
Robert Haw, JPL; Eric Gustafson, NASA / JPL Caltech

Passive optical detection of a capsule in orbit around Mars by a Mars orbiter is investigated and compared with active capsule detection (radio beacon). Navigation trades while in pursuit of a rendezvous with the capsule are described. Passive methods are, to first order, unconstrained by time while a radiometric link is time-limited. The rendezvous operation is described in terms of far-field and near-field detection.

14:10 AAS 19-326 Low-Thrust Trajectory Bacon Plots for Mars Mission Design
Ryan Woolley, NASA / Caltech JPL; Austin Nicholas, Jet Propulsion Laboratory/Caltech; Frank Laipert, Jet Propulsion Laboratory; Zubin Olikara, NASA Jet Propulsion Laboratory

The best way to understand a mission design trade space is by creating a good map of all the possibilities, and by knowing how to read it. Bacon plots, which are low-thrust analogs to porkchop plots, give insight into key parameters and sensitivities of possible transfers to Mars (or other destinations). They are mission and parameter specific, and can be created to represent single or multiple legs. This paper outlines the creation process and lessons learned in interpreting the results. An example is given on how bacon plots have been employed for complex mission-level optimization.

14:30 AAS 19-345 Hybrid Chemical-Electric Trajectories for a Mars Sample Return Orbiter
Frank Laipert, Jet Propulsion Laboratory; Austin Nicholas, Jet Propulsion Laboratory/Caltech; Zubin Olikara, NASA Jet Propulsion Laboratory; Ryan Woolley, JPL/Caltech; Robert Lock, Caltech

The Earth return orbiter component of a Mars sample return campaign is a high-impulse mission with challenging timeline constraints. These competing demands mean a hybrid chemical-electric propulsion architecture may be needed for a feasible design, with chemical providing timely impulse and electric providing high volume impulse. We describe an approach to map out the hybrid trajectory design space and create a database to use in conjunction with a spacecraft design tool, enabling co-optimization of trajectory and spacecraft. This method is applied to both the outbound and inbound legs of a Mars sample return mission concept.

14:50 AAS 19-456 Simultaneous Optimization of Spacecraft and Trajectory Design for Interplanetary Missions Utilizing Solar Electric Propulsion

Austin Nicholas, Jet Propulsion Laboratory/Caltech; Ryan Woolley, JPL/Caltech; Alan Didion, NASA Jet Propulsion Laboratory; Frank Laipert, Jet Propulsion Laboratory; Zubin Olikara, NASA Jet Propulsion Laboratory; Ryan Webb, NASA / JPL / Caltech; Robert Lock, Caltech

A major challenge in formulating interplanetary mission concepts utilizing electric propulsion is the large number of trajectory variables that must be considered (thrust profile, flyby options, launch vehicle delivery), all of which are affected by spacecraft design variables (power, mass, thruster, payload, staging). This is significantly more complex than traditional ballistic/chemical mission design and early concepts are often suboptimal as a result, potentially missing valuable options. This paper presents a novel tool (MORT) for simultaneously optimizing the spacecraft design alongside the trajectory given mission constraints and objectives, including example results relevant to the exploration of Mars.

15:10 AAS 19-458 Mission Analysis for a Potential Mars Sample Return Campaign in the 2020's

Austin Nicholas, Jet Propulsion Laboratory/Caltech; Alan Didion, NASA Jet Propulsion Laboratory; Frank Laipert, Jet Propulsion Laboratory; Zubin Olikara, NASA Jet Propulsion Laboratory; Ryan Woolley, JPL/Caltech; Robert Lock, Caltech

The Mars 2020 mission, currently under development by NASA, plans to acquire and cache up to 42 carefully-selected rock and regolith samples from the surface of Mars for potential future return. NASA and ESA are jointly studying options for returning those samples to Earth with missions launching in the 2020s. This paper demonstrates a method for modeling the various campaign elements, synthesizing coordinated campaign timelines, and assuring trajectory feasibility of in the presence of many constraints, and finally optimizing towards mission success. Options for complete sample return campaigns in multiple launch and arrival opportunities are explored and compared.

15:30 AAS 19-459 Chemical and Solar Electric Propulsion Orbit Matching for Mars Sample Rendezvous

Zubin Olikara, NASA Jet Propulsion Laboratory; Austin Nicholas, Jet Propulsion Laboratory/Caltech

A concept for returning samples from the surface of Mars involves rendezvous between an orbiter and a passive sample container in low Mars orbit. This work presents orbit matching maneuver design approaches for chemical and solar electric propulsion (SEP) options. The chemical scheme selects a sequence of intermediate orbits to achieve desired node and phase drifts. The SEP scheme optimizes the averaged relative dynamics accounting for eclipses, drift due to J2, and attitude rate constraints. The performance of these approaches is analyzed as a function of orbit inclination and sample container state dispersions.

15:50 AAS 19-583 Potential Campaign Architectures and Mission Design Challenges for International Mars Sample Return Mission Studies

Robert Lock, Caltech; Austin Nicholas, Jet Propulsion Laboratory/Caltech; Ryan Woolley, JPL/Caltech; Alan Didion, NASA Jet Propulsion Laboratory; Frank Laipert, Jet Propulsion Laboratory; Zubin Olikara, NASA Jet Propulsion Laboratory

Mars Sample Return is a high priority mission in the planetary science community and a decades-long goal of international planetary exploration programs. Architectures and mission options are currently under study by NASA and ESA to find potential partnership opportunities to develop and conduct MSR missions at Mars in the 2020s. The major elements of the MSR campaign have significant architectural options and mission launch, arrival and return options. The decision criteria often depend on mission design and functional allocations across many elements. This paper outlines the architecture trades and the mission design optimization challenges faced by the current studies.

16:10 AAS 19-555 OPTIMAL FEEDBACK CONTROL FOR THE HYPERSONICRE-ENTRY PROBLEM

mehrdad mirzaei, Aerospace Engineering; Puneet Singla, Pennsylvania State University; Maruthi R. Akella, University of Texas at Austin

In this paper, sparse collocation approach is applied to determine optimal feedback laws for Hypersonic vehicle (HV) reentry mission. The effective collocation process is used by applying the new developed Conjugate Unscented Transformation to prepare a minimal set of collocation points. In conjunction with the minimal cubature points, an l_1 norm minimization methodology is applied to optimally select the best basis functions from a larger complete dictionary of polynomial basis functions. Reentry problem for a hypersonic vehicle with inequality path constraint is considered.

Wednesday, January 16

Session 17: Space Situational Awareness & Conjunction Analysis
Wednesday, Kapulua
Chair: Florian Renk, European Space Agency

8:00 **AAS 19-241** **Hayabusa2 Mission Solar Conjunction Phase for Hovering Satellite: Trajectory Design, Navigation and Post-Operation Evaluation**
Stefania Soldini, ISAS/JAXA; Yuichi Tsuda, Japan Aerospace Exploration Agency; Tomohiro Yamaguchi, ISAS/JAXA

Hayabusa2 mission is the ongoing JAXA's sample and return mission to Ryugu asteroid. In late 2018, Ryugu will be in solar conjunction. Therefore, the Hayabusa2 spacecraft will experience communication blackouts while hovering at 20 km from Ryugu. In this article, the design of a safe conjunction trajectory is given in the Hill frame and then verified in the full-body. Two Trajectory Correction Manoeuvres (TCMs) are scheduled before and after the deep conjunction. A linear covariance analysis is shown together with the results of the Monte Carlo analysis to compute the stochastic delta-V at TCMs. Pre-/Post-flight operation data are also compared.

8:20 **AAS 19-284** **Maneuver Design for Asteroid Rendezvous Considering Uncertainty**
Marc Balducci, SpaceNav; Brandon Jones, University of Texas at Austin

When designing maneuvers for rendezvous in space, many current methods assume a deterministic system, leaving system uncertainty unquantified. This paper presents the case of a rendezvous while considering the propagated uncertainty of an asteroid and approaching spacecraft. Using the surrogate method of separated representations, uncertainty is efficiently propagated and utilized in an optimization under uncertainty algorithm which allows for variations in maneuver components. By estimating differences in position components rather than the position state of each object, the absolute accuracy of the surrogate is improved. From this, a tractable means of designing a rendezvous maneuver under uncertain conditions is formulated.

8:40 **AAS 19-433** **Context-Based Non-Compliance for GEO Satellite Reorbiting**
shiva iyer, University of Texas, Austin; Moriba K. Jah, University of Texas at Austin; Islam Hussein, Applied Defense Solutions; Emmanuel Delande, University of Texas at Austin; Drew McNeely, University of Texas, Austin

The Inter-Agency Space Debris Coordination Committee (IADC) established guidelines in 1997 to ensure proper disposal of GEO satellites at the end of their operational lifetimes. This paper analyzes inactive GEO satellites to determine the extent to which they comply with these guidelines. Space object data from USSTRATCOM, JSC Vimpel, the European Space Agency, and Union of Concerned Scientists catalogs are used to obtain the current population of inactive GEO satellites. A consistent data model is developed to capture the parameters of the problem. Context information including country of origin and launch year is used to identify patterns of behavior with regard to compliance.

9:00 **AAS 19-437** **A Probabilistic Approach for Reachability Set Computation for Efficient Space Situational Awareness**
Zachary Hall, Pennsylvania State University; Puneet Singla, Pennsylvania State University

The focus of this paper is the application of the polynomial approximation method to obtain satellite reachability sets for Space Situational Awareness (SSA) applications. Least squares coefficients for the approximation of the final state solution are calculated in a Jacobian free and computationally tractable manner. The Conjugate Unscented Transformation (CUT) method is utilized for this purpose, and is used to calculate the coefficients with a minimal number of full number of full model propagations. Numerical simulation results are given to validate the approach.

9:20 **AAS 19-452** **A new representation of uncertainty for collision assessment**

Emmanuel Delande, University of Texas at Austin; Moriba K. Jah, University of Texas at Austin; Brandon Jones, University of Texas at Austin

In the context of collision assessment, it is customary to represent the uncertainty on an object's state (kinematic state, attitude, etc.) with a random variable and an associated pdf. However, a probabilistic representation sometimes produces counter-intuitive results, with potentially dangerous implications for collision avoidance. We exploit an alternative representation based on outer probability measures (o.p.m.s) rather than probability distributions, matching more closely the information available on an uncertain system. We show that an o.p.m.-formulation of the objects' states leads to a more intuitive and satisfying interpretation of a collision assessment event, and we illustrate this concept on a few scenarios.

10:00 **Morning Break**

10:20 **AAS 19-483** **Early Collision and Fragmentation Detection of Space Objects without Orbit Determination**

Lyndy Axon, The Boeing Company; Marcus Holzinger, University of Colorado Boulder

This paper demonstrates that using the hypothesized constraint of the admissible regions, it is possible to determine if a combination of new uncorrelated debris objects have a common origin that also intersects with a known catalog object orbit, thus indicating a collision or fragmentation has occurred. Admissible region methods are used to bound the feasible orbit solutions of multiple observations using constraints on energy and radius of periapsis, propagating them to a common epoch in the past, and using sequential quadratic programming to find a set of solution states that minimize the Euclidean distance between the observations at that time.

10:40 **AAS 19-355** **A New Impact-Time Guidance Strategy via Dual Virtual-Target Concept**

Yanning Guo, Harbin Institute of Technology; Pengyu Wang, Harbin Institute of Technology; Yueyong Lyu, Harbin Institute of Technology; Bong Wie, Iowa State University

The paper investigates the problem of impact time control for homing missile in the context of employing the differential geometric guidance approach, subject to nonlinear kinematics and lateral acceleration limits. A circular predictive impact time guidance law and two progressive virtual target approaches are developed to achieve the impact time requirement and bedeck the guidance procedure. The new guidance strategy has great potential for autonomous onboard implementation since it can avoid the time-to-go estimation and computational iterations. Theoretical analysis and numerical simulations are exhibited to validate the effectiveness of the proposed guidance strategy.

11:00 AAS 19-506 Spacecraft Detection Avoidance Maneuver Optimization Using Reinforcement Learning

Jason Reiter, Penn State ARGoPS; David B. Spencer, Pennsylvania State University; RICHARD LINARES, Massachusetts Institute of Technology

Spacecraft maneuvers are planned with operational objectives in mind, usually ranging from making up for orbit perturbations to maneuvering to avoid a possible collision. Though these areas have been researched in depth, little work has been done exploring maneuvers performed to avoid detection by sensors. This paper explores the optimization of detection avoidance maneuvers using reinforcement learning. Numerical transcription is used for comparison purposes, but the open-loop nature of optimal control is not conducive to solving the entirety of the detection avoidance problem. Reinforcement learning produces reliable results for maneuver optimization which will provide a unique alternative for maneuver planning.

11:20 AAS 19-517 AN INITIAL ANALYSIS OF AUTOMATING CONJUNCTION ASSESSMENT AND COLLISION AVOIDANCE PLANNING IN SPACE TRAFFIC MANAGEMENT

Jannuel Cabrera, Purdue University, NASA Ames Research Center, and Bay Area Environmental Research Institute; Sreeja Nag, NASA Ames Research Center and Bay Area Environmental Research Institute; David Murakami, NASA Ames Research Center

Conjunction assessment (CA) and collision avoidance (COLA) involve the respective detection and mitigation of threatening encounters in orbit and both are vital components of a space traffic management (STM) system. Safe operations in space requires near-continuous CA, and COLA where necessary, leading to a need for autonomous interoperability and distributed decision-making within a capable STM system. This paper presents a software framework being developed at NASA Ames Research Center that utilizes readily-available commercial and open-source software tools to support a fully-automated CA and COLA process in STM.

Session 18: Asteroid & Non-Earth Orbiting Missions II

Wednesday, Napili

Chair: Mar Vaquero, Jet Propulsion Laboratory

8:00 AAS 19-427 Asteroid Manipulation with Active Boulder Removal

Daniel Brack, University of Colorado Boulder; Jay McMahon, CCAR (Colorado Center for Astrodynamics Research)

A control law that links an asteroid's rotation and orbit to activity on its surface is presented. The control law is simulated using the Combined Asteroid Surface-Boulder model which observes the dynamical effects of boulder motion and surface topography changes on an asteroid's rotation and orbital states. This control law is used to maneuver an asteroid in its orbit while preventing a significant change in its rotation state, and to disrupt an asteroid's rotation in such a way that induces surface activity.

8:20 AAS 19-436 Large Constellations and Formations for Exploring Interstellar Objects and Long-Period Comets

Soon-Jo Chung, California Institute of Technology; Karen Meech, Institute for Astronomy,

University of Hawaii; Julie Castillo-Rogez, Jet Propulsion Laboratory, California Institute of Technology

This paper identifies the best strategies of using formation flying spacecraft for the in-depth exploration of planetary bodies with very long periods, i.e., bodies that cross our solar system and approach Earth only once in a lifetime. These bodies include Oort cloud comets and, now, interstellar objects, as the recently discovered 'Oumuamua is not the first, and certainly not the last interstellar visitor in our solar system. Long-period comets are the most primitive witnesses of the early solar system. Hence the scientific value of exploring these objects is unbounded.

8:40 **AAS 19-450** **Effect of Shifted Origin on the Osculating Orbital Elements of Terminator Orbit**
Shota Takahashi, University of Colorado Boulder; Daniel Scheeres, University of Colorado at Boulder

The secular dynamics of SRP perturbed two-body problem has been proven to have a closed-form solution. As there is an offset between the orbit and mass centers, however, actual dynamics deviates from the solution of secular dynamics. What causes this discrepancy is a short-period variation over one orbit period. In this research, we introduce an arbitrary offset along the Sun-asteroid line and investigate a short-period oscillation of orbital elements defined about the offset. The optimal offset will be analytically formulated and numerically verified. Further corrections to better define a frozen terminator orbit are also discussed.

9:00 **AAS 19-509** **Modeling Imaging Uncertainty For OSIRIS-REx's Asteroid Approach Observations**
Kristofer Drozd, University of Arizona; Roberto Furfaro, The University of Arizona; Diane Lambert, University of Arizona; John Kidd, University of Arizona; Bill Boynton, OSIRIS-REx

This paper outlines and solves the problem of imaging the asteroid Bennu to a confidence of 3-sigma in the presence of spacecraft state perturbation during OSIRIS-REx's approach trajectory. The problem consists of the uncertainty ellipse, that a mosaic must cover, changing size as the spacecraft state is perturbed. A method for determining how much to over image the uncertainty ellipse, in order to satisfy observation requirements, is developed and utilized for the Approach Late OCAMS Shape Model observations. Machine learning classification techniques are also implemented to explore their utility at predicting mosaic coverage for future OSIRIS-REx observations.

9:20 **AAS 19-529** **Expected Accuracy of Density Recovery using Satellite Swarm Gravity Measurements**
William Ledbetter, University of Alabama; Rohan Sood, University of Alabama; Jeffrey Stuart, Jet Propulsion Laboratory

Asteroids represent the remnants of planetary formation, and effective, rapid characterization of their internal structure can facilitate identification of bodies that merit closer investigation. Previous work outlined a preliminary framework for such characterization, but lacked comprehensive stochastic validation. In this paper, the researchers build upon the existing method by performing the necessary stochastic analysis, as well as expanding the recovery technique by testing various iterative update algorithms.

10:00 **Morning Break**

10:20 AAS 19-234 On the design of multiple-revolution solar gravity driven orbital transfers around Mars

Stijn De Smet, University of Colorado; Daniel Scheeres, University of Colorado at Boulder; Jeff Parker, CCAR, Advanced Space, LLC

Current solar electric propulsion and launch vehicle technology enable sending multiple spacecraft to Mars simultaneously. For capture orbits with very high apoapse, solar gravity perturbations can deploy the spacecraft into vastly different orbits. This paper utilizes artificial neural networks to efficiently identify transfers with multiple solar perturbed revolutions and intermediate maneuvers at periareion. The methodology is applied to several applications. Transfers are identified that arrive at Phobos or Deimos, and transfers that target both Phobos and Deimos on a single trajectory. Besides the efficient determination of initial conditions, the frequency with which transfers exist in the phase space is computed.

10:40 AAS 19-244 Swarm Optimization of Lunar Transfers from Earth Orbit with Radiation Dose Constraints

Justin Mansell, Purdue University; Samantha Dickmann, Purdue University; David A. Spencer, Purdue University

Due to the frequent launches of primary satellites into geosynchronous transfer orbits, lunar transfer from an initial geosynchronous transfer orbit represents an attractive option for secondary payloads with lunar mission objectives. Lunar trajectory design from such orbits involves trade offs between coasting time and radiation dose. We train a mixture density neural network on state-of-the-art radiation environment models to estimate dose distributions rapidly. The network is combined with the particle swarm method to optimize the coasting and transfer arcs of a lunar mission while obeying radiation dose constraints with high confidence. Results are refined in a high fidelity orbit propagator.

11:00 AAS 19-415 SRP-based orbit control with application to orbit stationkeeping at small bodies

Kenshiro Oguri, University of Colorado Boulder; Jay McMahon, CCAR (Colorado Center for Astrodynamics Research)

With appropriate control algorithms, solar radiation pressure (SRP) can be effectively utilized as a source of orbit control force around asteroids. In contrast to the historical treatment of SRP as a disturbance at the weak gravity environment, the present paper finds active control of spacecraft attitude promising for orbit control. Based on the authors' previous development of an SRP-based orbit control law, the present paper investigates its applications to orbit stationkeeping problems at small bodies. As preliminary results, numerical simulations confirm the effectiveness of the SRP-based control, where an originally unstable terminator orbit is stabilized by the stationkeeping control.

11:20 AAS 19-547 Ballistic Moon-Moon Transfers in the Cislunar Restricted Four-Body Problem

Anthony Genova, NASA; Brian Kaplinger, Florida Institute of Technology; David Dunham, KinetX, Inc.

This paper investigates the continuity of several families of transfer trajectories using ballistic lunar capture. Ballistic capture trajectories are of interest for spacecraft with low-thrust propulsion or

those otherwise unable to enter lunar orbit from a traditional lunar transfer orbit. A continuation model is used to map two-body problem candidate solutions into trajectories satisfying the dynamics of the Sun-Earth-Moon (SEM) restricted four-body problem. The change of each family of candidate solutions with SEM angle of the initial lunar flyby is expected to impact the ability to claim existence of a solution across a wide range of initial TLI epochs.

11:40 AAS 19-371 Gravitational capture at Saturn with low-thrust assistance

Elena Fantino, Khalifa University of Science and Technology; Jesus Pelaez, Technical University of Madrid (UPM); Roberto Flores, International Center for Numerical Methods in Engineering; Virginia Raposo-Pulido

Orbit insertion at Saturn requires a large manoeuver with chemical thrusters to compensate for the energy difference between the spacecraft and the planet. The impact that this has on the propellant budget is huge. This paper discusses an alternative strategy: after a gravity assist with Jupiter, an electrical motor with an ad hoc thrusting law modifies the orbital elements to minimize the hyperbolic excess speed at Saturn and, thus, facilitate the capture. The control law algorithm, as well as all the dynamical and technological aspects are discussed and presented.

Session 19: Proximity Missions & Formation Flying I

Wednesday, Kula

Chair: Brett Newman, Old Dominion Univ.

8:00 AAS 19-235 Exact Keplerian Relative Motion: An Elementary Formulation of the Initial-Value Problem

Paul W. Schumacher, Air Force Research Laboratory / RDSM; Wesley Jackson, Department of Astronautical Engineering; Ryan Olson, Department of Astronautical Engineering

This paper presents the explicit solution for the initial-value problem of exact nonlinear relative motion between satellites in Keplerian orbits. The elementary approach taken here is designed to complement several more advanced mathematical formulations published by other authors in recent years. Although this approach can be used to represent the relative motion between any two orbits having non-zero angular momentum, the present analysis is limited to elliptical chief and deputy orbits. Formulas are given for computing the deputy's relative position and velocity in any inertially-oriented frame centered on the chief and in the usual Euler-Hill frame. Several numerical examples are included.

8:20 AAS 19-290 Relative Motion Analysis Using Third- and Fourth-Order Solutions of the Relative Two-Body Problem

Julio Caesar Benavides, Embry-Riddle Aeronautical University; David B. Spencer, Pennsylvania State University

In this paper, third-order and fourth-order, time-dependent solutions of the relative two-body problem in conjunction with the general equations of relative motion to analyze the relative motion of a chase vehicle with respect to a target vehicle in low-Earth orbit are used. The results of this analysis are then compared to the outcomes that are derived from the Hill-Clohessy-Wiltshire equations and the numerical integration of the general equations of relative motion. The results

demonstrate that the third- and forth-order formulations provide a robust method of analyzing relative motion that is not hindered by the assumptions of linear orbit theory.

8:40 **AAS 19-338** **ANALYTICAL SPACECRAFT FORMATION DYNAMICS IN ECCENTRIC ORBITS WITH GRAVITATIONAL, DRAG AND THIRD-BODY PERTURBATIONS**

Ahmad yazan Chihabi, Carleton University; Steve Ulrich, Carleton University

There has been a growing interest in spacecraft formation-flying for space science applications. Such missions will require an accurate and efficient dynamics model, on-board the flight computer, to calculate and control the desired relative motion. Hence, an analytical dynamics model which can be applied to eccentric orbits and includes perturbations that can provide an increase in accuracy and efficiency. This paper achieves an accurate analytical solution of relative motion between two spacecraft by propagating each spacecraft's classical orbital elements forward in time and calculating the relative position of the chaser spacecraft at each time-step.

9:00 **AAS 19-364** **Second Order Analytical Solution for Relative Motion on Arbitrarily Eccentric Orbits**

Matthew Willis, Stanford University; Simone Damico, Stanford University; Alan Lovell

Analytical solutions describing the relative motion of two spacecraft in close proximity are desirable for onboard implementation of guidance and navigation algorithms. A new, second-order, Cartesian state solution applicable to orbits of arbitrary eccentricity has been derived by extension of the first-order Yamanaka-Ankersen solution through perturbation methods. The new solution is shown to give better accuracy than existing first-, second-, and third-order translational state solutions over a wide range of orbit eccentricities and inter-spacecraft separations when compared to 2-body dynamics.

9:20 **AAS 19-282** **Simultaneous Localization and Mapping for Satellite Rendezvous and Proximity Operations Using Random Finite Sets**

Lauren Schlenker; Mark Moretto, University of Colorado Boulder; David Gaylor, NASA Goddard Space Flight Center; RICHARD LINARES, Massachusetts Institute of Technology

Current approaches to spacecraft relative navigation require computationally expensive data association and precise a priori maps and can have difficulties with clutter measurements. Recently, new estimation filters based on random finite sets (RFS) have emerged that have shown much promise in addressing these issues. RFS based filters have been successfully applied to Simultaneous Localization and Mapping (SLAM) for terrestrial navigation. This paper proposes using an RFS-SLAM approach for spacecraft relative navigation and presents simulation results demonstrating the feasibility of using RFS-SLAM for autonomous, precise relative navigation to support on-orbit assembly and servicing of spacecraft or asteroid/comet circumnavigation and sample return.

10:00 **Morning Break**

10:20 **AAS** **Analysis fo a swarm deployment for very low Earth orbit operations**

19-582 *Bogdan Udrea, VisSidus Technologies, Inc.*

Preliminary results of orbit analysis for a 12-space vehicle swarm are presented

10:40 AAS 19-501 Rapid Algorithm for Satellite Close Approaches Determination

Huijiang Wang, Beihang University; Xiucong Sun; Chao Han, Beihang University

A rapid algorithm to determine the satellite close approaches is presented in this paper. Close approaches determination is vital for satellite safety and collision avoidance, this paper proposed an adaptive piecewise interpolation technique to rapidly compute the close approaches. The entry-and-exit opportunities are determined by the close approach function, the algorithm adopts forth-order derivative and "half-value consistency check" technique to control the approximation error and interpolation step. The algorithm is applicable for non-circular and perturbed orbits. Numerical simulations show that, compared with the exhaustive search, the adaptive algorithm achieves over 90% decrease in computation time with adequate accuracy.

11:00 AAS 19-511 A Tip-Tilt Hardware-in-the-loop air-bearing test bed with physical emulation of the relative orbital dynamics

Ayansola Ogundele, Naval Postgraduate School; Josep Virgili-Llop, Naval Postgraduate School; Marcello Romano, Naval Postgraduate School

This paper presents the development of a hardware-in-the-loop air bearing test bed that is capable of physically emulating the relative orbital dynamics. Typically, air bearing test beds consist of test vehicles operating on top of a planar and horizontally-leveled surface. These test beds have been widely adopted but they are limited to reproduce short maneuvers where the vehicles are in very close proximity of each other. Here, we propose to emulate the relative orbital dynamics by dynamically changing the inclination of the operating surface. Finally, a maneuver example showcasing the capabilities of the prototype implementation is provided.

Session 20: Trajectory Design & Optimization IV

Wednesday, Hana

Chair: Atri Dutta, Wichita State University

8:00 AAS 19-361 Time-Optimal Repointing Maneuver of a Rigid Spacecraft with One Degree of Freedom for Final Attitude

Yuanzhuo Geng; Chuanjiang Li; Yanning Guo, Harbin Institute of Technology

This paper deals with the problem of time-optimal repointing maneuver of a rigid spacecraft that performs a staring operation. It only contrains the orientation of the body-fixed optic axis and thus the final rotation of the spacecraft about optic axis is free. The problem is first formulated and solved using a numerical method. Motion characteristics and four-switch solutions are presented. Furthermore, a simple yet efficient eigenaxis determination method under eigenaxis maneuver scheme is proposed in which eigenaxis direction is determined analytically to minimize manerver time. Numerical results are evaluated to demonstrate the effectiveness of the proposed method.

8:20 AAS Series Solution for Motion in an Arbitrary Potential Field

19-443 *Nathan Strange, NASA / JPL*

In this paper, the equations of motion for a test particle in an arbitrary potential field is solved as a formal power series. This solution is in terms of the time derivatives of the motion of the test particle. These derivative may be used to construct a Taylor series for the motion of the particle in the vicinity of given initial conditions.

8:40 **AAS 19-389** **Science Orbits Design for The Lunar CubeSat EQUULEUS and for The Phobos Sample Return Mission MMX**

Takuya Chikazawa, University of Tokyo; Nicola Baresi, Institute of Space and Astronautical Science; Naoya Ozaki, ISAS, JAXA; Stefano Campagnola, Jet Propulsion Laboratory; Yasuhiro Kawakatsu, JAXA / ISAS

We present the candidate science orbits for two JAXA missions, satisfying science and flight system constraints, including thermal and power budgets. To minimize the eclipse time, we restricted the design space to synodic resonant periodic orbits, with a period that take a certain ratio of the synodic period, which is a period where geometry of three celestial bodies repeats the same relative geometry. We introduce two key design parameters, synodic ratio and elongation, that we vary to maximize the science benefits and enforce a maximum eclipse time constraint.

9:00 **AAS 19-398** **MULTI-OBJECTIVE OPTIMIZATION OF LOW THRUST TRAJECTORIES FOR PROPELLANT MASS, TIME OF FLIGHT, AND RADIATION DOSE**

Christopher Lorenz, The Aerospace Corporation; Lake Singh, The Aerospace Corporation; Jose Guzman, The Aerospace Corporation

Low thrust trajectories typically trade propellant usage and transfer time. Radiation dosage is traditionally minimized using transfer time as a surrogate, which may not fully capture the radiation exposure of the satellite. This paper treats radiation dose directly by adopting a multi-objective optimization approach with the inclusion of a radiation model to explore the trade-space of trajectory options for the objectives of minimum propellant usage, minimum transfer time, and minimum radiation dose. Results indicate that trajectories are available that offer decreased radiation dose at the expense of increased transfer time and/or increased propellant usage, providing increased flexibility for mission planners.

9:20 **AAS 19-406** **A Relaxation Approach for Hybrid Multi-Objective Optimal Control: Application to Multiple Debris Removal Missions**

Lorenzo Angelo Ricciardi, University of Strathclyde; Massimiliano Vasile, University of Strathclyde

This paper presents a novel approach to the solution of multi-phase multi-objective hybrid optimal control problems. The proposed solution strategy extends previous work which integrated the Direct Finite Elements Transcription (DFET) method to transcribe dynamics and objectives, with a memetic strategy called Multi Agent Collaborative Search (MACS). The approach is first tested on a motorised travelling salesmen problem, for which solutions are available in the literature, and then applied to the mission design of a multiple debris removal mission.

10:00 **Morning Break**

10:20 AAS 19-408 Low Energy Escape Using Tube Dynamics Associated with Quasi-halo Orbit
Kazutoshi Takemura, Waseda University; Nicola Baresi, Institute of Space and Astronautical Science; Yasuhiro Kawakatsu, JAXA / ISAS; Hiroaki Yoshimura, Waseda University

In spacecraft trajectory design based on dynamical theory, research extended to the spatial problem is insufficient. This work discusses on designing Mars escape trajectory in the three-body system via invariant manifolds. In contrast with the conventional methods, we propose to use an invariant manifold from a quasi-halo orbit. We have computed a quasi-halo orbit and its manifold. We investigate how invariant manifolds of quasi-periodic orbits can provide new escape trajectories from the Martian system in the circular restricted three-body problem.

10:40 AAS 19-422 QUASI-SATELLITE ORBIT TRANSFERS VIA MULTI-REVOLUTIONAL PERIODIC ORBITS
Kento Ichinomiya, Waseda University; Nicola Baresi, Institute of Space and Astronautical Science; Yasuhiro Kawakatsu, JAXA / ISAS; Tomohiro Yanao, Waseda University

Several international teams are currently planning to send probes around the Martian moons, Phobos and Deimos, using single-revolutional periodic quasi-satellite orbits or SP-QSOs. While the orbital stability of SP-QSOs is well known, it is still unclear whether reasonable transfer orbits can be found from/to or between them. This paper investigates the application of multi-revolutional periodic quasi-satellite orbits or MP-QSOs to design transfer orbits between SP-QSOs. In this research, we generate MP-QSOs from bifurcation points of the SP-QSO family using standard predictor/corrector procedures, classify them based on practical rules for orbit design and consider their application to orbit transfer problems.

11:00 AAS 19-424 Integrated Optimization of Ascent Trajectory and SRM Design of Multistage Launch Vehicles
Lorenzo Federici, Sapienza University of Rome; Alessandro Zavoli; Guido Colasurdo, Università di Roma Sapienza; Lucandrea Mancini; Agostino Neri, ESA ESRIN - VEGA Integrated Project Team

This paper presents a methodology for the concurrent first-stage preliminary design and ascent trajectory optimization, with application to a VEGA-derived Light Launch Vehicle. The reuse as first stage of an existing upper-stage (Z40) requires a grain redesign, to account for the mutated operating conditions. An optimization code based on the parallel running of several Differential Evolution algorithm is used to find the optimal internal pressure law during Z40 operation, together with the optimal thrust direction and other relefant flight parameters of the ascent trajectory. Payload injected into a target orbit is maximized, while respecting multiple design and path constraints. Numerical results for SSO injection are presented.

11:20 AAS 19-442 Using the Paramat System in Mission Analysis and Design
Darrel Conway, Thinking Systems, Inc.

Thinking Systems is building a parallel processing mission analysis tool, Paramat, for large scale analysis problems. Paramat is an extension of the General Mission Analysis Tool (GMAT), taking the GMAT system as the core numerical engine for analysis in a parallel processing environment. Recent additions to the tool enable launch window analysis and parametric scans to

seek and find viable trajectories. In this paper, the combination of Paramat and GMAT is used for two problems: a transfer from low Eaerth orbit to a lunar flyby, and an Earth to Venus transfer starting from a piggybacked ride on another vehicle.

11:40 AAS 19-426 Missed Thrust Analysis and Design for Low Thrust Cislunar Transfers
Steven McCarty, NASA Glenn Research Center; Daniel Grebow, NASA / Caltech JPL

In a continuation of previous analysis of low thrust cislunar transfers, analysis is completed to understand and address their sensitivities to periods of unplanned thrust outages. Previous studies have addressed this challenge for interplanetary trajectories where the flight times are long and the dynamics are relatively benign, whereas this study will address the challenge in a more chaotic cislunar regime where the appropriate design strategies may be different. This paper includes missed thrust analysis, one or more approaches to missed thrust design, and general thoughts, considerations and strategies for addressing missed thrust for a set of reference cislunar transfers.

Session 21: Space Situational Awareness & Flight Dynamics Operations

Wednesday, Kapulua

Chairs: Ryan Park, Jet Propulsion Laboratory & Nathan Strange, Jet Propulsion Laboratory / California Institute of Technology

13:30 AAS 19-534 Real-Time Telescope Tasking for Custody and Anomaly Resolution Using Judicial Evidential Reasoning
Daniel Aguilar Marsillach, University of Colorado - Boulder; Shahzad Virani, University of Colorado - Boulder; Marcus Holzinger, University of Colorado Boulder; Moses Chan; Prakash Shenoy, The University of Kansas

Sensor tasking for space situational awareness remains an area where tactical improvements can be made. At its core, tasking boils down to resource allocation and decision-making. A new form of which is hypothesis based using Dempster- Shafer evidential reasoning to mathematically formulate hypotheses that need to be resolved. One such method, known as judicial evidential reasoning, lead to promising results for unbiased hypothesis resolution under time constraints. This paper primarily focuses on resolving new hypotheses, formulating new evidence to hypothesis belief mappings in Dempster-Shafer theory, and implementing the algorithm in real-time with a narrow field of view telescope.

13:50 AAS 19-540 Label Assignments in CubeSat Cluster Deployment Tracking
John Gaebler, University of Colorado at Boulder; Penina Axelrad

A Labeled Multi-Bernoulli filter is used to estimate the states and *identities* of multiple CubeSats deployed in a cluster during the first few days in orbit. This work focuses on the label assignments in a scenario combining labeled measurements provided by owner/operators with typical radar observations. When objects are clustered, there can be enough uncertainty (in a priori positions and measurements) that labeled measurements cannot be unambiguously associated with specific objects. A method is presented to probabilistically manage label assignments as additional hypotheses within the LMB framework. A simulation of the 88-CubeSat deployment from PSLV-37 demonstrates the approach.

14:10 AAS Automated Near Real-time Validation and Data Integrity Assessment Using an

19-521 Unscented Schmidt Kalman Filter (USKF)
Thomas M. Kelecy, L3 Applied Defense Solutions

Quality of the data affects the quality of the derived orbit products and, in particular, data biases will result in biased orbits and subsequent predictions. In this paper we demonstrate an automated near real-time assessment of data biases with an appropriately implemented Unscented Schmidt Kalman Filter (USKF). Known biases that are not observable and cannot immediately be estimated are accounted for as consider parameters. The work presents a multi-state filter which "unifies" estimates of observable sensor performance parameters, when observable and when appropriately vetted sensor or reference data are available, and demonstrates immediate performance benefits in the state estimation process.

14:30 AAS 19-551 DISTANT RETROGRADE ORBIT CONSTELLATIONS FOR RELATIVE-ONLY NAVIGATION IN NEAR RECTILINEAR HALO ORBITS
Michael Volle, a.i. solutions, Inc.

The performance of relative-only navigation between the Gateway spacecraft in an NRHO and a constellation of navigation relay spacecraft in Distant Retrograde Orbits (DROs) are examined and compared to DSN tracking using a Square Root Information Filter (SRIF). Crewed orbit disturbances such as CO2 and waste dumps, attitude deadbanding and momentum unloads are modeled based on realistic attitude information for Gateway. Multiple constellation configurations and tracking scenarios are examined using a closed-loop simulation where navigation errors inform maneuver planning and maneuver execution errors affect navigation performance.

14:50 AAS 19-563 COGITATION OF SPACE CURVE PRINCIPLES FOR LAPLACE ORBIT DETERMINATION
Brett Newman, Old Dominion Univ.; Alan Lovell

This paper investigates application of space curve principles to Laplace orbit determination with benefits including new insights and computations. The curve traced out on a unit sphere, by the satellite line-of-sight unit vector, is first established. The unit sphere track is then described with a Frenet coordinate system. The angular velocity of the Frenet axes and their relationship to the line-of-sight rates are developed. The angular velocity components provide new physical insights and facilitate isolation of crossrange and downrange components. Advantages of transforming measurement equations to the Frenet axes and transforming to angular velocity unknowns are explored.

15:30 Afternoon Break

15:50 AAS 19-569 ACCURATE AND ROBUST ESTIMATION METHOD OF AUTONOMOUS ORBIT DETERMINATION USING ACTIVE MANEUVERS AND INTER-SATELLITE RANGING
Kota Kakihara, The University of Tokyo; Naoya Ozaki, ISAS, JAXA; Ryu Funase, The University of Tokyo; Shinichi Nakasuka, The University of Tokyo

Autonomous orbit determination is a key technology for future low-cost and frequent deep-space missions. Previous study shows that inter-satellite ranging is applicable to autonomous orbit

determination in two-body problems by using active ΔV maneuvers. Orbit determination algorithm, however, proposed in the previous study does not consider maneuver execution errors and orbit determination accuracy become worse when there are ΔV execution errors. This paper proposes more accurate and robust orbit determination algorithm considering ΔV execution errors. Numerical simulation shows proposed method results improved orbit determination accuracy and more stable estimation than previous study.

16:10 AAS 19-227 New Horizons 2014MU69 (Ultima Thule) Flyby Design and Execution

Gabe D. Rogers, The Johns Hopkins University Applied Physics Laboratory; Alice Bowman, JHUAPL; Chris Hersman, JHUAPL; Ann Harch, Southwest Research Institute; Ann Harch, Southwest Research Institute

Since the encounter with the Pluto system in 2015, the New Horizons team has been preparing for a flyby of the Kuiper Belt Object $2014MU_{69}$ (Ultima Thule). This paper discusses how the team designed and executed the spacecraft encounter within the various constraints imposed after the Pluto flyby. In addition to a brief overview of key spacecraft subsystems, it will describe how the design needed to accommodate for large uncertainties in the target's position while minimizing image smear during science observations. It will detail resource management, maneuver planning, and power and data downlink constraint management.

16:30 AAS 19-383 Orbit Determination Simulation for Korea Pathfinder Lunar Orbiter Using Sequential Estimation Approach

Young-Rok Kim, Korea Aerospace Research Institute; Young-Joo Song, Korea Aerospace Research Institute; Jonghee Bae, Korea Aerospace Research Institute; Seok-Weon Choi, Korea Aerospace Research Institute

The Korea Pathfinder Lunar Orbiter (KPLO) is Korea's first lunar exploration program developed by Korea Aerospace Research Institute and will be launched in late 2020. The KPLO will employ a 3.5 phasing loop and 100 km altitude lunar polar orbit. In this study, we introduce orbit determination (OD) strategy of KPLO and demonstrate OD simulation results using sequential estimation technique during trans-lunar and mission orbit phase. For OD accuracy assessment, orbital element and position uncertainties are utilized for trans-lunar and mission orbit, respectively. Finally, we confirmed that the simulated OD performance addresses the OD requirements of KPLO.

16:50 AAS 19-474 Single-Waypoint Guidance for Rotating Target Formation Flying

Armando Rolins, Embraer Executive Jets; Brian Kaplinger, Florida Institute of Technology

This paper addresses an autonomous rendezvous procedure between two spacecraft in close proximity in which the chaser object is attempting to dock at a location on a rotating target. This research proposes to use a fully closed-loop control to perform this kind of rendezvous and compares the cost attained by three different control laws given the same problem parameters. The proposed solution makes use of a single waypoint to avoid a trajectory which causes a collision while meeting all boundary conditions. Proposed methods for the efficient choice of waypoint based on a rigorous search are addressed.

Session22: Guidance, Navigation, and Control I

Wednesday, Napili
Chair: Robyn Woollands, Jet Propulsion Laboratory

13:30 AAS 19-207 Unscented Guidance for Zero-Feedback Reaction Wheel Slews
Lara Magallanes, Naval Postgraduate School; Mark Karpenko, Naval Postgraduate School

Spacecraft control system failures are often mission ending even when the payload remains operational. Few, if any, methodologies currently exist to enable an accurate slew to a target in the absence of feedback. An approach will be explored using unscented guidance to expand the limits of control system operation by enabling attitude control authority to be recovered in the event of feedback sensor failures. This paper will explain the mechanism underlying the unscented guidance solution that enables a slew to a target to be completed in the absence of feedback.

13:50 AAS 19-221 Modern Aerocapture Guidance to Enable Reduced-lift Vehicles at Neptune
Casey Heidrich, University of Colorado Boulder; Soumyo Dutta, NASA Langley Research Center; Robert Braun, University of Colorado Boulder

Modern predictor-corrector guidance strategies have shown promise in recent years to provide robust control schemes in-situ. This research implements modern predictor-corrector guidance for moderate-lift vehicles at Neptune. Previous studies required vehicles with high lift-to-drag ratios to account for in-flight uncertainties. Reducing lift-to-drag requirements will enable heritage flight-proven vehicles to perform aerocapture, greatly improving options for Neptune exploration.

14:10 AAS 19-246 A DIRECT CHEBYSHEV PICARD ITERATION APPROACH TO PERTUBED BALLISTIC PROPAGATION AND LAMBERT BOUNDARY VALUE PROBLEMS
Charles Wright, Cummings Aerospace

A simplified approach to Modified Chebyshev Picard Iteration (MCPI) is introduced which relies on exact analytical integration of the Chebyshev polynomials. Unlike other MCPI methods, the Direct Chebyshev Picard Iteration (DCPI) approach does not calculate separate polynomial series coefficients for each integral. It simply applies the original series coefficients to the integrated Chebyshev polynomials to form invariant integral transformation matrices. The boundary conditions are applied after the integrations to perform either a Lambert Boundary Value Problem (BVP), or a ballistic propagation Initial Value Problem (IVP) in a way that is intuitive to anyone familiar with basic integral Calculus.

14:30 AAS 19-276 Using GNSS Receiver at Near Rectlinear Halo Orbit
Yu Nakajima, JAXA; Toru Yamamoto, Japan Aerospace Exploration Agency; Hitoshi Ikeda, Japan Aerospace Exploration Agency

In this paper, feasibility to use GNSS receiver on Cis-Lunar Near Rectilinear Halo Orbits (NRHO) was examined. We describe the purpose, overall picture of using GNSS receiver on NRHO. The receiver was based on those used at geostationary orbit and optimized for the Cis-lunar orbit. In addition, we verify the feasibility of the proposed idea by presenting received power analysis, dilution of precision analysis, and navigation performance simulation. Furthermore, we propose an example case of using GNSS on NRHO from the analysis results.

14:50 **AAS 19-293** **Adaptive Guidance with Reinforcement Meta Learning**

Brian Gaudet, Deep AnalytX, LLC; RICHARD LINARES, Massachusetts Institute of Technology

This paper proposes a novel adaptive guidance system developed using reinforcement meta learning with a recurrent policy and value function approximator. The use of recurrent network layers allows the deployed policy to adapt real time to environmental forces acting on the agent. We evaluate the performance of the agent trained via reinforcement meta-learning on four difficult tasks. These tasks include a safe Mars landing with random engine failure and a landing on an asteroid with unknown environmental dynamics. We also demonstrate the ability of a recurrent policy to navigate using only Doppler radar altimeter returns, thus integrating guidance and navigation.

15:30 **Afternoon Break**

15:50 **AAS 19-303** **Drag-Free and Attitude Control System, lessons learned from MICROSCOPE flight (2016-2018)**

Pascal PRIEUR, Centre National d'Etudes Spatiales; Stéphanie DELAVAULT, Centre National d'Etudes Spatiales; Thomas LIENART; Manuel RODRIGUES, ONERA; Bernard FOULON, ONERA; John MOYARD, Centre National d'Etudes Spatiales; Alain ROBERT, Centre National d'Etudes Spatiales; Pierre-Yves GUIDOTTI, Centre National d'Etudes Spatiales

Microscope is a CNES-ESA-ONERA-CNRS-OCA-DLR-ZARM mission dedicated to the test of the Equivalence Principle with an improved accuracy of 10^{-15}. The 300kg drag-free microsatellite has recently completed its 2-year flight. The Drag Free and Attitude Control System (DFACS) aims at giving a pure gravitational motion to the scientific instrument. The paper presents the main lessons learnt from this mission, from phase A to the de-orbitation: the key choices of DFACS architecture, the performance observed in flight, comparison to other missions (Gravity-Probe-B, GOCE Lisa-Pathfinder). What could be a good DFACS design for Microscope II ?

16:10 **AAS 19-305** **A New Guidance and Control Architecture for Accurate Orbit Injection**

Mauro Pontani, Sapienza University of Rome ; Fabio Celani, Sapienza University of Rome - School of Aerospace Engineering

Orbit insertion maneuvers represent a crucial issue in several mission scenarios, both for spacecraft orbiting the Earth and for payload release from an ascent vehicle. This research considers a new guidance and control architecture based on the combined use of (i) the variable-time-domain neighboring optimal guidance technique and (ii) the constrained proportional-derivative algorithm for attitude control, with the aim of achieving precise orbit insertion, in the presence of nonnominal flight conditions. Extensive Monte Carlo (MC) campaigns demonstrate that the guidance and control architecture at hand is effective for determining precise and fuel-efficient orbit injection maneuvers.

16:30 **AAS 19-313** **Data-driven model-free adaptive sliding mode attitude control of combined spacecraft**

Yueyong Lyu, Harbin Institute of Technology; Han Gao; Guangfu Ma, Harbin Institute of Technology; Zhiyong She

In this paper, a novel data-driven model-free adaptive sliding mode attitude control (MFASMC) method is proposed for the postcapture combined spacecraft in the presence of unknown mathematical model and external disturbance. A sliding-mode-based supplementary controller is introduced to improve the tracking performance of MFAC in terms of robustness. Compared with the existing works, the designed control scheme only utilizes the attitude angle and attitude angular velocity of the combined spacecraft and no mechanism model of combined spacecraft is required.

16:50 AAS 19-351 AN ANALYSIS OF LOW-THRUST GUIDANCE ALGORITHMS AROUND SMALL BODIES

Donald Kuettel, Colorado Center for Astrodynamics Research; Jay McMahon, CCAR (Colorado Center for Astrodynamics Research)

This paper examines the performance of low-thrust guidance algorithms around small bodies. Current small body missions (e.g. OSIRIS-Rex and Rosetta) use chemical thrusters which are inefficient for maneuvering in the microgravity environment around small bodies. When compared to impulsive propulsion systems, low-thrust propulsion provides a smaller force with greater efficiency while still having a high control authority. By perturbing the initial conditions or dynamics of a nominal trajectory, the performance of the guidance algorithms can be tested. It is hypothesized that these low-thrust guidance algorithms will provide accurate, mass-efficient, and robust guidance to a perturbed spacecraft trajectory around small bodies.

Session 23: Proximity Missions & Formation Flying II

Wednesday, Kula

Chair: Roby Wilson, Jet Propulsion Laboratory

13:30 AAS 19-482 Random Finite Set Theory and Optimal Control of Large Spacecraft Swarms

Bryce Doerr, University of Minnesota; RICHARD LINARES, Massachusetts Institute of Technology; Pingping Zhu, Department of Mechanical and Aerospace Engineering, Cornell University; Silvia Ferrari, Sibley School of Mechanical and Aerospace Engineering Cornell University

Controlling large swarms of robotic agents has many challenges including, but not limited to, computational complexity due to the number of agents, uncertainty in the functionality of each agent in the swarm, and uncertainty in the swarm's configuration. This work generalizes the swarm state using Random Finite Set (RFS) theory and solves the control problem using model predictive control (MPC) and iterative linear quadratic regular (ILQR). This work uses information divergence to define the distance between swarm RFS and a desired distribution. The RFS control solution is applied to the spacecraft relative-motion problem showing the viability for this real-world scenario.

13:50 AAS 19-349 Network architecture for UWB-based relative navigation of multiple spacecraft in formation flight

Nobuhiro Funabiki, the University of Tokyo; Satoshi Ikari, The University of Tokyo; Ryu Funase, The University of Tokyo; Shinichi Nakasuka, The University of Tokyo

To realize a formation flight of multiple spacecraft, relative navigation among the member spacecraft is essential. In this paper, the use of an Ultra-Wide Band (UWB) positioning system for spacecraft formation flight is proposed. When a formation is composed of tens or hundreds of

spacecraft, it is not realistic to measure relative distances among the all member spacecraft in terms of the time consumption for UWB ranging. This paper discusses the kinds of ranging network based on UWB devices are effective to increase the accuracy of the relative navigation.

14:10 AAS 19-350 Pose Estimation For Non-Cooperative Spacecraft Rendezvous Using Neural Networks
Sumant Sharma, Stanford University; Simone Damico, Stanford University

The paper presents a novel pose estimation technique that uses neural networks to determine the pose of a target spacecraft from a single image. The pose from the networks is used for the initialization as well as the measurement update of a multiplicative kinematic kalman filter. In contrast to current techniques, this technique does not require the assumption of small baseline changes between subsequent images during tracking or favorable relative motion during initialization. The technique is trained and validated using the Spacecraft Pose Estimation Dataset (SPEED) benchmark. Sensitivity analysis of the performance with respect to synthetic image fidelity is presented.

14:30 AAS 19-405 Spacecraft Pose Estimation and Swarm Localization Performance Under Varying Illumination and Viewing Conditions
William Bezouska, University of Southern California

Spacecraft swarm localization using relative pose measurements from passive cameras will be impacted by viewing conditions including relative solar angle and relative orientation between the target and the observer. This work attempts to assess the pose estimation performance under all viewing geometries by simulating stereo images using both computer graphics rendering and real images of a spacecraft model under partially collimated lighting. The relative pose estimation error when using stereo vision and point cloud registration is computed. This error information is then incoprorated into an Extended Kalman Filter cooperative localization scheme to determine the overall impact on swarm localization.

14:50 AAS 19-407 Optimal Inspection of a Nadir-Pointing Satellite with Dynamic Angle Constraints
Mark Mercier; Kirk W. Johnson, US Air Force

Recent advancements in on-orbit proximity operations facilitate more complex inspection missions of active satellites with active sensors. These sensors can be simulated by keep-out cones; many will be nadir-pointing, but others may change direction in the local-horizontal/local-vertical frame. These keep-out cones define dynamic angle constraints for a satellite on a fuel-optimal inspection trajectory. This study will pose and solve the corresponding optimization problem using the multi-phase Gauss Pseuspectral Solver, GPOPS-II, with linearized Hill-Clohessy-Wiltshire dynamics. This solution method will allow for the flexibility to incorporate various dynamic keep-out cone constraints as well as desired viewing angle constraints.

15:10 AAS 19-471 Impact of Internal Heating on Spacecraft Thermal Signature
Scott Carnahan, Colorado Center for Astrodynamics Research; Hanspeter Schaub, University of Colorado; Benjamin Lane, Draper Lab

Infrared (IR) vision-based navigation has gained more interest recently for uncooperative rendezvous because it can produce clear images regardless of eclipse conditions. Image matching algorithms have been demonstrated as feasible for spacecraft recognition in IR, but these methods

often struggle with attitude ambiguity due to spacecraft symmetry. This work aims to address the issue of attitude ambiguity by the incorporation of additional IR-visual information due to internal thermal systems. Simulated IR images of spacecraft are generated using internal quasi-1D thermal networks combined with external radiation models.

15:30 **Afternoon Break**

15:50 **AAS 19-535** **Optimal Range Observability Maneuvers for Angles-Only Navigation in Elliptic Orbits**

Francisco José Franquiz Maldonado, Embry-Riddle Aeronautical University; Bogdan Udrea, VisSidus Technologies, Inc.; Troy Henderson, Embry-Riddle Aeronautical University

A generalization of existing methods for planning optimal observability trajectories for spacecraft using angles-only measurements of a non-cooperative target is proposed. Dynamics are modeled using a state transition matrix applicable to elliptical planetary orbits of arbitrary eccentricity. Together with a pseudo-time parameterization of relative trajectories, transfers between any two feasible flight paths can be calculated without the need for numerical integration. Simulation results are presented which compare representative examples of proximity operations in low Earth orbit at different eccentricities. Results include a preliminary verification procedure which uses unscented filtering to demonstrate improved navigational performance due to the planned maneuvers.

16:10 **AAS 19-539** **Prototype Test Results of IVA Hopping Maneuvers of an Autonomous Robotic Vehicle**

Katrina Alsup, Naval Postgraduate School; Justin Komma, Naval Postgraduate School; Josep Virgili-Llop, Naval Postgraduate School; Marcello Romano, Naval Postgraduate School

Hopping is an alternative mobility approach for intravehicular activities (IVA). In a hopping maneuver a spacecraft uses its robotic manipulator to execute a hop between two locations. In previous work we have derived the formulation of IVA hopping maneuvers. Here we use this derivation to develop a series of controllers for the three phases of the hopping maneuver. We then use these controllers on NASA's Astrobee free-flyer to simulate IVA hopping maneuvers inside the International Space Station. Here the controllers implementation and the simulation results are presented in details. The video of a simulated maneuver can be found at https://youtu.be/QBWxiiJGZmY.

16:30 **AAS 19-307** **Output Regulation Control for Satellite Formation Flying Using Differential Drag**

Mohamed Shouman, Department of Aeronautics and Astronautics, Kyushu University.; Mai Bando, Kyushu University; Shinji Hokamoto, Kyushu University

This paper studies the viability of using differentials in drag with thrusters for satellite formation flying (SFF) missions. For the atmospheric drag control, it is revealed that the tracking problem is not solvable, therefore thrust input in another direction is added to achieve asymptotic tracking for exogenous SFF system. The output regulator algorithm is derived based on a linear Scheiwgart-Sedwick model for SFF using atmospheric drag and thrust force and subject to saturation. All numerical simulations for relative models and high precision orbit propagator are implemented to validate the stability and analyze the performance of the proposed control algorithm.

16:50 AAS 19-367 AUTONOMOUS SPACECRAFT RENDEZVOUS BY LINE-OF-SIGHT CONTROL

George Zhu, York University; Peng Li, York University

The paper investigates the autonomous spacecraft rendezvous by line-of-sight control. Nonlinear model predictive control method is applied for the problem and it is formulated in terms of line-of-sight range and azimuth angle. The numerical results show that the newly proposed line-of-sight nonlinear model predictive control scheme is able to effectively generate optimized approach trajectories with satisfactory control accuracy and the proposed method is insensitive to the measurement uncertainties.

17:10 AAS 19-475 3-Dimensional Reachable Set Applications to Multi-Spacecraft Trajectory Coordination

Chandrakanth Venigalla, University of Colorado Boulder; Daniel Scheeres, University of Colorado at Boulder

To work towards advancing mission design capabilities for spacecraft formations and constellations, we investigate the application of reachable sets to solve coordination problems. We generate three-dimensional reachable sets that give the set of reachable orbits for a given spacecraft in semimajor axis-eccentricity-inclination space. We verify the delta-V optimality of these sets which are generated using an analytic control law, and then use the sets to explore optimal rendezvous orbits for systems of 2 and more spacecraft. Rendezvous optimality criteria includes, but is not limited to total delta-V. We further investigate how these sets allow us to find optimal evasion strategies.

Session 24: Trajectory Design & Optimization V

Wednesday, Hana

Chair: Roberto Armellin, University of Surrey

13:30 AAS 19-448 Q-Law Aided Direct Trajectory Optimization for the High-Fidelity, Many-Revolution Low-Thrust Orbit Transfer Problem

Jackson Shannon, University of Maryland; Martin Ozimek, The Johns Hopkins University Applied Physics Laboratory; Justin Atchison, JHU Applied Physics Laboratory; Christine Hartzell

Low-thrust spacecraft trajectory optimization for the many-revolution orbital transfer problem is especially challenging due to the dimension of the problem and the fact that perturbation effects play a role in preventing accurate analytical solutions. This analysis seeks to simplify the calculation of the non-averaged, high-fidelity spiral trajectory through the use of the well-known Q-Law Guidance. Here, Q-Law is used to seed various phases of the direct trajectory optimization problem. We demonstrate the trade space between calculation speed of Q-Law and the optimality of the full optimization problem on the common example problem of the GTO to GEO transfer.

13:50 AAS 19-449 Visual Interactive Trajectory Design

Ravishankar Mathur, Emergent Space Technologies, Inc.

A method of altering trajectories via visual "grab-and-drag" gestures with immediate graphical response, called Visual Interactive Trajectory Design (VITD), is presented. The various components of VITD are defined (e.g. draggable objects), and how they affect the trajectory is discussed. An

implementation of VITD is demonstrated that uses the General Mission Analysis Tool (GMAT) to propagate trajectories, and visualizes them in realtime using the OpenFrames 3D visualization API. Examples of using VITD are shown, including finding a lunar free-return trajectory by simply dragging the trajectory's initial velocity vector. The benefits of VITD to rapidly generating initial-guess trajectories for optimization are explored.

14:10 **AAS 19-451** **On-Orbit Servicing Mission Design in a Dynamic Client Environment**
Jennifer Hudson, Western Michigan University; Daniel Kolosa

Mission design for a versatile, robotic servicing spacecraft can be formulated as a combinatorial-optimization problem. If a servicing spacecraft operates in a dynamic environment, where new client spacecraft with urgent servicing needs emerge at different times, then decisions about operational sequencing and client-to-client transfer trajectories will play a significant role in overall mission success and profitability. This problem is investigated using stochastic methods. A model for future client demand is proposed and Monte Carlo simulations are used to evaluate likely mission scenarios. High-thrust and low-thrust cases are considered.

14:30 **AAS 19-461** **Dynamic Optimization for Large Scale Active Debris Removal Mission Design Applications**
Tyler Doogan, Texas A&M University; Manoranjan Majji, Texas A&M University, College Station

This paper uses a multi-step approach to tackle large scale (decades long) ADR mission design. Firstly, a clustering algorithm is applied to a large list of high risk debris objects, splitting them into groups of a user defined size (5 in this case). Each cluster represents a separate mission, each of which occurs in a successive, user-defined, timespan. Then a dynamic traveling salesman problem is solved for each of these clusters in order to find the optimal order of visitation for each mission.

14:50 **AAS 19-464** **Modeling Attitude-Dependent Maneuver Errors with Polynomial Chaos Expansions**
Brandon Jones, University of Texas at Austin

This paper presents a framework for including random inputs on the unit sphere in Polynomial Chaos Expansions (PCEs) to decouple attitude dependent execution errors from magnitude errors. To maintain efficiency in the expansion, the basis functions must be orthogonal with respect to the density function of the inputs. Due to the unit norm constraint, random directions in three-dimensional space are defined on the unit sphere, which requires an extension to existing PCE methods. This paper presents the mathematical framework and revisits previous test cases in the literature that leveraged directional quantities.

15:30 **Afternoon Break**

15:50 **AAS 19-466** **Disposal, Deployment, and Debris in Near Rectilinear Halo Orbits**
Diane Davis, a.i. solutions, Inc.; Kenza Boudad, Purdue University; Sean Phillips; Kathleen C. Howell, Purdue University

A proposed Gateway facility in a lunar Near Rectilinear Halo Orbit (NRHO) will serve as an outpost in deep space, with spacecraft periodically arriving and departing. Departing objects will include Logistics Elements, requiring safe disposal, cubesats, deployed to various destinations, and debris objects, whose precise paths may be unknown. Escape dynamics from NRHOs are complex; primarily influenced by the Earth and Moon within the orbit, spacecraft are significantly impacted by solar gravity upon departure. The current investigation explores the dynamics of departure from the NRHO, including the risk of debris recontact, safe heliocentric disposal, and deployment to select destinations.

16:10 AAS 19-324 Automating Tour Design with Applications for Europa Lander

Kaela Martin, Embry-Riddle Aeronautical University (ERAU); Damon Landau, NASA / JPL; Stefano Campagnola, Jet Propulsion Laboratory; Tim McElrath, JPL/Caltech

Creating a tour design can involve a great deal of trial and error to produce a viable end-to-end trajectory. This paper highlights a new methodology which starts with a broad-search patch-conic tool and ends with an integrated optimizer. The tool is applied to Europa Lander starting at the second Ganymede flyby and ending with the first Europa flyby to produce a trajectory option for a 2033 landing date.

16:30 AAS 19-486 Robust Trajectory Design for Asteroid Orbiters

Erica Jenson, University of Colorado Boulder; Daniel Scheeres, University of Colorado at Boulder

In low gravity environments with significant uncertainty, robust trajectories may be preferred over fuel optimal trajectories. This paper will investigate two parametric robust optimization methods with applications to asteroid missions, where the robust-optimal solution will minimize the variance of error in a terminal constraint. The first method will address trajectories with open loop control and the second will allow downstream maneuvers to be redesigned given new state estimates throughout the trajectory. Robust trajectories will be designed for three cases: orbit corrections using the Clohessy-Wiltshire equations, orbit transfers in the two-body problem, and an asteroid approach trajectory approximated with rectilinear motion.

16:50 AAS 19-477 Mission Designs for Human Lunar Surface Access from an Earth-Moon Near Rectilinear Halo Orbit

Raymond Merrill, NASA Langley Research Center; Min Qu, AMA; David Komar, NASA Langley Research Center; Dan Mazanek, NASA Langley / Space Mission Analysis Branch; Daniel Tiffin, NASA LaRC / Space Mission Analysis Branch

The mission design trade space for human lunar return has multiple staging locations, varied vehicle functional responsibilities, and options for partial to full system evolution to reusability. These options fit within a constraint space governed by NASA's current investments, current and near future commercial launch vehicle capabilities, and the recent confirmation of ice at the Moon's poles. When assessing Human lunar return architectures it is important to understand both the nominal mission design and contingency options associated with each transportation architecture option prior to selecting one and beginning to set requirements for individual elements.

Thursday, January 17

Session 25: Guidance, Navigation, and Control II
Thursday, Kapulua
Chairs: Troy Henderson, Embry-Riddle Aeronautical University & Christopher Scott, The Johns Hopkins University Applied Physics Laboratory

8:00 **AAS 19-315** **New improvements on atmospheric trajectory optimization of a rocket reusable first stage with turbo engines**
Eric Bourgeois, CNES; Jérémie Hassin; Nicolas Praly

Following paper 16-230, methodological improvements are presented to optimize the trajectory of a reusable microlauncher first stage. The stage comes back to the launch site thanks to aerodynamics and turbo engines. Thrust characteristics of turboengines depend on flight conditions, and allow a wide thrust modulation, challenging methods to optimize rocket trajectory. Firstly, two simplified methods were combined to benefit from their respective assets, this process allowing to ensure feasible trajectory, with no guaranty on optimality. Now is presented a method relying on optimal control theory taking into account a turboengine model defining relationships between flight conditions, thrust and kerosene consumption.

8:20 **AAS 19-522** **Coordination of a Decentralized Satellite Swarm with Internal Formation**
John McCormack, UNH Mechanical Engineering; May-Win Thein, University of New Hampshire

An Artificial Potential Field (APF) using Sliding Mode Control (SMC) is proposed for control and coordination of spacecraft in constellation/swarm missions. The APF will be analyzed to ensure satisfaction of necessary assumptions made for a given proof of stability: specifically, gain boundedness and equilibrium locations. Attractive nodes will be introduced to create a decentralized spacecraft swarm capable of aggregating a formation with additional agents present. Gain ranges for the APF equation will be determined to ensure that spacecraft maintain "safe distance". Numerical simulations will be presented to demonstrate feasibility of this swarm coordination control technique.

8:40 **AAS 19-542** **Integrated Targeting, Guidance, Navigation and Control for Unmanned Aerial Vehicles**
Evan Kawamura; Dilmurat Azimov, University of Hawaii at Manoa

This study aims to develop targeting, guidance, navigation and control (TGNC) functions and their integration for applications. Due to its simplicity and accessibility, the INAV software has been selected a framework for the proposed integration. It is shown that the proposed study changes the current PID control laws and the utility of new nonlinear control schemes allow us to leverage the flight autonomy thereby paving the way for creating an autonomous TGNC technology with real-time target-relative guidance capabilities. An illustrative example is considered to demonstrate the utility of GNC functions in INAV to perform a rolling maneuver.

9:00 **AAS 19-391** **MULTI-SENSOR NAVIGATION WITH SPACECRAFT DYNAMICS BASED ON FACTOR GRAPH**
Yongchao Zhao; Shijie Zhang; Botian Zhou; Xu Tang, Research Center of Satellite

Technology, Harbin Institute of Technology; Kaicheng Zhang

This paper presents a new method for improving *accuracy of f*actor graph based integrated navigation. Traditional algorithms, without updating velocities covariance matrix, suffer the limitation of estimation accuracy. To address this problem, we incorporate the aircraft dynamics into the factor graph which can predict the aircraft state and its variance. Meanwhile, we build the factor graph model of Inertial Measurement Unit, Global Positioning System receivers and star sensor, which can update the position, velocity, orientation and angular velocity of aircraft and its variance. The simulation is expected to demonstrate the proposed method can improve the navigation accuracy compared with the traditional methods.

9:20 **AAS 19-429** **Gyroscope-Based Spacecraft Angular Rate and Mass Properties Estimation**

Cameron Helmuth; Jacob Darling, Air Force Research Laboratory; Kyle DeMars, Missouri University of Science and Technology

Typically, the center of mass and inertia tensor of a spacecraft are estimated pre- launch using a mass properties table and/or a CAD model of the spacecraft. If these estimates are not sufficiently accurate to meet mission requirements, they can be refined after launch using sensor data from the spacecraft. In order to refine pre-launch estimates of these properties, a gyroscope-based Kalman filter is developed to operate alongside a conventional gyroscope-based attitude filter to estimate the angular rate of the spacecraft as well as its inertia tensor.

10:00 **Morning Break**

10:20 **AAS 19-435** **Optimal Steering Law for Single-Gimbal Control Moment Gyroscopes with Singularity Avoidance and Vibration Suppression**

Zhili Hou, Tsinghua univercity; Simeng Huang, Politecnico di Milano

This paper presents an optimal steering law for the Single-Gimbal Control Moment Gyroscopes (SGCMG) system to cope with the SGCMG singularity problem as well as the residual vibration problem. The designing process is comprised of three steps. Firstly, a combined performance index for the SGCMG gimbal rates and the reference angular acceleration amplitude is dsigned. Secondly, the residual vibrations of the points near the natrual frequency is constrained to be zero to suppress the vibrations. Thirdly, an analytical solution for the steering law is derived by minimizing the combined performance index under the constraints in the second step.

10:40 **AAS 19-574** **A Real-Time GNC Framework for Rendezvous of Small Satellites Using Constant Thrust in a Uniform Gravitational Field**

Jonathan De Leon, University of Hawaii at Manoa

With the use of small satellites on the rise as a cheap alternative to conventional satellites, there is a rising need for autonomous solutions for their maneuvers. The purpose of this research is to generate an real time analytical solution for rendezvous of small satellites in a uniform gravitational field using constant thrust and create a Guidance Navigation and Control (GNC) solution for this rendezvous problem. This analytical solution will make computations less expensive than the current numerical methods that are in use.

11:00 AAS 19-494 CENTROIDING PERFORMANCE FOR HORIZON-BASED OPTICAL NAVIGATION WITH CASSINI IMAGES OF DIONE AND RHEA

Courtney Hollenberg, Rensselaer Polytechnic Institute; John Christian, Rensselaer Polytechnic Institute; Shyam Bhaskaran, Jet Propulsion Laboratory; William Owen, Jet Propulsion Laboratory

In recent work, the authors introduced a new horizon-based optical navigation (OPNAV) technique that combines an improved subpixel edge localization method with a noniterative solution for spacecraft position relative to an ellipsoidal body. In this work, the performance of the new technique is evaluated on OPNAV images of the Saturnian satellites Dione and Rhea from the Cassini spacecraft. Image plane centroid estimates from the new method are compared to the legacy centerfinding results produced by JPL in support of the Cassini mission, which were computed via an iterative limb-scan technique. Additionally, kinematic position residuals are presented for the full mission

11:20 AAS 19-570 Model-Based Optical Navigation and Guidance for Autonomous Landing on Asteroids

Yuki Takao, The University of Tokyo; Yuichi Tsuda, Japan Aerospace Exploration Agency; Takanao Saiki, JAXA / ISAS; Naoko Ogawa, Japan Aerospace Exploration Agency

An optical navigation and guidance scheme for autonomous landing on asteroids using asteroid shape model is presented. Vertices of the shape model are tracked in the sequential images obtained by a monocular camera. The proposed method does not need the process of landmark detection or mapping. The pose of the spacecraft is estimated using extended Kalman filter, including the dynamics around the asteroid. The stochastic performance of control loop is evaluated via numerical simulation using computer graphics rendered from the shape model. The effectiveness of the proposed method is also validated using the flight results in Hayabusa2 Mission.

Session 26: Astrodynamics

Thursday, Napili

Chairs: Juan Arrieta, Nabla Zero Labs & Rohan Sood, University of Alabama

8:00 AAS 19-492 Parking orbit design for generic near-Earth object flyby missions

Oscar Fuentes-Munoz, University of Colorado Boulder; Daniel Scheeres, University of Colorado at Boulder

Near Earth Objects (NEOs) are promising targets of opportunity for science. We propose and analyze an observation system to be placed in orbit until an interesting NEO is found. Afterwards, a probe would be injected to a flyby mission from that orbit. This paper investigates both a suitable parking orbit design and the desired maneuver capabilities for the system. Each proposed parking orbit performance is described statistically based on the NEO database.Discovery conditions arise naturally as design constraints. Results show the polar Laplace plane equilibrium solution as a suitable parking orbit. Lastly, stability concerns of the flyby orbits are covered.

8:20 AAS 19-421 Vertically Stable and Unstable Manifolds of Planar Periodic Orbits: Applications to Spacecraft and Asteroid Trajectories

Kenta Oshima, National Astronomical Observatory of Japan

This study explores applications of stable and unstable manifolds associated with vertical instability of planar periodic orbits in the circular restricted three-body problem. For spacecraft trajectories, significant savings of delta-v as compared with known solutions are achieved for impulsive transfers from near rectilinear halo orbits to planar distant retrograde orbits (DROs) by exploiting vertically stable manifolds emanating from planar Lyapunov orbits in the Earth-Moon system. For asteroid trajectories, we point out the possibility that Jupiter's DROs may host undetected potentially hazardous asteroids based on inclination oscillations of vertically unstable manifolds associated with vertical instability of DROs.

8:40 **AAS 19-455** **Connecting Resonant Trajectories to a Europa Capture through Lissajous Staging Orbits**

Sonia Hernandez, Jet Propulsion Laboratory; Ricardo Restrepo, University of Texas at Austin; Rodney L. Anderson, Jet Propulsion Laboratory/Caltech

Efficient strategies such as a low energy moon tour are needed to land on the surface of Europa. This strategy provides natural access to the moon via the L2 gateway. Staging around this libration point allows to decouple the moon tour and the landing trajectory, allowing to design each phase separately. Furthermore, a staging step frees the landing time from the capture phase, adding an additional degree of freedom. In this paper, the possible ballistic connections between the resonances from the moon tour and Lissajous orbits are studied, including the different geometries that allow for time phasing control.

9:00 **AAS 19-481** **The Stability of Orbital Resonances for Europa Quarantine Design: Escape Orbit Case**

Brian Anderson, University of Southern California; Martin Wen-Yu Lo, Jet Propulsion Laboratory; Mar Vaquero, Jet Propulsion Laboratory

NASA's planetary protection policies require that spacecraft seek to avoid biologically contaminating Europa. For low-energy missions to Europa, we study the feasibility of placing spacecraft in quarantine orbits. This study sought to define what would be needed for the spacecraft to remain in quarantine orbit around Jupiter long enough to become sterilized by Jupiter's radiation environment. The mutual resonance of the four Galilean moons leads us to predict certain resonances as more stable in the ephemeris model. We verify this through a six-body Galilean System model Poincare Map and propagation in the ephemeris model.

9:20 **AAS 19-484** **Surfing in the phase space of Earth's oblateness and third body perturbations**

Camilla Colombo, Politecnico di Milano; Francesca Scala, Politecnico di Milano; Ioannis Gkolias, Politecnico di Milano

We consider the exploitation of luni-solar perturbations for the post-mission disposal of satellites in high-altitude orbits. A representation of the double averaged dynamical system with respect to the plane of the perturbing body, yields a two degree of freedom Hamiltonian. An analytical method is proposed for designing the disposal manoeuvre with the goal to achieve natural re-entry by exploiting the long-term effect of the natural perturbations, enhanced by impulsive manoeuvres. The optimal initial conditions during the natural evolution of the argument of perigee and the orbit eccentricity are designed through a gradient based method in the phase space.

9:40 **AAS** **JUICE Equinox Jupiter Tour: the Challenge of Long Eclipses**

19-413 *Arnaud Boutonnet, European Space Agency / ESOC; Gábor Varga, European Space Agency*

JUICE is the next ESA L-class mission towards Jupiter and its Galilean moons. The Jupiter tour is composed of several very different phases requiring a total of 29 flybys before injection in-orbit around Ganymede. The baseline tour in 2022 corresponds to a solstice mission. The backup tour in 2023 leads to an equinox tour and to unacceptable eclipse duration when reusing the baseline tour structure. This paper presents the profound modifications of the tour that were necessary to remain compliant with the spacecraft design constraint.

10:00 **Morning Break**

10:20 **AAS 19-562** **A Data Mining Approach to Using Poincaré Maps in Multi-Body Trajectory Design Strategies**

Natasha Bosanac, University of Colorado, Boulder

Poincaré maps representing two-dimensional data sets are a powerful tool for rapid trajectory design in multi-body systems. However, projections of higher-dimensional data sets onto a map are challenging to analyze. To reduce their complexity, data mining is employed to cluster map crossings by the geometry of their associated trajectories. Then, interactive data analysis can be performed via a global view of a reduced data set summarizing the clusters and an individual view of the solutions in a single cluster. This data mining approach to leveraging Poincaré maps in the trajectory design process is demonstrated in the circular restricted three-body problem.

10:40 **AAS 19-215** **A Kriging based framework for rapid satellite-to-site visibility determination**

Xinwei Wang, Beihang University; Chao Han, Beihang University

Rapid satellite-to-site visibility determination is of great significance to coverage analysis of satellite constellations as well as onboard mission planning of autonomous spacecraft. A Kriging interpolation technique based framework for rapid visibility determination is proposed in this paper. Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points. The idea is introduced in the paper to determine the rise and set times of visibility, where the estimation errors are controlled by weighted surrounding measurement values. To further increase the computational speed, an interval shrinking strategy preprocessing is adopted via investigating the geometric relationship

11:00 **AAS 19-223** **LANDING ON EUROPA: KEY CHALLENGES AND ARCHITECTURE CONCEPT**

Aline K. Zimmer, Jet Propulsion Laboratory; Eli Skulsky, Jet Propulsion Laboratory; A. Miguel San Martin, NASA Jet Propulsion Laboratory; Gurkipal Singh, Jet Propulsion Laboratory; Nikolas Trawny, NASA/JPL; Tejas Kulkarni, Jet Propulsion Laboratory; Martin Greco, NASA / Caltech JPL

NASA has extended the scope of the potential exploration of Europa beyond the planned Europa Clipper mission and initiated a Pre-Phase A mission concept study of a potential Europa Lander. Jupiter's hostile radiation environment and the lack of information about the moon's terrain at the scale of a lander spacecraft would require significant technology development to overcome the inherent landing challenges. This paper provides an overview of the Europa Lander mission concept

and describes the significant challenges associated with landing on Europa, the technologies required to overcome those challenges, and a strategy for Deorbit, Descent, and Landing (DDL).

11:20 AAS 19-286 OPTIMAL-FEEDBACK ACCELERATED PICARD ITERATION METHODS AND A FISH-SCALE GROWING METHOD FOR WIDE-RANGING AND MULTIPLE-REVOLUTION PERTURBED LAMBERT'S PROBLEMS

Xuechuan Wang, Texas Tech University; Satya Atluri, texas tech university

Wide-ranging and multiple-revolution perturbed Lambert's problems are building blocks for practical missions such as development of cislunar space, interplanetary navigation, orbital rendezvous, etc. However, it is of a great challenge to solve these problems both accurately and efficiently, considering the long transfer time and the complexity of high-fidelity mod-eling of space environment. For that, a methodology combining Optimal-Feedback Accelerated Picard Iteration methods and Fish-Scale Growing Method is demonstrated. The resulting iterative formulae are explicitly de-rived and applied to an Earth-Moon restricted three-body problem and mul-ti-revolution earth rendezvous problem. The examples demonstrate the va-lidity and high efficiency of the proposed methods.

11:40 AAS 19-292 Enabling Repeat Pass Interferometry from Low Venus Orbit

Mark Wallace, Jet Propulsion Laboratory, California Institute of Technology; Theodore H. (Ted) Sweetser, Jet Propulsion Laboratory; Robert Haw, NASA / Caltech JPL; Eunice Lau, NASA / Caltech JPL; Scott Hensley, Jet Propulsion Laboratory, California Institute of Technology

Repeat-pass interferometry is a powerful technique for determining changes in topography by flying a radar over the terrain two or more times. These overflights must be very close to each other in space. To design and maintain a low Venus orbit which enables this requires the consideration of drag, non-spherical gravitational effects, and solar tides. Once the orbit is designed, the spacecraft must be navigated. To do so requires the use of radar-based terrain-relative navigation in addition to the traditional radiometric datatypes. The mission design and navigation to enable repeat pass interferometry at Venus are described.

Session 27: Proximity Missions & Formation Flying III

Thursday, Kula

Chair: Mauro Massari, Politecnico di Milano

8:00 AAS 19-258 Spacecraft Formations Using Artificial Potential Functions and Relative Orbital Elements

Sylvain Renevey, Purdue University; David A. Spencer, Purdue University

Spacecraft formation flight has applications to numerous science and infrastructure mission applications. The disaggregation of a single monolithic spacecraft into multiple smaller spacecraft flying in formation offers enhanced resilience and flexibility. However, the design of relative motion trajectories using Cartesian coordinates is challenging, and the need for collision avoidance requires computationally efficient control algorithms. In this paper, a control algorithm based on artificial potential functions and using a set of relative orbital elements is presented. This method allows the straightforward design and efficient control of a spacecraft formation. The effectiveness

of the control algorithm is illustrated with numerical simulations.

8:20 **AAS 19-314** **An Artificial Bifurcation Potential Field Method for Spacecraft Swarm Formation Planning**

Mu Li, Beihang University; Haibing Chen, Beihang University; Hengxian Jin, Beihang University; Wei Lin; Kang Li, Beijing Institute of Control Engineering

Spacecraft swarms with huge members have great advantages in many applications. In traditional formation control framework, path planning needs to be settled before orbital maneuver, and every spacecraft follows the preconditioned path. When the number of spacecraft reaches to swarm level, the computation consuming may be not affordable. A new formation planning methodology is proposed by using nonlinear bifurcation dynamics. The artificial force filed with bifurcation characteristics is designed. With bifurcation arising, each spacecraft can be drove to new position under bifurcation dynamics to accomplish formation capture, maintenance and reconfiguration. The presented method is more applicable and less calculation consuming.

8:40 **AAS 19-325** **Evolutionary Neurocontrol for Spacecraft Proximity Operations**

Cole George, Air Force Institute of Technology; Joshuah Hess, Air Force Institute of Technology; Richard Cobb, Air Force Institute of Technology

Recent research has demonstrated the potential of evolutionary strategies to the solution of deep reinforcement learning problems. In this paper, such techniques are applied to the control of relative spacecraft motion. Open-loop and closed-loop feedback controllers, represented by multi-layer artificial neural networks, are developed using evolutionary optimization. The implementation and performance of these so-called evolutionary neurocontrollers are compared to classical optimal and nonlinear control techniques. For this problem space, recommendations are made on appropriate network hyperparameters and input-output representations. The resulting analysis is expected to provide an alternative control approach for spacecraft proximity operations.

9:00 **AAS 19-346** **Relative Maneuvering for Multiple Spacecraft via Differential Drag using LQR and Constrained Least Squares.**

Camilo Riano-Rios, University of Florida; Riccardo Bevilacqua, University of Florida; Warren Dixon, University of Florida

In this paper, a spacecraft fleet with multiple chasers and a single target is considered for relative maneuvering, with each spacecraft capable of changing its experienced drag force in a continuous way. This feature is exploited to develop a control framework where the relative states of each chaser-target pair are driven to zero using an LQR with linearized relative dynamics. A Constrained Least Squares Problem is then formulated to find the best achievable set of individual inputs to control all chasers simultaneously. Preliminary results are shown along with a description of current work to reduce the risk of potential collisions.

9:20 **AAS 19-505** **Fractional Control of Relative Orbit Trajectories**

David Yaylali, University of Arizona; Eric Butcher, University of Arizona; Andrew J. Sinclair, Air Force Research Laboratory

Fractional control laws are formulated for linearized relative orbit dynamics. In these controllers, fractional-order derivative feedback of the relative position is used in addition to standard

proportional and integer-order derivative feedback terms. The fractional order serves as an additional tunable parameter which allows one more freedom in shaping the closed-loop relative orbit trajectory. Methods of optimizing such controllers are investigated, including parameter space surveys and fractional variational calculus. Specific cases where fractional relative-orbit controllers outperform standard integer-order controllers are shown.

9:40 **AAS 19-384** **Controllability Analysis of Propellant-Free Satellite Formation Flight**

Mohamed Shouman, Department of Aeronautics and Astronautics, Kyushu University.; Mai Bando, Kyushu University; Shinji Hokamoto, Kyushu University

This paper analyzes the controllability of relative motion using different space environmental forces. It mainly considers the controllability of relative motion by environmental forces as atmospheric drag, solar radiation pressure and Lorentz forces and propose a minimal configuration for the missions exploiting such forces. It illustrates the constraints in each space environmental force. It studies the integration of these forces to achieve full controllability of the satellite formation flight for near-circular low earth orbits with different orbit configurations. Numerical simulations are investigated to validate the full controllability of different configurations for the combined space environmental forces.

10:00 **Morning Break**

10:20 **AAS 19-400** **Proximity Operations with Obstacles Avoidance based on Artificial Potential Field and Sliding Mode Control**

Nicoletta Bloise, Politecnico di Torino; Elisa Capello , Politecnico di Torino CNR-IEIIT; Elisabetta Punta

This paper combines Guidance and Control algorithms for spacecraft proximity operations in presence of obstacles. The guidance algorithm is based on Artificial Potential Field theory, while the adopted control strategies are first-order Sliding Mode considering two different methods: the simplex-based and the component-wise. Both control strategies result to be effective and suitable to be implemented by the mono-directional actuation system and for a ground test-bed developed within the STEPS project (Systems and Technologies for Space Exploration). The algorithms result to be suitable for real-time control with a minimum on-board computational effort and to avoid obstacles and local minima.

10:40 **AAS 19-410** **Safe Rendezvous Trajectory Design for the Restore-L Mission**

Matthew Vavrina, a.i. solutions; Eugene Skelton; Keith DeWeese; Bo Naasz, NASA ; David Gaylor, NASA Goddard Space Flight Center

The Restore-L mission will capture and robotically service Landsat 7 in the early 2020s. The rendezvous will be autonomous with onboard sensors providing relative navigation measurements and onboard guidance algorithms controlling to a reference trajectory. The trajectory design is predicated on maintaining passive safety through any fault until relative navigation is sufficiently accurate to proceed within proximity of Landsat 7. This requirement must be addressed with consideration for sensor range, measurement accuracy, dispersions, thruster faults, and lighting, among others. The trajectory design incorporates co-elliptic transfers for gradual far-field approach and periodic relative motion strategies for near-field approach and inspection.

11:00 AAS 19-416 SATELLITE FORMATION FLYING: ON-GROUND EXPERIMENT ON RELATIVE ORBIT ELEMENTS-BASED CONTROL

Lisa DeWitte, University of Florida; Lucas Bassett-Audain, University of Florida; Aastha Rajbhandary, University of Florida; Brandon Paz, University of Florida; Giuseppe Di Mauro, University of Florida; Riccardo Bevilacqua, University of Florida

Accurate preflight testing environments for formation flying are crucial in transitioning between numerical simulation and actual orbital flight. A 3DOF experimental testbed was developed at the Advanced Autonomous Multiple Spacecraft (ADAMUS) laboratory to validate a relative orbit elements-based control strategy for satellite formation reconfiguration maneuvering. The experimental facility consists of two completely autonomous vehicles floating on an epoxy 4×4 m surface. To mimic the hardware capabilities of a small spacecraft, the control algorithm was executed by the space-qualified Tyvak Intrepid computer board. The paper presents the design and integration of the vehi-cles with their preliminary experimental results.

11:20 AAS 19-430 Low-Thrust Reconfiguration for Formation Flying Using Jordan Normal Form Theory

Xue Bai; Ming Xu; Yuying Liang

Reconfiguration is a hot topic due to its scalability and flexibility of the formation in on-orbit assembly and servicing. Jordan normal form of C-W equation is used to guide reconfiguration strategy, which decompose all the terms in relative motions. The initial value is regarded as the invariants of configuration just as the definition of orbital elements for Keplerian orbit. The reconfiguring path is derived and then proved as a functional from initial to final configuration. The polynomial series method is used to approximate the functional. The optimal coefficients of polynomial series are much easier to be found than previous optimizations.

Session 28: Trajectory Design & Optimization VI

Thursday, Hana

Chairs: Pradipto Ghosh, Analytical Graphics, Inc. & Jennifer Hudson, Western Michigan University

8:00 AAS 19-487 Efficient Computation of Optimal Low Thrust Gravity Perturbed Orbit Transfers

Robyn Woollands, Jet Propulsion Laboratory; Ehsan Taheri, Texas A&M University; John L. Junkins, Texas A&M University

We have developed a new method for solving the optimal low thrust minimum-fuel orbit transfer problem in the vicinity of a large body, considering a high fidelity spherical harmonic gravity model. The algorithm is formulated via the indirect variational calculus approach, leading to a two-point boundary value problem. We make use of a hyperbolic tangent smoothing law for performing continuation on the thrust magnitude to reduce the sharpness of the control switches in early iterations and thus promote convergence. The two-point boundary value problem is solved using the method of particular solutions shooting method and Picard-Chebyshev numerical integration.

8:20 AAS 19-568 Synthesis of fuel-optimal powered descent trajectories for planetary landing missions

Minji Jo, University of Hawaii at Manoa; Dilmurat Azimov, University of Hawaii at Manoa

Synthesis of feasible and extremal planetary entry, descent and landing trajectories is investigated for a central Newtonian field. In this synthesis, all trajectories are started with the initial thrust arc and ended with the final thrust arc, and the ballistic arc connects both thrust arcs. The proposed synthesis is presented for feasible and extremal and fuel-optimal trajectories. The feasible trajectories are designed with the 7-state model and the extremal trajectories are considered with the 14-state model. The proposed synthesis can be used in mission design for planetary landing missions including moon and Mars missions, and sample return missions.

8:40 AAS 19-496 Hyperbolic-Tangent-Based Smoothing with State Transition Matrix implementation for generating Fuel-optimal trajectories

Vishala Arya, Texas A & M University; Ehsan Taheri, Texas A&M University; John L. Junkins, Texas A&M University

Indirect methods are among the powerful techniques for formulating and solving optimal control problems since they guarantee local optimality of the resulting solutions. Traditionally, smoothing techniques such as quadratic, logarithmic and extended logarithmic have been employed with homotopy to alleviate non-smoothness arising due to bang-bang control structures. In this work, a recently introduced hyperbolic tangent smoothing (HTS) is used for designing time-fixed, rendezvous-type, fuel-optimal maneuvers. Implementation of the State Transition Matrix (STM) within the HTS is demonstrated that enhances convergence performance of solvers that rely on Newton update iterative schemes. Utility of the method is demonstrated through interplanetary low-thrust trajectories.

9:00 AAS 19-500 Transfer Trajectory Options for Servicing Sun-Earth-Moon Libration Point Missions

David Folta, NASA Goddard Space Flight Center; Cassandra Webster, NASA Goddard Space Flight Center

Future missions to the Sun-Earth Libration L_1 and L_2 regions will require scheduled servicing to maintain hardware and replenish consumables. While there have been statements made by various NASA programs regarding servicing of vehicles at these locations or in Cis-lunar space, a true feasibility transfer study has not been extensively investigated in an operational fashion. This investigation uses dynamical systems and operational models to design transfer trajectories between the Sun-Earth Libration region (Lyapunov, Lissajous, and Quasi-halo) and the Earth-Moon vicinity (Distant Retrograde, Quasi-Halo, Lissajous, and Near Rectilinear Halo Orbits). We address the cost of transfers between each pair of locations.

9:20 AAS 19-504 Vector Formulations for Spherically Bounded Search Spaces

David Hinckley, University of Vermont; Darren Hitt, University of Vermont

In the optimization of spacecraft trajectories, it is often the case that there is some naturally arising bound(s) on the magnitudes of the associated velocities. Such constraints lead to a spherical or, more generally, an elliptical search space. Unfortunately, typical problem transcriptions instead search within a Cartesian box, applying these bounds to each dimension independently. This leads to a search space where nearly half of the search space is known to be useless {\it a priori}. The present work investigates an alternate interpretation of a velocity decision vector and assesses the effects of precluding this known sub-optimal space.

9:40 AAS Multi-Objective Optimization For Spacecraft Detection Avoidance Using Reachability

19-514 Sets

Jason Reiter, Penn State ARGoPS; Zachary Hall, Pennsylvania State University; David B. Spencer, Pennsylvania State University; Puneet Singla, Pennsylvania State University

The Conjugate Unscented Transform allows for an easy calculation of reachabil-ity sets with a minimal number of full model propagations. The computation time savings that come with this method encourages implementation of reachability sets in more complex problems. Spacecraft maneuvers planning for detection avoidance is unique in that all objectives may not be met by moving some mini-mum distance from the nominal orbit. Analyzing the reachable sets in topographic coordinates instead presents a unique metric for quantifying detection avoidance. Combining ground-track manipulation and propellant-use in reachability-based multi-objective optimization gives planners an efficient and accurate method for designing detection avoidance maneuvers.

10:00 **Morning Break**

10:20 AAS 19-519 ANALYSIS OF ANALOG-TO-DIGITAL CONVERSION TECHNIQUES FOR SATELLITE ORBITAL MANEUVERING USING COLD GAS THRUSTERS

Spencer Harwood, South Dakota State University

Analog-to-digital conversion strategies for cold gas thrust actuation are examined. In particular, the interest is directed toward the accurate and efficient actuation of continuous thrust histories via on-off thrusting action. We considered different actuation strategies, including pulse-width modulation, delta-sigma modulation, and a novel compensated pulse-width modulation. The scenario of interest involves an orbiting small satellite performing proximity maneuvers propelled by a single cold gas thruster. Different settings for the actuation strategies are studied to determine their effects on actuation accuracy and efficiency in propellant usage.

10:40 AAS 19-536 Multi-Objective Optimization of Spacecraft Trajectories for Small-Body Coverage Missions with Non-Keplerian Orbit Dynamics

David Hinckley, University of Vermont; Jason Pearl, University of Vermont; Darren Hitt, University of Vermont

Visual coverage of surface elements of a small-body requires multiple images to be taken that meet many requirements on their viewing angles, illumination angles, times of day, and combinations thereof. Finding trajectories that allow for these conditions to be met in a timely manner is a nontrivial task; made more difficult by the competing criteria for such trajectories. This work phrases the search for suitable trajectories as an optimization problem handled with a multi-objective evolutionary algorithm.

11:00 AAS 19-541 Innovative Solar Sail Earth-Trailing Trajectories Enabling Sustainable Heliophysics Missions

James Pezent, The University of Alabama; Andrew Heaton, NASA Marshall Space Flight Center; Rohan Sood, University of Alabama

As a successor to NEA Scout, there is a growing interest in leveraging solar sails for heliophysics science missions. The presented work is a design study demonstrating the feasibility of possible

trajectory architectures under specific operational constraints and initial conditions. Trade studies are carried out to ensure that a solar sail can reach and maintain innovative science orbits about Earth-trailing equilibrium points. Additionally, optimal solutions in terms of time of flight (TOF) and solar observation time are presented. Preliminary results suggest that the proposed trajectories are robust to varying initial conditions, sail performance levels, and operational constraints.

11:20 AAS 19-567 Objective Function Weight Selection for Sequential Low-Thrust Orbit-Raising Optimization Problem

Atri Dutta, Wichita State University; Lakshay Arora, Wichita State University

In this paper, we consider the low-thrust orbit-raising problem formulated at a sequence of optimal control sub-problems. This formulation is helpful in rapid and robust generation of geocentric electric orbit-raising trajectories, however this advantage comes at the cost of sub-optimality of the solutions. This paper explores the impact of weights in the objective function on the optimality gap of computed solutions. Numerical simulations are presented to illustrate the effect.

Program by time

January 14, 2019

Session	Room	Doc. #	Presenter		Title
Session 3: Attitude Dynamics & Control I	Kula	AAS 19-202	Julie Halverson	8:00 - 8:20	Lunar Reconnaissance Orbiter Operations Without a Gyro
Session 1: Orbit Determination & Space-Surveillance Tracking	Kapulua	AAS 19-220	Sarah Elizabeth McCandless	8:00 - 8:20	Analyzing Feasibility of Optical Communication Observables for Navigation
Session 2: Orbital Dynamics, Perturbations, and Stability I	Napili	AAS 19-254	Daniel Grebow	8:00 - 8:20	Stability and Targeting in Dawn's Final Orbit
Session 4: Trajectory Design & Optimization I	Hana	AAS 19-201	Bradley Wall	8:00 - 8:20	INDIRECT OPTIMIZATION OF LOW-THRUST TRAJECTORIES USING HOMOTOPY
Session 3: Attitude Dynamics & Control I	Kula	AAS 19-240	Botian Zhou	8:20 - 8:40	CONFIGURATION OPTIMAZATION OF 0-1 SUN SENSORS FOR SUN VECTOR DETERMINATION
Session 1: Orbit Determination & Space-Surveillance Tracking	Kapulua	AAS 19-231	Shyam Bhaskaran	8:20 - 8:40	Navigation Accuracy at Jupiter and Saturn using Optical Observations of Planetary Satellites
Session 2: Orbital Dynamics, Perturbations, and Stability I	Napili	AAS 19-270	Roberto Armellin	8:20 - 8:40	Design and Control of Repeat Ground Track Orbit in High Fidelity Dynamical Model via High Order Poincaré Mapping
Session 4: Trajectory	Hana	AAS 19-203	Fernando Abilleira	8:20 - 8:40	Mars 2020 Mission Design and Navigation Overview

Design & Optimization I					
Session 3: Attitude Dynamics & Control I	Kula	AAS 19-296	Renato Zanetti	8:40 - 9:00	Rotations, Transformations, Left Quaternions, Right Quaternions?
Session 1: Orbit Determination & Space-Surveillance Tracking	Kapulua	AAS 19-271	Zahi Tarzi	8:40 - 9:00	ORBIT DETERMINATION SENSITIVITY ANALYSIS FOR THE EUROPA CLIPPER MISSION TOUR
Session 2: Orbital Dynamics, Perturbations, and Stability I	Napili	AAS 19-277	Yuying Liang	8:40 - 9:00	Capture an asteroid to the Earth-Moon system via triangular libration points
Session 4: Trajectory Design & Optimization I	Hana	AAS 19-206	Chris Ranieri	8:40 - 9:00	AL YAH 3 ORBIT TRANSFER RECOVERY DESIGN
Session 3: Attitude Dynamics & Control I	Kula	AAS 19-368	Kamesh Subbarao	9:00 - 9:20	UNCERTAINTY QUANTIFICATION AND ANALYSIS OF INVARIANTS OF RIGID BODY ATTITUDE DYNAMICS
Session 1: Orbit Determination & Space-Surveillance Tracking	Kapulua	AAS 19-445	Simone Servadio	9:00 - 9:20	RECURSIVE POLYNOMIAL MINIMUM MEAN SQUARE ERROR ESTIMATION WITH APPLICATIONS TO ORBIT DETERMINATION
Session 2: Orbital Dynamics, Perturbations, and Stability I	Napili	AAS 19-310	Virginia Raposo-Pulido	9:00 - 9:20	DROMO propagator for highly perturbed problems
Session 4: Trajectory Design & Optimization I	Hana	AAS 19-226	Patrick Chai	9:00 - 9:20	Hybrid Transportation System Integrated Trajectory Design and Optimization for Mars Landing Site Accessibility

Session 3: Attitude Dynamics & Control I	Kula	AAS 19-399	Hongwen Wang	9:20 - 9:40	Fault Points Detection for Large Solar Panel Based on Photogrammetry
Session 1: Orbit Determination & Space-Surveillance Tracking	Kapulua	AAS 19-518	Troy Henderson	9:20 - 9:40	INDENTIFYING SPACECRAFT CONFIGURATION USING DEEP NEURAL NETWORKS FOR PRECISE ORBIT ESTIMATION
Session 2: Orbital Dynamics, Perturbations, and Stability I	Napili	AAS 19-322	Carmine Giordano	9:20 - 9:40	Dedicated Mission to the Sun-Earth Saddle Point: A Feasibility Assessment
Session 4: Trajectory Design & Optimization I	Hana	AAS 19-236	Zhemin Chi	9:20 - 9:40	Optimization of Variable-Specific-Impulse Gravity-Assist Trajectories
Morning Break 10:00 - 10:20					
Session 3: Attitude Dynamics & Control I	Kula	AAS 19-460	Thibaud Teil	10:20 - 10:40	Removing Rate Un-observability in Sun Heading Filters Without Rate Gyros
Session 1: Orbit Determination & Space-Surveillance Tracking	Kapulua	AAS 19-507	Yoola Hwang	10:20 - 10:40	GEOSTATIONARY SATELLITE ORBIT ACCURACY ANALYSIS FOR MANEVEUR EFFICIENCY CALIBRATION
Session 2: Orbital Dynamics, Perturbations, and Stability I	Napili	AAS 19-328	Hodei Urrutxua	10:20 - 10:40	Sensitivity Analysis of Regularised Orbit Formulations with Interval Arithmetic
Session 4: Trajectory Design & Optimization I	Hana	AAS 19-242	Tim McElrath	10:20 - 10:40	On Alighting Daintily at Jupiter: Innovative Methods for Efficiently Achieving Jovian Orbit
Session 3: Attitude Dynamics &	Kula	AAS 19-473	Christine Schmid	10:40 - 11:00	Angular Correlation using Rogers-Szego-Chaos

Control I					
Session 1: Orbit Determination & Space-Surveillance Tracking	Kapulua	AAS 19-513	David Ciliberto	10:40 - 11:00	Extended Kalman Filtering in Regularized Coordinates for Orbit Determination
Session 2: Orbital Dynamics, Perturbations, and Stability I	Napili	AAS 19-375	Mark Moretto	10:40 - 11:00	Attitude Dependent Evolution of Orbits about Active Comets
Session 4: Trajectory Design & Optimization I	Hana	AAS 19-245	Juan Arrieta	10:40 - 11:00	High Performance Interpolation of Chebyshev Ephemerides
Session 3: Attitude Dynamics & Control I	Kula	AAS 19-503	Sital Khatiwada	11:00 - 11:20	Control of an Earth-Based Satellite Test Platform through Vision Based Position Measurement
Session 1: Orbit Determination & Space-Surveillance Tracking	Kapulua	AAS 19-515	Troy Henderson	11:00 - 11:20	INITIAL RELATIVE ORBIT DETERMINATION SOLUTIONS USING POLYNOMIAL SYSTEMS
Session 2: Orbital Dynamics, Perturbations, and Stability I	Napili	AAS 19-379	Andres Dono	11:00 - 11:20	Stability and spin-orbit resonance analysis of low altitude Martian orbits
Session 4: Trajectory Design & Optimization I	Hana	AAS 19-248	Elisabet Canalias	11:00 - 11:20	Transfer between planar and three-dimensional Quasi Satellit Orbits in the vicinity of Phobos
Session 3: Attitude Dynamics & Control I	Kula	AAS 19-531	Patrick Kenneally	11:20 - 11:40	SPACECRAFT RADIATION PRESSURE USING COMPLEX BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTIONS ON GRAPHICS PROCESSING UNIT

Session 4: Trajectory Design & Optimization I	Hana	AAS 19-249	William Stein	11:20 - 11:40	The Implementation of Maximum Likelihood Estimation in Space Launch System Vehicle Design
Session 3: Attitude Dynamics & Control I	Kula	AAS 19-545	Clark Newman	11:40 - 12:00	Attitude Control and Orbit Determination of a Crewed Spacecraft With a Lander in Near Rectilinear Halo Orbit
Session 4: Trajectory Design & Optimization I	Hana	AAS 19-255	Naoya Ozaki	11:40 - 12:00	Tube Stochastic Optimal Control For Nonlinear Constrained Trajectory Optimization Problems

Session	Room	Doc. #	Presenter		Title
Session 5: Artificial Intelligence in Astrodynamics	Kapulua	AAS 19-304	Lin Cheng	13:30 - 13:50	Real-time Optimal Control for Irregular Asteroid Landings Using Deep Neural Networks
Session 6: Asteroid & Non-Earth Orbiting Missions I	Napili	AAS 19-243	Stefaan Van Wal	13:30 - 13:50	Deployment analysis and trajectory reconstruction of MINERVA-II rovers on asteroid Ryugu
Session 7: Attitude Dynamics & Control II	Kula	AAS 19-210	Fabio Celani	13:30 - 13:50	Spacecraft Attitude Motion Planning on SO(3) using Gradient-based Optimization
Session 8: Trajectory Design & Optimization II	Hana	AAS 19-259	Kanta Yanagida	13:30 - 13:50	Designing Low-Energy Transfers from Low-Earth Orbit to a Temporarily-Captured Orbiter
Session 5: Artificial Intelligence in Astrodynamics	Kapulua	AAS 19-441	Andrea Scorsoglio	13:50 - 14:10	Actor-Critic Reinforcement Learning Approach to Relative Motion Guidance in Near-Rectilinear Orbit
Session 6: Asteroid & Non-Earth Orbiting Missions I	Napili	AAS 19-253	Benjamin Bercovici	13:50 - 14:10	Initial Orbit Determination about Small Bodies Using Flash LIDAR and Rigid Transform Invariants
Session 7:	Kula	AAS 19-	Yasuhiro	13:50 - 14:10	Innovative Guidance and

Attitude Dynamics & Control II		257	Morita		Control Design of the Versatile Orbit Transfer Space Vehicle of the Epsilon Rocket
Session 8: Trajectory Design & Optimization II	Hana	AAS 19-265	Mar Vaquero	13:50 - 14:10	A TITAN GRAVITY-ASSIST TECHNIQUE FOR BALLISTIC TOURS SKIMMING OVER THE RINGS OF SATURN
Session 5: Artificial Intelligence in Astrodynamics	Kapulua	AAS 19-447	Andrew Harris	14:10 - 14:30	Spacecraft Decision-Making Autonomy using Deep Reinforcement Learning
Session 6: Asteroid & Non-Earth Orbiting Missions I	Napili	AAS 19-260	Javier Roa	14:10 - 14:30	Multilayer Clustered Sampling Technique (MLCS) for Near-Earth Asteroid Impact Hazard Assessment
Session 7: Attitude Dynamics & Control II	Kula	AAS 19-275	Ting Jin	14:10 - 14:30	HIGH PRECISION ATTITUDE CONTROL OF SPACECRAFT BASED ON ELECTRIC THRUSTER AND FLYWHEEL
Session 8: Trajectory Design & Optimization II	Hana	AAS 19-285	Marilena Di Carlo	14:10 - 14:30	Robust Optimisation of Low-Thrust Interplanetary Transfers using Evidence Theory
Session 5: Artificial Intelligence in Astrodynamics	Kapulua	AAS 19-462	Jacob Broida	14:30 - 14:50	SPACECRAFT RENDEZVOUS GUIDANCE IN CLUTTERED ENVIRONMENTS VIA REINFORCEMENT LEARNING
Session 6: Asteroid & Non-Earth Orbiting Missions I	Napili	AAS 19-269	Kenshiro Oguri	14:30 - 14:50	Science Orbit Design with Frozen Beta angle: Theory and Application to Psyche mission
Session 7: Attitude Dynamics &	Kula	AAS 19-283	Mark Karpenko	14:30 - 14:50	WAYPOINT FOLLOWING DYNAMICS OF A QUATERNION ERROR

Control II					FEEDBACK ATTITUDE CONTROL SYSTEM
Session 8: Trajectory Design & Optimization II	Hana	AAS 19-294	Powtawche Valerino	14:30 - 14:50	Charting a Course to the Sun: Flight Path Control for Parker Solar Probe
Session 5: Artificial Intelligence in Astrodynamics	Kapulua	AAS 19-479	Damien GUEHO	14:50 - 15:10	INVESTIGATION OF DIFFERENT NEURAL NETWORK ARCHITECTURES FOR DYNAMIC SYSTEM IDENTIFICATION: APPLICATIONS TO ORBITAL MECHANICS
Session 6: Asteroid & Non-Earth Orbiting Missions I	Napili	AAS 19-339	Jason Pearl	14:50 - 15:10	Curvilinear Surface-Based Gravity Model for Evolutionary Trajectory Optimization around Bennu
Session 7: Attitude Dynamics & Control II	Kula	AAS 19-287	Michael Marshall	14:50 - 15:10	Attitude Maneuver Design for Planar Space Solar Power Satellites
Session 8: Trajectory Design & Optimization II	Hana	AAS 19-295	Amanda Haapala	14:50 - 15:10	MARS GRAVITY ASSIST OPTIONS TO REDUCE MISSION ΔV FOR EUROPA LANDER
Session 5: Artificial Intelligence in Astrodynamics	Kapulua	AAS 19-537	Mohammad Ramadan	15:10 - 15:30	ADAPTIVE CONTROL BY REINFORCEMENT LEARNING FOR SPACECRAFT ATTITUDE CONTROL
Session 8: Trajectory Design & Optimization II	Hana	AAS 19-297	Pradipto Ghosh	15:10 - 15:30	A Survey of the Methods Available for the Design of Many-Revolution Low-Thrust Planetocentric Trajectories
Afternoon Break 15:30 - 15:50					
Session 5:	Kapulua	AAS 19-	Daniel	15:50 - 16:10	Low-Thrust Optimal

Artificial Intelligence in Astrodynamics		560	Miller		Control via Reinforcement Learning
Session 6: Asteroid & Non-Earth Orbiting Missions I	Napili	AAS 19-385	Florian Renk	15:50 - 16:10	Lagrange – Mission Analysis for the European Space Agency's Space Weather Mission to the Sun-Earth Libration Point L5
Session 7: Attitude Dynamics & Control II	Kula	AAS 19-319	Yash Khatavkar	15:50 - 16:10	Predicting Time-Optimal Slews Across Multiple Spacecraft with Inertia Ratios
Session 8: Trajectory Design & Optimization II	Hana	AAS 19-298	Julia Mihaylov	15:50 - 16:10	Julia Language 1.0 Ephemeris and Physical Constants Reader for Solar System Bodies
Session 5: Artificial Intelligence in Astrodynamics	Kapulua	AAS 19-566	Patrick Doran	16:10 - 16:30	COLLISION PREDICTION WITHIN A CUBESAT SWARM USING MACHINE LEARNING
Session 6: Asteroid & Non-Earth Orbiting Missions I	Napili	AAS 19-387	Francesco Topputo	16:10 - 16:30	Trajectory design for LUMIO CubeSat in the cislunar space
Session 7: Attitude Dynamics & Control II	Kula	AAS 19-374	Alanna Sharp	16:10 - 16:30	NUMERICAL RESULTS ON THE GENERAL TIME-OPTIMAL REST-TO-REST THREE-AXIS REORIENTATION OF A RIGID SPACECRAFT
Session 8: Trajectory Design & Optimization II	Hana	AAS 19-299	Kentaro Nishi	16:10 - 16:30	Multi-step Optimization of Orbit Raising Trajectories for All-electric Propulsion Geostationary Satellites
Session 5: Artificial Intelligence in Astrodynamics	Kapulua	AAS 19-573	Zachary Reinke	16:30 - 16:50	TRAINING SET DATA OPTIMIZATION FOR ARTIFICIAL NEURAL NETWORKS FOR ORBITAL

					STATE SPACE TRAJECTORY PREDICTIONS
Session 6: Asteroid & Non-Earth Orbiting Missions I	Napili	AAS 19-411	Elisabet Canalias	16:30 - 16:50	Mascot: flight dynamics activities in support of an asteroid landing mission
Session 7: Attitude Dynamics & Control II	Kula	AAS 19-490	Bing Song	16:30 - 16:50	Discrete-Time Iterative Learning Control for Nonlinear Systems by Feedback Linearization
Session 8: Trajectory Design & Optimization II	Hana	AAS 19-306	Zhaowei Wang	16:30 - 16:50	REACHABLE DOMAIN OF CONTINUOUS LOW-THRUST TRAJECTORIES WITH LINEARIZED DYNAMIC MODEL
Session 5: Artificial Intelligence in Astrodynamics	Kapulua	AAS 19-336	Haiyang Li	16:50 - 17:10	Deep neural networks of Optimal Low-Thrust Orbit Raising
Session 6: Asteroid & Non-Earth Orbiting Missions I	Napili	AAS 19-412	Fabio Ferrari	16:50 - 17:10	A new environment to simulate the dynamics in the close proximity of rubble-pile asteroids
Session 7: Attitude Dynamics & Control II	Kula	AAS 19-572	Bowen Wang	16:50 - 17:10	ON THE USE OF SINGULAR VALUE DECOMPOSITION BASIS FUNCTIONS TO PREVENT ERROR SIGNAL ACCUMULATION IN ITERATIVE LEARNING CONTROL
Session 8: Trajectory Design & Optimization II	Hana	AAS 19-308	Mauro Pontani	16:50 - 17:10	Optimal Hyperbolic Rendezvous Trajectories for Cycler Missions
Session 5: Artificial Intelligence in Astrodynamics	Kapulua	AAS 19-397	Lin Cheng	17:10 - 17:30	Fast Estimation of Gravitational Field of Irregular Asteroids Based on Deep Learning and Its Applications

Session 8: Trajectory Design & Optimization II	Hana	AAS 19-311	Di Wu	17:10 - 17:30	Adjoint Estimation Method for Low-thrust Many-revolution Trajectory Optimization

January 15, 2019

Session	Room	Doc. #	Presenter		Title
Session 11: Atmospheric Re-entry & Satellite Constellations	Kula	AAS 19-212	Rohan Deshmukh	8:00 - 8:20	Investigation of Direct Force Control for Planetary Aerocapture at Neptune
Session 9: Orbital Debris & Space Environment	Kapulua	AAS 19-229	Mark Vincent	8:00 - 8:20	Conjunction Assessment and Risk Mitigation Automation (CARMA)
Session 10: Orbital Dynamics, Perturbations, and Stability II	Napili	AAS 19-390	Xiaoyu Liu	8:00 - 8:20	SECULAR ORBITAL ELEMENT VARIATIONS DUE TO CONTINUOUS LOW-THRUST CONTROL AND THIRD-BODY PERTURBATIONS
Session 12: Trajectory Design & Optimization III	Hana	AAS 19-316	Luke Bury	8:00 - 8:20	Low-Energy Trajectories as Staging Points for Landing on the Secondary Body in the CR3BP
Session 11: Atmospheric Re-entry & Satellite Constellations	Kula	AAS 19-301	Penglei Zhao	8:20 - 8:40	Autopilot for Near-Space Hypersonic Vehicle Controlled by Aerodynamic Lift and Divert Thrusters with Off-Centered Seeker Window
Session 9: Orbital Debris & Space Environment	Kapulua	AAS 19-557	Aaron J. Rosengren	8:20 - 8:40	Resident Space Object Proper Orbital Elements
Session 10: Orbital Dynamics,	Napili	AAS 19-396	Yuki Oshima	8:20 - 8:40	Trajectory Design in the Circular Restricted Three-body Problem Using

Perturbations, and Stability II					Artificial Invariant Manifolds
Session 12: Trajectory Design & Optimization III	Hana	AAS 19-323	Carmine Giordano	8:20 - 8:40	Modeling and Optimization of Aero-Ballistic Capture
Session 11: Atmospheric Re-entry & Satellite Constellations	Kula	AAS 19-463	Evan Zinner	8:40 - 9:00	PARKING ORBIT SELECTION FOR MARS AEROCAPTURE-ENTRY SYSTEMS
Session 9: Orbital Debris & Space Environment	Kapulua	AAS 19-268	Matthew Richardson	8:40 - 9:00	Mass Estimation Through Fusion of Astrometric and Photometric Data Collection with Applications to Orbital Debris Characterization
Session 10: Orbital Dynamics, Perturbations, and Stability II	Napili	AAS 19-401	Zachary Folcik	8:40 - 9:00	VERY LONG ARC TIMING COEFFICIENT AND SOLAR LUNAR PLANETARY EPHEMERIS FILES AND APPLICATIONS
Session 12: Trajectory Design & Optimization III	Hana	AAS 19-356	Collin York	8:40 - 9:00	A Two-Level Differential Corrections Algorithm for Low-Thrust Spacecraft Trajectory Targeting
Session 11: Atmospheric Re-entry & Satellite Constellations	Kula	AAS 19-468	Puneet Singla	9:00 - 9:20	STOCHASTIC REACHABILITY ANALYSIS FOR THE HYPERSONIC RE-ENTRY PROBLEM
Session 9: Orbital Debris & Space Environment	Kapulua	AAS 19-320	Stefan Frey	9:00 - 9:20	Interpolation and Integration of Phase Space Density for Estimation of Fragmentation Cloud Distribution
Session 10: Orbital Dynamics,	Napili	AAS 19-512	Tahsinul Haque Tasif	9:00 - 9:20	A HIGH ORDER ANALYTIC CONTINUATION TECHNIQUE FOR THE

Perturbations, and Stability II					PERTURBED TWO-BODY PROBLEM STATE TRANSITION MATRIX
Session 12: Trajectory Design & Optimization III	Hana	AAS 19-327	Stefano Campagnola	9:00 - 9:20	Europa Lander trajectory design: case studies for the Direct-To-Earth architecture
Session 11: Atmospheric Re-entry & Satellite Constellations	Kula	AAS 19-499	Breanna Johnson	9:20 - 9:40	Mid-Lift-to-Drag ratio Rigid Vehicle 6-DoF EDL Performance Using Tunable Apollo Powered Guidance
Session 9: Orbital Debris & Space Environment	Kapulua	AAS 19-438	Piyush Mehta	9:20 - 9:40	Data-driven investigation of thermospheric variations
Session 10: Orbital Dynamics, Perturbations, and Stability II	Napili	AAS 19-470	Jules Simo	9:20 - 9:40	Identification of Families of Periodic Orbits Above/Below the Solar Sail Earth-Moon Libration Points
Session 12: Trajectory Design & Optimization III	Hana	AAS 19-329	Brian McCarthy	9:20 - 9:40	Trajectory Design Using Quasi-Periodic Orbits in the Multi-Body Problem
Session 9: Orbital Debris & Space Environment	Kapulua	AAS 19-439	Piyush Mehta	9:40 - 10:00	On deriving Self-Consistent, High-accuracy Mass Density Measurements
Session 10: Orbital Dynamics, Perturbations, and Stability II	Napili	AAS 19-510	Robyn Woollands	9:40 - 10:00	Feasibility study of near-frozen, near-circular, near-polar and extremely low altitude lunar orbits
Session 12: Trajectory Design & Optimization	Hana	AAS 19-330	Anthony Craig	9:40 - 10:00	Mission Design for the Lunar Pallet Lander

III

Morning Break 10:00 - 10:20					
Session 11: Atmospheric Re-entry & Satellite Constellations	Kula	AAS 19-491	Hao Wang	10:20 - 10:40	Neural Network Trained Controller for Atmospheric Entry in Mars Missions
Session 9: Orbital Debris & Space Environment	Kapulua	AAS 19-465	Marielle Pellegrino	10:20 - 10:40	Robustness of Targeting Regions of Chaos In the GNSS Regime
Session 10: Orbital Dynamics, Perturbations, and Stability II	Napili	AAS 19-526	Satoshi Ikari	10:20 - 10:40	ANALYSIS OF DISTURBANCE ANOMALY OF INTERPLANETARY MICRO-SPACECRAFT PROCYON
Session 12: Trajectory Design & Optimization III	Hana	AAS 19-331	Anthony Craig	10:20 - 10:40	NASA Exploration Mission 2 Mission Design
Session 11: Atmospheric Re-entry & Satellite Constellations	Kula	AAS 19-508	Larissa Balestrero Machado	10:40 - 11:00	Guidance and Control System Design for Mars Aerocapture
Session 9: Orbital Debris & Space Environment	Kapulua	AAS 19-502	RICHARD LINARES	10:40 - 11:00	Koopman Operator Theory for Thermospheric Density Modeling
Session 10: Orbital Dynamics, Perturbations, and Stability II	Napili	AAS 19-544	Ahmed Atallah	10:40 - 11:00	Analytical Radial Adaptive Method for Spherical Harmonics Gravity Models
Session 12: Trajectory Design & Optimization III	Hana	AAS 19-333	Mauro Massari	10:40 - 11:00	Fuel-Optimal Convex Trajectory Optimization of Rendezvous on Elliptical Orbits

Session 11: Atmospheric Re-entry & Satellite Constellations	Kula	AAS 19-402	Katherine Mott	11:00 - 11:20	DESIGN OF A RESILIENT RIDESHARE-BASED SMALL SATELLITE CONSTELLATION USING A GENETIC ALGORITHM
Session 9: Orbital Debris & Space Environment	Kapulua	AAS 19-409	Mirko Trisolini	11:00 - 11:20	A density-based approach to the propagation of re-entry uncertainties
Session 10: Orbital Dynamics, Perturbations, and Stability II	Napili	AAS 19-554	Yusuke Oki	11:00 - 11:20	Retrograde Teardrop Orbits about Asteroids: Application to the Hayabusa2 Mission
Session 12: Trajectory Design & Optimization III	Hana	AAS 19-334	Yanping Guo	11:00 - 11:20	New Horizons 2014MU69 Flyby Design and Operation
Session 11: Atmospheric Re-entry & Satellite Constellations	Kula	AAS 19-431	Andrew Harris	11:20 - 11:40	Differential Lift and Drag Based Constellation Control Using Trimmed Attitude
Session 9: Orbital Debris & Space Environment	Kapulua	AAS 19-480	Simeng Huang	11:20 - 11:40	Large Constellation De-Orbiting with Low-Thrust Propulsion
Session 10: Orbital Dynamics, Perturbations, and Stability II	Napili	AAS 19-564	Yupeng Gong	11:20 - 11:40	ANALYTIC PROBABILITY DENSITY MODEL OF SATELLITE SWARMS
Session 12: Trajectory Design & Optimization III	Hana	AAS 19-348	Martin Ozimek	11:20 - 11:40	The Low-Thrust Interplanetary Explorer: A Medium-Fidelity Algorithm for Multi-Gravity Assist Low-Thrust Trajectory Optimization

Session	Room	Doc. #	Presenter	Title

Session 14: Dynamical Systems Theory	Napili	AAS 19-266	Ian Elliott	13:30 - 13:50	Designing Low-Thrust Enabled Trajectories for A Heliophysics SmallSat Mission to Sun-Earth L5
Session 13: Large Space Structures & Tethers	Kapulua	AAS 19-238	Dong-Huei Tseng	13:30 - 13:50	Identification of Stiffness and Damping Matrices of High Degree-of-Freedom Structural Models
Session 15: Special Session - Mars Insight	Kula	AAS 19-204	Fernando Abilleira	13:30 - 13:50	2018 Mars InSight Trajectory Reconstruction and Performance from Launch through Landing
Session 16: Special Session - Mars Sample Return	Hana	AAS 19-225	Min Qu	13:30 - 13:50	End to End Optimization of a Mars Hybrid Transportation Architecture
Session 14: Dynamical Systems Theory	Napili	AAS 19-267	Christopher Sullivan	13:50 - 14:10	Exploring the Low-Thrust Trajectory Design Space for SmallSat Missions to the Sun-Earth Triangular Equilibrium Points
Session 13: Large Space Structures & Tethers	Kapulua	AAS 19-239	Minh Phan	13:50 - 14:10	Partial System Identification of Stiffness and Damping Matrices From Output Measurements Only
Session 15: Special Session - Mars Insight	Kula	AAS 19-209	Premkumar Menon	13:50 - 14:10	Mars Reconnaissance Orbiter Navigation Strategy for Support of InSight Lander's Entry, Descent and Landing Sequence
Session 16: Special Session - Mars Sample Return	Hana	AAS 19-230	Robert Haw	13:50 - 14:10	Mars Sample Return -- ORBITAL RENDEZVOUS DETECTION METHODS
Session 14: Dynamical Systems Theory	Napili	AAS 19-280	Andrew Cox	14:10 - 14:30	Transit and Capture in the Planar Three-Body Problem Leveraging Low-Thrust Dynamical Structures
Session 13: Large Space	Kapulua	AAS 19-247	Hongwen Wang	14:10 - 14:30	Optimal Control of Space Debris Deorbit Using Space

Structures & Tethers					Tethered System
Session 15: Special Session - Mars Insight	Kula	AAS 19-213	Eric Gustafson	14:10 - 14:30	InSight Orbit Determination
Session 16: Special Session - Mars Sample Return	Hana	AAS 19-326	Ryan Woolley	14:10 - 14:30	Low-Thrust Trajectory Bacon Plots for Mars Mission Design
Session 14: Dynamical Systems Theory	Napili	AAS 19-366	Damon Landau	14:30 - 14:50	GLOBAL SEARCH OF RESONANT TRANSFERS FOR EUROPA LANDER TO CLIPPER DATA RELAY
Session 13: Large Space Structures & Tethers	Kapulua	AAS 19-363	George Zhu	14:30 - 14:50	HIGH-FIDELITY DYNAMIC MODELLING OF PARTIAL SPACE ELEVATOR WITH DEPOYMENT OR RETRIEVAL OF TETHER
Session 15: Special Session - Mars Insight	Kula	AAS 19-222	Jill Seubert	14:30 - 14:50	InSight Attitude Control System Thruster Characterization and Calibration for Successful Navigation to Mars
Session 16: Special Session - Mars Sample Return	Hana	AAS 19-345	Frank Laipert	14:30 - 14:50	Hybrid Chemical-Electric Trajectories for a Mars Sample Return Orbiter
Session 14: Dynamical Systems Theory	Napili	AAS 19-342	Francisco Crespo	14:50 - 15:10	Attitude Dynamics of a Rigid Body in Circular Orbit
Session 13: Large Space Structures & Tethers	Kapulua	AAS 19-365	George Zhu	14:50 - 15:10	FLIGHT DYNAMICS AND CONTROL STRATEGY OF FLEXIBLE ELECTRIC SOLAR WIND SAIL
Session 15: Special Session - Mars Insight	Kula	AAS 19-228	Allen Halsell	14:50 - 15:10	Navigation Performance of the 2018 InSight Mars Lander Mission

Session 16: Special Session - Mars Sample Return	Hana	AAS 19-456	Austin Nicholas	14:50 - 15:10	Simultaneous Optimization of Spacecraft and Trajectory Design for Interplanetary Missions Utilizing Solar Electric Propulsion
Session 14: Dynamical Systems Theory	Napili	AAS 19-359	Yuki Kayama	15:10 - 15:30	Sparse Optimal Trajectory Design in Three-Body Problem
Session 13: Large Space Structures & Tethers	Kapulua	AAS 19-369	George Zhu	15:10 - 15:30	PARALLEL OPTIMAL CONTROL FOR PARTIAL SPACE ELEVATOR
Session 15: Special Session - Mars Insight	Kula	AAS 19-232	Min-Kun Chung	15:10 - 15:30	Maneuver Design Overview of the 2018 InSight Mars Lander Mission
Session 16: Special Session - Mars Sample Return	Hana	AAS 19-458	Austin Nicholas	15:10 - 15:30	Mission Analysis for a Potential Mars Sample Return Campaign in the 2020's
Session 14: Dynamical Systems Theory	Napili	AAS 19-372	Marcello Romano	15:30 - 15:50	New Results on Minimum-time Control of Linear Systems between Arbitrary States with Applicability to Space Flight
Session 13: Large Space Structures & Tethers	Kapulua	AAS 19-370	George Zhu	15:30 - 15:50	NANOSATELLITE MISSION FOR SPACE DEBRIS DEORBIT DEMONSTRATION BY ELECTRODYNAMIC TETHER
Session 15: Special Session - Mars Insight	Kula	AAS 19-233	Sean Wagner	15:30 - 15:50	Mars Reconnaissance Orbiter Maneuver Plan for Mars 2020 Entry, Descent, and Landing Support and Beyond
Session 16: Special Session - Mars Sample Return	Hana	AAS 19-459	Zubin Olikara	15:30 - 15:50	Chemical and Solar Electric Propulsion Orbit Matching for Mars Sample Rendezvous

Session 14: Dynamical Systems Theory	Napili	AAS 19-543	David Hinckley	15:50 - 16:10	Finding Symmetric Halo Orbits Framed as a Global Optimization problem Using Monotonic Basin Hopping
Session 13: Large Space Structures & Tethers	Kapulua	AAS 19-251	Virgil Hutchinson	15:50 - 16:10	A Multidisciplinary Performance Analysis for the Cygnus Cargo Resupply Mission to the ISS
Session 15: Special Session - Mars Insight	Kula	AAS 19-264	Eugene Bonfiglio	15:50 - 16:10	Atmospheric Impacts on EDL Maneuver Targeting for the Insight Mission and Unguided Mars Landers
Session 16: Special Session - Mars Sample Return	Hana	AAS 19-583	Robert Lock	15:50 - 16:10	Potential Campaign Architectures and Mission Design Challenges for International Mars Sample Return Mission Studies
Session 15: Special Session - Mars Insight	Kula	AAS 19-291	Mark Wallace	16:10 - 16:30	Orbiters, Cubesats, and Radio Telescopes, Oh My; Entry, Descent, and Landing Communications for the 2018 InSight Mars Lander Mission
Session 16: Special Session - Mars Sample Return	Hana	AAS 19-555	Puneet Singla	16:10 - 16:30	OPTIMAL FEEDBACK CONTROL FOR THE HYPERSONICRE-ENTRY PROBLEM

January 16, 2019

Session	Room	Doc. #	Presenter		Title
Session 18: Asteroid & Non-Earth Orbiting Missions II	Napili	AAS 19-427	Daniel Brack	8:00 - 8:20	Asteroid Manipulation with Active Boulder Removal
Session 19: Proximity Missions & Formation Flying I	Kula	AAS 19-235	Paul Schumacher	8:00 - 8:20	Exact Keplerian Relative Motion: An Elementary Formulation of the Initial-Value Problem

Session 17: Space Situational Awareness & Conjunction Analysis	Kapulua	AAS 19-241	Stefania Soldini	8:00 - 8:20	Hayabusa2 Mission Solar Conjunction Phase for Hovering Satellite: Trajectory Design, Navigation and Post-Operation Evaluation
Session 20: Trajectory Design & Optimization IV	Hana	AAS 19-361	Yuanzhuo Geng	8:00 - 8:20	Time-Optimal Repointing Maneuver of a Rigid Spacecraft with One Degree of Freedom for Final Attitude
Session 18: Asteroid & Non-Earth Orbiting Missions II	Napili	AAS 19-436	Soon-Jo Chung	8:20 - 8:40	Large Constellations and Formations for Exploring Interstellar Objects and Long-Period Comets
Session 19: Proximity Missions & Formation Flying I	Kula	AAS 19-290	Julio Cesar Benavides	8:20 - 8:40	Relative Motion Analysis Using Third- and Fourth-Order Solutions of the Relative Two-Body Problem
Session 17: Space Situational Awareness & Conjunction Analysis	Kapulua	AAS 19-284	Marc Balducci	8:20 - 8:40	Maneuver Design for Asteroid Rendezvous Considering Uncertainty
Session 20: Trajectory Design & Optimization IV	Hana	AAS 19-443	Nathan Strange	8:20 - 8:40	Series Solution for Motion in an Arbitrary Potential Field
Session 18: Asteroid & Non-Earth Orbiting Missions II	Napili	AAS 19-450	Shota Takahashi	8:40 - 9:00	Effect of Shifted Origin on the Osculating Orbital Elements of Terminator Orbit
Session 19: Proximity Missions & Formation	Kula	AAS 19-338	Ahmad yazan Chihabi	8:40 - 9:00	ANALYTICAL SPACECRAFT FORMATION DYNAMICS IN ECCENTRIC ORBITS WITH GRAVITATIONAL, DRAG AND

Flying I					THIRD-BODY PERTURBATIONS
Session 17: Space Situational Awareness & Conjunction Analysis	Kapulua	AAS 19-433	shiva iyer	8:40 - 9:00	Context-Based Non-Compliance for GEO Satellite Reorbiting
Session 20: Trajectory Design & Optimization IV	Hana	AAS 19-389	Takuya Chikazawa	8:40 - 9:00	Science Orbits Design for The Lunar CubeSat EQUULEUS and for The Phobos Sample Return Mission MMX
Session 18: Asteroid & Non-Earth Orbiting Missions II	Napili	AAS 19-509	Kristofer Drozd	9:00 - 9:20	Modeling Imaging Uncertainty For OSIRIS-REx's Asteroid Approach Observations
Session 19: Proximity Missions & Formation Flying I	Kula	AAS 19-364	Matthew Willis	9:00 - 9:20	Second-Order Analytical Solution for Relative Motion on Arbitrarily Eccentric Orbits
Session 17: Space Situational Awareness & Conjunction Analysis	Kapulua	AAS 19-437	Zachary Hall	9:00 - 9:20	A Probabilistic Approach for Reachability Set Computation for Efficient Space Situational Awareness
Session 20: Trajectory Design & Optimization IV	Hana	AAS 19-398	Christopher Lorenz	9:00 - 9:20	MULTI-OBJECTIVE OPTIMIZATION OF LOW THRUST TRAJECTORIES FOR PROPELLANT MASS, TIME OF FLIGHT, AND RADIATION DOSE
Session 18: Asteroid & Non-Earth Orbiting Missions II	Napili	AAS 19-529	William Ledbetter	9:20 - 9:40	Expected Accuracy of Density Recovery using Satellite Swarm Gravity Measurements

Session 19: Proximity Missions & Formation Flying I	Kula	AAS 19-282	Lauren Schlenker	9:20 - 9:40	Simultaneous Localization and Mapping for Satellite Rendezvous and Proximity Operations Using Random Finite Sets
Session 17: Space Situational Awareness & Conjunction Analysis	Kapulua	AAS 19-452	Emmanuel Delande	9:20 - 9:40	A new representation of uncertainty for collision assessment
Session 20: Trajectory Design & Optimization IV	Hana	AAS 19-406	Lorenzo Angelo Ricciardi	9:20 - 9:40	A Relaxation Approach for Hybrid Multi-Objective Optimal Control: Application to Multiple Debris Removal Missions
Morning Break 10:00 - 10:20					
Session 18: Asteroid & Non-Earth Orbiting Missions II	Napili	AAS 19-234	Stijn De Smet	10:20 - 10:40	On the design of multiple-revolution solar gravity driven orbital transfers around Mars
Session 19: Proximity Missions & Formation Flying I	Kula	AAS 19-582	Bogdan Udrea	10:20 - 10:40	Analysis fo a swarm deployment for very low Earth orbit operations
Session 17: Space Situational Awareness & Conjunction Analysis	Kapulua	AAS 19-483	Lyndy Axon	10:20 - 10:40	Early Collision and Fragmentation Detection of Space Objects without Orbit Determination
Session 20: Trajectory Design & Optimization IV	Hana	AAS 19-408	Kazutoshi Takemura	10:20 - 10:40	Low Energy Escape Using Tube Dynamics Associated with Quasi-halo Orbit
Session 18: Asteroid &	Napili	AAS 19-244	Justin Mansell	10:40 - 11:00	Swarm Optimization of Lunar Transfers from Earth Orbit

Non-Earth Orbiting Missions II					with Radiation Dose Constraints
Session 19: Proximity Missions & Formation Flying I	Kula	AAS 19-501	Hongwen Wang	10:40 - 11:00	Rapid Algorithm to Determine the Close Approaches and Durations Between Satellites
Session 17: Space Situational Awareness & Conjunction Analysis	Kapulua	AAS 19-355	Yueyong Lyu	10:40 - 11:00	Two-Phase Impact Time Guidance Strategy via Dual-Virtual-Target Concept
Session 20: Trajectory Design & Optimization IV	Hana	AAS 19-422	Kento Ichinomiya	10:40 - 11:00	QUASI-SATELLITE ORBIT TRANSFERS VIA MULTI-REVOLUTIONAL PERIODIC ORBITS
Session 18: Asteroid & Non-Earth Orbiting Missions II	Napili	AAS 19-415	Kenshiro Oguri	11:00 - 11:20	SRP-based orbit control with application to orbit stationkeeping at small bodies
Session 19: Proximity Missions & Formation Flying I	Kula	AAS 19-511	Ayansola Ogundele	11:00 - 11:20	A Tip-Tilt Hardware-in-the-loop air-bearing test bed with physical emulation of the relative orbital dynamics
Session 17: Space Situational Awareness & Conjunction Analysis	Kapulua	AAS 19-506	Jason Reiter	11:00 - 11:20	Spacecraft Detection Avoidance Maneuver Optimization Using Reinforcement Learning
Session 20: Trajectory Design & Optimization IV	Hana	AAS 19-424	Lorenzo Federici	11:00 - 11:20	Integrated Optimization of Ascent Trajectory and SRM Design of Multistage Launch Vehicles

Session 18: Asteroid & Non-Earth Orbiting Missions II	Napili	AAS 19-547	Anthony Genova	11:20 - 11:40	Ballistic Moon-Moon Transfers in the Cislunar Restricted Four-Body Problem
Session 17: Space Situational Awareness & Conjunction Analysis	Kapulua	AAS 19-517	Jannuel Cabrera	11:20 - 11:40	AN INITIAL ANALYSIS OF AUTOMATING CONJUNCTION ASSESSMENT AND COLLISION AVOIDANCE PLANNING IN SPACE TRAFFIC MANAGEMENT
Session 20: Trajectory Design & Optimization IV	Hana	AAS 19-442	Darrel Conway	11:20 - 11:40	Using the Paramat System in Mission Analysis and Design
Session 18: Asteroid & Non-Earth Orbiting Missions II	Napili	AAS 19-371	Virginia Raposo-Pulido	11:40 - 12:00	Gravitational capture at Saturn with low-thrust assistance
Session 20: Trajectory Design & Optimization IV	Hana	AAS 19-426	Steven McCarty	11:40 - 12:00	Missed Thrust Analysis and Design for Low Thrust Cislunar Transfers

Session	Room	Doc. #	Presenter		Title
Session 22: Guidance, Navigation, and Control I	Napili	AAS 19-207	Lara Magallanes	13:30 - 13:50	Unscented Guidance for Zero-Feedback Reaction Wheel Slews
Session 23: Proximity Missions & Formation Flying II	Kula	AAS 19-482	Bryce Doerr	13:30 - 13:50	Random Finite Set Theory and Optimal Control of Large Spacecraft Swarms
Session 21: Space Situational Awareness & Flight	Kapulua	AAS 19-534	Daniel Aguilar Marsillach	13:30 - 13:50	Real-Time Telescope Tasking for Custody and Anomaly Resolution Using Judicial Evidential Reasoning

Dynamics Operations					
Session 24: Trajectory Design & Optimization V	Hana	AAS 19-448	Jackson Shannon	13:30 - 13:50	Q-Law Aided Direct Trajectory Optimization for the High-Fidelity, Many-Revolution Low-Thrust Orbit Transfer Problem
Session 22: Guidance, Navigation, and Control I	Napili	AAS 19-221	Casey Heidrich	13:50 - 14:10	Modern Aerocapture Guidance to Enable Reduced-lift Vehicles at Neptune
Session 23: Proximity Missions & Formation Flying II	Kula	AAS 19-349	Nobuhiro Funabiki	13:50 - 14:10	Network architecture for UWB-based relative navigation of multiple spacecraft in formation flight
Session 21: Space Situational Awareness & Flight Dynamics Operations	Kapulua	AAS 19-540	John Gaebler	13:50 - 14:10	Label Assignments in CubeSat Cluster Deployment Tracking
Session 24: Trajectory Design & Optimization V	Hana	AAS 19-449	Ravishankar Mathur	13:50 - 14:10	Visual Interactive Trajectory Design
Session 22: Guidance, Navigation, and Control I	Napili	AAS 19-246	Charles Wright	14:10 - 14:30	A DIRECT CHEBYSHEV PICARD ITERATION APPROACH TO PERTUBED BALLISTIC PROPAGATION AND LAMBERT BOUNDARY VALUE PROBLEMS
Session 23: Proximity Missions & Formation Flying II	Kula	AAS 19-350	Sumant Sharma	14:10 - 14:30	Pose Estimation For Non-Cooperative Spacecraft Rendezvous Using Neural Networks
Session 21: Space Situational	Kapulua	AAS 19-521	Thomas Kelecy	14:10 - 14:30	Automated Near Real-time Validation and Data Integrity Assessment Using an

Awareness & Flight Dynamics Operations					Unscented Schmidt Kalman Filter (USKF)
Session 24: Trajectory Design & Optimization V	Hana	AAS 19-451	Jennifer Hudson	14:10 - 14:30	On-Orbit Servicing Mission Design in a Dynamic Client Environment
Session 22: Guidance, Navigation, and Control I	Napili	AAS 19-276	Yu Nakajima	14:30 - 14:50	Using GNSS Receiver at Near Rectlinear Halo Orbit
Session 23: Proximity Missions & Formation Flying II	Kula	AAS 19-405	William Bezouska	14:30 - 14:50	Spacecraft Pose Estimation and Swarm Localization Performance Under Varying Illumination and Viewing Conditions
Session 21: Space Situational Awareness & Flight Dynamics Operations	Kapulua	AAS 19-551	Michael Volle	14:30 - 14:50	DISTANT RETROGRADE ORBIT CONSTELLATIONS FOR RELATIVE-ONLY NAVIGATION IN NEAR RECTILINEAR HALO ORBITS
Session 24: Trajectory Design & Optimization V	Hana	AAS 19-461	Tyler Doogan	14:30 - 14:50	Dynamic Optimization for Large Scale Active Debris Removal Mission Design Applications
Session 22: Guidance, Navigation, and Control I	Napili	AAS 19-293	RICHARD LINARES	14:50 - 15:10	Adaptive Guidance with Reinforcement Meta Learning
Session 23: Proximity Missions & Formation Flying II	Kula	AAS 19-407	Mark Mercier	14:50 - 15:10	Optimal Inspection of a Nadir-Pointing Satellite with Dynamic Angle Constraints
Session 21: Space Situational	Kapulua	AAS 19-563	Brett Newman	14:50 - 15:10	COGITATION OF SPACE CURVE PRINCIPLES FOR LAPLACE ORBIT

Awareness & Flight Dynamics Operations					DETERMINATION
Session 24: Trajectory Design & Optimization V	Hana	AAS 19-464	Brandon Jones	14:50 - 15:10	Modeling Attitude-Dependent Maneuver Errors with Polynomial Chaos Expansions
Session 23: Proximity Missions & Formation Flying II	Kula	AAS 19-471	Scott Carnahan	15:10 - 15:30	Impact of Internal Heating on Spacecraft Thermal Signature
Afternoon Break 15:30 - 15:50					
Session 22: Guidance, Navigation, and Control I	Napili	AAS 19-303	Pascal PRIEUR	15:50 - 16:10	Drag-Free and Attitude Control System, lessons learned from MICROSCOPE flight (2016-2018)
Session 23: Proximity Missions & Formation Flying II	Kula	AAS 19-535	Francisco José Franquiz Maldonado	15:50 - 16:10	Optimal Range Observability Maneuvers for Angles-Only Navigation in Elliptic Orbits
Session 21: Space Situational Awareness & Flight Dynamics Operations	Kapulua	AAS 19-569	Kota Kakihara	15:50 - 16:10	ACCURATE AND ROBUST ESTIMATION METHOD OF AUTONOMOUS ORBIT DETERMINATION USING ACTIVE MANEUVERS AND INTER-SATELLITE RANGING
Session 24: Trajectory Design & Optimization V	Hana	AAS 19-466	Diane Davis	15:50 - 16:10	Disposal, Deployment, and Debris in Near Rectilinear Halo Orbits
Session 22: Guidance, Navigation, and Control I	Napili	AAS 19-305	Mauro Pontani	16:10 - 16:30	A New Guidance and Control Architecture for Accurate Orbit Injection
Session 23:	Kula	AAS 19-	Marcello	16:10 - 16:30	Prototype Test Results of IVA

Proximity Missions & Formation Flying II		539	Romano		Hopping Maneuvers of an Autonomous Robotic Vehicle
Session 21: Space Situational Awareness & Flight Dynamics Operations	Kapulua	AAS 19-227	Gabe D. Rogers	16:10 - 16:30	New Horizons 2014MU69 (Ultima Thule) Flyby Design and Execution
Session 24: Trajectory Design & Optimization V	Hana	AAS 19-324	Kaela Martin	16:10 - 16:30	Automating Tour Design with Applications for Europa Lander
Session 22: Guidance, Navigation, and Control I	Napili	AAS 19-313	Yueyong Lyu	16:30 - 16:50	Data-driven model-free adaptive sliding mode attitude control of combined spacecraft
Session 23: Proximity Missions & Formation Flying II	Kula	AAS 19-307	Mohamed Shouman	16:30 - 16:50	Output Regulation Control for Satellite Formation Flying Using Differential Drag
Session 21: Space Situational Awareness & Flight Dynamics Operations	Kapulua	AAS 19-383	Young-Rok Kim	16:30 - 16:50	Orbit Determination Simulation for Korea Pathfinder Lunar Orbiter Using Sequential Estimation Approach
Session 24: Trajectory Design & Optimization V	Hana	AAS 19-486	Erica Jenson	16:30 - 16:50	Robust Trajectory Design for Asteroid Orbiters
Session 22: Guidance, Navigation, and Control I	Napili	AAS 19-351	Donald Kuettel	16:50 - 17:10	AN ANALYSIS OF LOW-THRUST GUIDANCE ALGORITHMS AROUND SMALL BODIES
Session 23:	Kula	AAS 19-	George Zhu	16:50 - 17:10	AUTONOMOUS SPACECRAFT

Proximity Missions & Formation Flying II		367			RENDEZVOUS BY LINE-OF-SIGHT CONTROL
Session 21: Space Situational Awareness & Flight Dynamics Operations	Kapulua	AAS 19-474	Brian Kaplinger	16:50 - 17:10	Single-Waypoint Guidance for Rotating Target Formation Flying
Session 24: Trajectory Design & Optimization V	Hana	AAS 19-477	Raymond Merrill	16:50 - 17:10	Mission Designs for Human Lunar Surface Access from an Earth-Moon Near Rectilinear Halo Orbit
Session 23: Proximity Missions & Formation Flying II	Kula	AAS 19-475	Chandrakanth Venigalla	17:10 - 17:30	3-Dimensional Reachable Set Applications to Multi-Spacecraft Trajectory Coordination

January 17, 2019

Session	Room	Doc. #	Presenter		Title
Session 26: Astrodynamics	Napili	AAS 19-492	Oscar Fuentes-Munoz	8:00 - 8:20	Parking orbit design for generic near-Earth object flyby missions
Session 25: Guidance, Navigation, and Control II	Kapulua	AAS 19-315	Eric Bourgeois	8:00 - 8:20	New improvements on atmospheric trajectory optimization of a rocket reusable first stage with turbo engines
Session 27: Proximity Missions & Formation Flying III	Kula	AAS 19-258	Sylvain Renevey	8:00 - 8:20	Spacecraft Formations Using Artificial Potential Functions and Relative Orbital Elements
Session 28: Trajectory Design & Optimization	Hana	AAS 19-487	Robyn Woollands	8:00 - 8:20	Efficient Computation of Optimal Low Thrust Gravity Perturbed Orbit Transfers

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Session 26: Astrodynamics	Napili	AAS 19-421	Kenta Oshima	8:20 - 8:40	Vertically Stable and Unstable Manifolds of Planar Periodic Orbits: Applications to Spacecraft and Asteroid Trajectories
Session 25: Guidance, Navigation, and Control II	Kapulua	AAS 19-522	John McCormack	8:20 - 8:40	Coordination of a Decentralized Satellite Swarm with Internal Formation
Session 27: Proximity Missions & Formation Flying III	Kula	AAS 19-314	Wei Lin	8:20 - 8:40	An Artificial Bifurcation Potential Field Method for Spacecraft Swarm Formation Planning
Session 28: Trajectory Design & Optimization VI	Hana	AAS 19-568	Minji Jo	8:20 - 8:40	Synthesis of fuel-optimal powered descent trajectories for planetary landing missions
Session 26: Astrodynamics	Napili	AAS 19-455	Sonia Hernandez	8:40 - 9:00	Connecting Resonant Trajectories to a Europa Capture through Lissajous Staging Orbits
Session 25: Guidance, Navigation, and Control II	Kapulua	AAS 19-542	Evan Kawamura	8:40 - 9:00	Integrated Targeting, Guidance, Navigation and Control for Unmanned Aerial Vehicles
Session 27: Proximity Missions & Formation Flying III	Kula	AAS 19-325	Cole George	8:40 - 9:00	Evolutionary Neurocontrol for Spacecraft Proximity Operations
Session 28: Trajectory Design & Optimization VI	Hana	AAS 19-496	Vishala Arya	8:40 - 9:00	Hyperbolic-Tangent-Based Smoothing with State Transition Matrix implementation for generating Fuel-optimal trajectories
Session 26: Astrodynamics	Napili	AAS 19-481	Brian Anderson	9:00 - 9:20	The Stability of Orbital Resonances for Europa Quarantine Design: Escape

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Session 27: Proximity Missions & Formation Flying III	Kula	AAS 19-346	Camilo Riano-Rios	9:00 - 9:20	Relative Maneuvering for Multiple Spacecraft via Differential Drag using LQR and Constrained Least Squares.
Session 28: Trajectory Design & Optimization VI	Hana	AAS 19-500	David Folta	9:00 - 9:20	Transfer Trajectory Options for Servicing Sun-Earth-Moon Libration Point Missions
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Session 25: Guidance, Navigation, and Control II	Kapulua	AAS 19-429	Cameron Helmuth	9:20 - 9:40	Gyroscope-Based Spacecraft Angular Rate and Mass Properties Estimation
Session 27: Proximity Missions & Formation Flying III	Kula	AAS 19-505	David Yaylali	9:20 - 9:40	Fractional Control of Relative Orbit Trajectories
Session 28: Trajectory Design & Optimization VI	Hana	AAS 19-504	David Hinckley	9:20 - 9:40	Vector Formulations for Spherically Bounded Search Spaces
Session 26: Astrodynamics	Napili	AAS 19-413	Arnaud Boutonnet	9:40 - 10:00	JUICE Equinox Jupiter Tour: the Challenge of Long Eclipses
Session 27: Proximity Missions & Formation Flying III	Kula	AAS 19-384	Mohamed Shouman	9:40 - 10:00	Controllability Analysis of Propellant-Free Satellite Formation Flight
Session 28: Trajectory	Hana	AAS 19-514	Jason Reiter	9:40 - 10:00	Multi-Objective Optimization For

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Session 26: Astrodynamics	Napili	AAS 19-562	Natasha Bosanac	10:20 - 10:40	A Data Mining Approach to Using Poincaré Maps in Multi-Body Trajectory Design Strategies
Session 25: Guidance, Navigation, and Control II	Kapulua	AAS 19-435	Simeng Huang	10:20 - 10:40	Optimal Steering Law for Single-Gimbal Control Moment Gyroscopes with Singularity Avoidance and Vibration Suppression
Session 27: Proximity Missions & Formation Flying III	Kula	AAS 19-400	Elisa Capello	10:20 - 10:40	Proximity Operations with Obstacles Avoidance based on Artificial Potential Field and Sliding Mode Control
Session 28: Trajectory Design & Optimization VI	Hana	AAS 19-519	Spencer Harwood	10:20 - 10:40	ANALYSIS OF ANALOG-TO-DIGITAL CONVERSION TECHNIQUES FOR SATELLITE ORBITAL MANEUVERING USING COLD GAS THRUSTERS
Session 26: Astrodynamics	Napili	AAS 19-215	Xinwei Wang	10:40 - 11:00	A Kriging based framework for rapid satellite-to-site visibility determination
Session 25: Guidance, Navigation, and Control II	Kapulua	AAS 19-574	Jonathan De Leon	10:40 - 11:00	A Real-Time GNC Framework for Rendezvous of Small Satellites Using Constant Thrust in a Uniform Gravitational Field
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Session 28: Trajectory Design & Optimization	Hana	AAS 19-536	David Hinckley	10:40 - 11:00	Multi-Objective Optimization of Spacecraft Trajectories for Small-Body Coverage Missions with

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Session 25: Guidance, Navigation, and Control II	Kapulua	AAS 19-494	Courtney Hollenberg	11:00 - 11:20	CENTROIDING PERFORMANCE FOR HORIZON-BASED OPTICAL NAVIGATION WITH CASSINI IMAGES OF DIONE AND RHEA
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Pearl, Jason - Asteroid & Non-Earth Orbiting Missions I , Trajectory Design & Optimization VI
Pelaez, Jesus - Asteroid & Non-Earth Orbiting Missions II , Orbital Dynamics, Perturbations, and Stability I
Pellegrini, Etienne - Trajectory Design & Optimization V
Pellegrino, Marielle - Orbital Debris & Space Environment
Pellegrino, Sergio - Attitude Dynamics & Control II
Pengjie, Li - Attitude Dynamics & Control I , Large Space Structures & Tethers
Perryman, Trey - Trajectory Design & Optimization III
Petropoulos, Anastassios - Trajectory Design & Optimization I
Pezent, James - Trajectory Design & Optimization VI
Pfrang, Kaila - Trajectory Design & Optimization I
Phan, Minh - Attitude Dynamics & Control II , Large Space Structures & Tethers
Phillips, Sean - Trajectory Design & Optimization V
Piggott, Scott - Attitude Dynamics & Control I
Plice, Laura - Orbital Dynamics, Perturbations, and Stability I
Pontani, Mauro - Guidance, Navigation, and Control I , Trajectory Design & Optimization II
Praly, Nicolas - Guidance, Navigation, and Control II
PRIEUR, Pascal - Guidance, Navigation, and Control I
Punta, Elisabetta - Proximity Missions & Formation Flying III
Putnam, Zachary - Atmospheric Re-entry & Satellite Constellations
Qu, Min - Special Session - Mars Sample Return , Trajectory Design & Optimization I ,

Trajectory Design & Optimization V
Rajbhandary, Aastha - Proximity Missions & Formation Flying III
Ramadan, Mohammad - Artificial Intelligence in Astrodynamics
Ranieri, Chris - Trajectory Design & Optimization I
Raposo-Pulido, Virginia - Asteroid & Non-Earth Orbiting Missions II , Orbital Dynamics, Perturbations, and Stability I
Reinke, Zachary - Artificial Intelligence in Astrodynamics
Reiter, Jason - Space Situational Awareness & Conjunction Analysis , Trajectory Design & Optimization VI
Renevey, Sylvain - Proximity Missions & Formation Flying III
Renk, Florian - Asteroid & Non-Earth Orbiting Missions I
Restrepo, Ricardo - Astrodynamics
Riano-Rios, Camilo - Proximity Missions & Formation Flying III
Ricciardi, Lorenzo Angelo - Trajectory Design & Optimization IV
Richardson, Matthew - Orbital Debris & Space Environment
Riley, Jack - Trajectory Design & Optimization III
Roa, Javier - Asteroid & Non-Earth Orbiting Missions I
ROBERT, Alain - Guidance, Navigation, and Control I
RODRIGUES, Manuel - Guidance, Navigation, and Control I
Rogers, Gabe D. - Space Situational Awareness & Flight Dynamics Operations
Rolins, Armando - Space Situational Awareness & Flight Dynamics Operations
Romano, Marcello - Attitude Dynamics & Control II , Dynamical Systems Theory , Proximity Missions & Formation Flying I , Proximity Missions & Formation Flying II
Rosengren, Aaron J. - Orbital Debris & Space Environment
Ryne, Mark - Trajectory Design & Optimization I , Trajectory Design & Optimization II
Saiki, Takanao - Guidance, Navigation, and Control II , Orbital Dynamics, Perturbations, and Stability II
San Martin, A. Miguel - Astrodynamics
Scala, Francesca - Astrodynamics
Schaub, Hanspeter - Artificial Intelligence in Astrodynamics , Atmospheric Re-entry & Satellite Constellations , Attitude Dynamics & Control I , Proximity Missions & Formation Flying II
Scheeres, Daniel Asteroid & Non-Earth Orbiting Missions II , Astrodynamics , Orbital Debris & Space Environment , Proximity Missions & Formation Flying II , Trajectory Design & Optimization V
Schlei, Wayne - Trajectory Design & Optimization III
Schlenker, Lauren - Proximity Missions & Formation Flying I
Schmid, Christine - Attitude Dynamics & Control I
Schulze, William - Special Session - Mars Insight
Schumacher, Paul - Proximity Missions & Formation Flying I
Scorsoglio, Andrea - Artificial Intelligence in Astrodynamics
Scoubeau, Mehdi - Asteroid & Non-Earth Orbiting Missions I
Senent, Juan - Trajectory Design & Optimization II
Servadio, Simone - Orbit Determination & Space-Surveillance Tracking
Seubert, Jill - Special Session - Mars Insight , Trajectory Design & Optimization I
Shan, Jinjun - Orbital Dynamics, Perturbations, and Stability I
Shannon, Jackson - Trajectory Design & Optimization V

Sharma, Sumant - Proximity Missions & Formation Flying II
Sharp, Alanna - Attitude Dynamics & Control II
Shenoy, Prakash - Space Situational Awareness & Flight Dynamics Operations
Shouman, Mohamed - Proximity Missions & Formation Flying II , Proximity Missions & Formation Flying III
Siddique, Fazle - Trajectory Design & Optimization I , Trajectory Design & Optimization II
Sieling, Ryan - Attitude Dynamics & Control I
Signori, Gina - Special Session - Mars Insight
Simo, Jules - Orbital Dynamics, Perturbations, and Stability II
Sinclair, Andrew J. - Proximity Missions & Formation Flying III
Singh, Gurkipal - Astrodynamics
Singh, Lake - Trajectory Design & Optimization IV
Singh, Sandeep - Orbital Dynamics, Perturbations, and Stability II
Singla, Puneet - Artificial Intelligence in Astrodynamics , Atmospheric Re-entry & Satellite Constellations , Orbit Determination & Space-Surveillance Tracking , Space Situational Awareness & Conjunction Analysis , Special Session - Mars Sample Return , Trajectory Design & Optimization VI
Sizemore, Alex - Orbit Determination & Space-Surveillance Tracking
Skelton, Eugene - Proximity Missions & Formation Flying III
Sklyanskiy, Evgeniy - Special Session - Mars Insight
Skulsky, Eli - Astrodynamics
Soldini, Stefania - Space Situational Awareness & Conjunction Analysis
Song, Bing - Attitude Dynamics & Control II
Song, Young-Joo - Space Situational Awareness & Flight Dynamics Operations
Song, Yu Artificial - Intelligence in Astrodynamics
Sood, Rohan - Asteroid & Non-Earth Orbiting Missions II , Trajectory Design & Optimization VI
Souied, Youssef - Orbital Dynamics, Perturbations, and Stability I
Spear, Renee - Trajectory Design & Optimization II
Spencer, David A. - Asteroid & Non-Earth Orbiting Missions II , Atmospheric Re-entry & Satellite Constellations , Proximity Missions & Formation Flying III
Spencer, David B. - Proximity Missions & Formation Flying I , Space Situational Awareness & Conjunction Analysis , Trajectory Design & Optimization VI
Statham, Tamara - Trajectory Design & Optimization I
Stauch, Jason - Orbital Debris & Space Environment
Stein, William - Trajectory Design & Optimization I
Strange, Nathan - Trajectory Design & Optimization IV
Stuart, Jeffrey - Asteroid & Non-Earth Orbiting Missions II , Dynamical Systems Theory
Subbarao, Kamesh - Attitude Dynamics & Control I
Sullivan, Christopher - Dynamical Systems Theory
Sun, Xiucong - Proximity Missions & Formation Flying I
Sweetser, Theodore H. (Ted) - Astrodynamics
Taheri, Ehsan - Orbital Dynamics, Perturbations, and Stability II, Trajectory Design & Optimization VI
Takahashi, Shota - Asteroid & Non-Earth Orbiting Missions II
Takao, Yuki - Guidance, Navigation, and Control II
Takei, Yuto - Orbital Dynamics, Perturbations, and Stability II

Takemura, Kazutoshi - Trajectory Design & Optimization IV
Takeuchi, Hiroshi - Orbital Dynamics, Perturbations, and Stability II
Tang, Xu - Guidance, Navigation, and Control II
Tarzi, Zahi - Orbit Determination & Space-Surveillance Tracking
Tasif, Tahsinul Haque - Orbital Dynamics, Perturbations, and Stability II
Teil, Thibaud - Artificial Intelligence in Astrodynamics , Attitude Dynamics & Control I
Thein, May-Win - Attitude Dynamics & Control I , Guidance, Navigation, and Control II
Thompson, Paul Frank - Trajectory Design & Optimization II
Thompson, Seth - Trajectory Design & Optimization I , Trajectory Design & Optimization III
Tiffin, Daniel - Trajectory Design & Optimization V
Tiscareno, Matthew - Trajectory Design & Optimization II
Tiwari, Madhur - Orbit Determination & Space-Surveillance Tracking
Topputo, Francesco - Artificial Intelligence in Astrodynamics , Asteroid & Non-Earth Orbiting Missions I , Orbital Dynamics, Perturbations, and Stability I , Trajectory Design & Optimization III
Trawny, Nikolas - Astrodynamics
Trenkel, Christian - Orbital Dynamics, Perturbations, and Stability I
Trisolini, Mirko - Orbital Debris & Space Environment
Tseng, Dong-Huei - Large Space Structures & Tethers
Tsuda, Yuichi - Asteroid & Non-Earth Orbiting Missions I , Guidance, Navigation, and Control II , Orbital Dynamics, Perturbations, and Stability II , Space Situational Awareness & Conjunction Analysis
Udrea, Bogdan - Proximity Missions & Formation Flying I , Proximity Missions & Formation Flying II
Ulrich, Steve - Proximity Missions & Formation Flying I
Urrutxua, Hodei - Orbital Dynamics, Perturbations, and Stability I
Valerino, Powtawche - Trajectory Design & Optimization II
Van Wal, Stefaan - Asteroid & Non-Earth Orbiting Missions I
Vaquero, Mar -Astrodynamics , Trajectory Design & Optimization II
Varga, Gábor - Astrodynamics
Vasile, Massimiliano - Trajectory Design & Optimization II , Trajectory Design & Optimization IV
Vavrina, Matthew - Proximity Missions & Formation Flying III
Venigalla, Chandrakanth - Proximity Missions & Formation Flying II
Vincent, Mark - Orbital Debris & Space Environment
Virani, Shahzad - Space Situational Awareness & Conjunction Analysis , Space Situational Awareness & Flight Dynamics Operations
Virgili-Llop, Josep - Proximity Missions & Formation Flying I , Proximity Missions & Formation Flying II
Volle, Michael - Space Situational Awareness & Flight Dynamics Operations
Wagner, Sean - Special Session - Mars Insight , Trajectory Design & Optimization I
Wall, Bradley - Trajectory Design & Optimization I
Wallace, Mark - Astrodynamics , Special Session - Mars Insight
Wang, Bowen - Attitude Dynamics & Control II
Wang, Hao - Atmospheric Re-entry & Satellite Constellations
Wang, Hongwen - Attitude Dynamics & Control I , Large Space Structures & Tethers , Proximity

Missions & Formation Flying I
Wang, Huijiang - Proximity Missions & Formation Flying I
Wang, Pengyu - Space Situational Awareness & Conjunction Analysis
Wang, Shiqiang - Attitude Dynamics & Control I
Wang, Xinwei - Astrodynamics
Wang, Xuechuan - Astrodynamics
Wang, Xueqian - Guidance, Navigation, and Control II
Wang, Zhaowei - Trajectory Design & Optimization II
Wang, Zhenbo - Artificial Intelligence in Astrodynamics
Webb, Ryan - Special Session - Mars Sample Return
Webster, Cassandra - Trajectory Design & Optimization VI
Wetterer, Jack - Orbital Debris & Space Environment
Whitley, Ryan - Attitude Dynamics & Control I
Wie, Bong - Space Situational Awareness & Conjunction Analysis
Wilde, Markus - Atmospheric Re-entry & Satellite Constellations
Willis, Matthew - Proximity Missions & Formation Flying I
Wong, Mau C. - Trajectory Design & Optimization I
Woollands, Robyn - Orbital Dynamics, Perturbations, and Stability II , Special Session - Mars Insight , Trajectory Design & Optimization VI
Woolley, Ryan - Special Session - Mars Sample Return
Wright, Charles - Guidance, Navigation, and Control I
Wu, Di - Trajectory Design & Optimization I , Trajectory Design & Optimization II
Xu, Ming - Orbital Dynamics, Perturbations, and Stability I , Proximity Missions & Formation Flying III
Xu, Shijie - Orbital Dynamics, Perturbations, and Stability I
Yamaguchi, Tomohiro - Space Situational Awareness & Conjunction Analysis
Yamamoto, Toru - Guidance, Navigation, and Control I
Yanagida, Kanta - Trajectory Design & Optimization II
Yanao, Tomohiro - Trajectory Design & Optimization IV
Yaylali, David - Proximity Missions & Formation Flying III
York, Collin - Trajectory Design & Optimization III
Yoshikawa, Kent - Asteroid & Non-Earth Orbiting Missions I
Yoshimura, Hiroaki - Trajectory Design & Optimization IV
Young, Brian - Orbit Determination & Space-Surveillance Tracking
Yu, Wenbin - Atmospheric Re-entry & Satellite Constellations
Zanetti, Renato - Attitude Dynamics & Control I , Orbit Determination & Space-Surveillance Tracking
Zapata, Jorge Luis - Dynamical Systems Theory
Zavoli, Alessandro - Trajectory Design & Optimization IV
Zhang, Kaicheng - Guidance, Navigation, and Control II
Zhang, Shijie - Attitude Dynamics & Control I , Guidance, Navigation, and Control II
Zhao, Penglei - Atmospheric Re-entry & Satellite Constellations
Zhao, Yongchao - Guidance, Navigation, and Control II
Zhaowei, Sun - Guidance, Navigation, and Control I
Zhong, Rui - Attitude Dynamics & Control I , Large Space Structures & Tethers
Zhou, Botian - Attitude Dynamics & Control I , Guidance, Navigation, and Control II

Zhu, George - Large Space Structures & Tethers , Proximity Missions & Formation Flying II
Zhu, Pingping - Proximity Missions & Formation Flying II
Zimmer, Aline K. - Astrodynamics , Trajectory Design & Optimization III
Zinner, Evan - Atmospheric Re-entry & Satellite Constellations
Zuehlke, David - Orbit Determination & Space-Surveillance Tracking

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Session Chairs

Armellin, Roberto - Trajectory Design & Optimization V
Arrieta, Juan - Astrodynamics
Ciarcia, Marco - Attitude Dynamics & Control II
D'Amico, Simone - Orbital Debris & Space Environment
Davis, Diane - Dynamical Systems Theory
Dutta, Atri - Trajectory Design & Optimization IV
Furfaro, Roberto - Artificial Intelligence in Astrodynamics
Ghosh, Pradipto - Trajectory Design & Optimization VI
Gustafson, Eric - Special Session - Mars Insight
Henderson, Troy - Guidance, Navigation, and Control II
Hernandez, Sonia - Trajectory Design & Optimization II
Hudson, Jennifer - Trajectory Design & Optimization VI
Hussein, Islam - Large Space Structures & Tethers
Jones, Brandon - Orbit Determination & Space-Surveillance Tracking
Kelecy, Thomas - Orbital Dynamics, Perturbations, and Stability II
Kim, Donghoon - Asteroid & Non-Earth Orbiting Missions I
Linares, Richard - Orbital Dynamics, Perturbations, and Stability I
Massari, Mauro - Proximity Missions & Formation Flying III
Newman, Brett - Proximity Missions & Formation Flying I
Ozimek, Martin - Trajectory Design & Optimization I
Park, Ryan - Space Situational Awareness & Flight Dynamics Operations
Renk, Florian - Space Situational Awareness & Conjunction Analysis
Romano, Marcello - Attitude Dynamics & Control I
Russell, Ryan - Trajectory Design & Optimization III
Scott, Christopher - Guidance, Navigation, and Control II
Sood, Rohan - Astrodynamics
Strange, Nathan - Space Situational Awareness & Flight Dynamics Operations
Subbarao, Kamesh - Atmospheric Re-entry & Satellite Constellations
Vaquero, Mar - Asteroid & Non-Earth Orbiting Missions II
Wilson, Roby - Proximity Missions & Formation Flying II
Woollands, Robyn - Guidance, Navigation, and Control I
Woolley, Ryan - Special Session - Mars Sample Return