# 2025 AAS/AIAA Astrodynamics Specialist Conference

## Boston, MA, August 10-14, 2025

American Astronautical Society

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# Conference Information

### General Information

The 2025 AAS/AIAA Astrodynamics Specialist Conference, hosted by the American Astronautical Society (AAS) and co-hosted by the American Institute of Aeronautics and Astronautics (AIAA) will be held August 10-14 in Boston, Massachusetts. The conference is organized by the AAS Space Flight Mechanics Committee and the AIAA Astrodynamics Technical Committee.

### Registration

Registration can be accessed at:
https://www.xcdsystem.com/aas/attendee/index.cfm?ID=dL5wZPa

| Registration Type | Early (On or before July 9, 2025) | Regular (July 10 to August 9, 2025) | Walkups (On or after August 10, 2025) |
|---|---|---|---|
| Full Registration - Current Member (AAS or AIAA) | $695 | $875 | $945 |
| Full Registration - Non-member | $795 | $975 | $1,045 |
| Student Registration - Current Member (AAS or AIAA) | $455 | $515 | $595 |
| Student Registration - Non-member | $505 | $565 | $645 |
| Retiree Registration - Current Member (AAS or AIAA) | $455 | $515 | $595 |
| Retiree Registration - Non-member | $510 | $570 | $650 |

The online registration system is programmed to accept Visa, Mastercard, Discover and American Express credit cards.

NOTE: Registration fees are calculated at the time of payment. Beginning the registration process without completing payment may result in a higher fee being charged as applicable based upon the early/late/on-site fee schedule set by the General Chairs.

### Conference Proceedings

We will partner with Springer Nature as our publisher for conference proceedings.

NOTE: One electronic proceedings for download is included with every Full Registration.

If you did not register with a Full Registration OR wish to purchase additional proceedings for download, you can do so during the online registration process.

## Sponsors

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## Conference Location

*General Inquiries* Hyatt Regency Boston
Hyatt Regency Boston
One Avenue de Lafayette, Boston, MA 02111, United States of America
Phone: (617) 912-1234
E-mail: qualitybosto@hyatt.com

*Conference Reservations*
Click to access online reservation page
To make a reservation over the phone, attendees may call the central reservations line at (617-912-1234) and mention the group rate for 2025 AAS/AIAA Astrodynamics Specialist Conference.


### Wi-fi Login

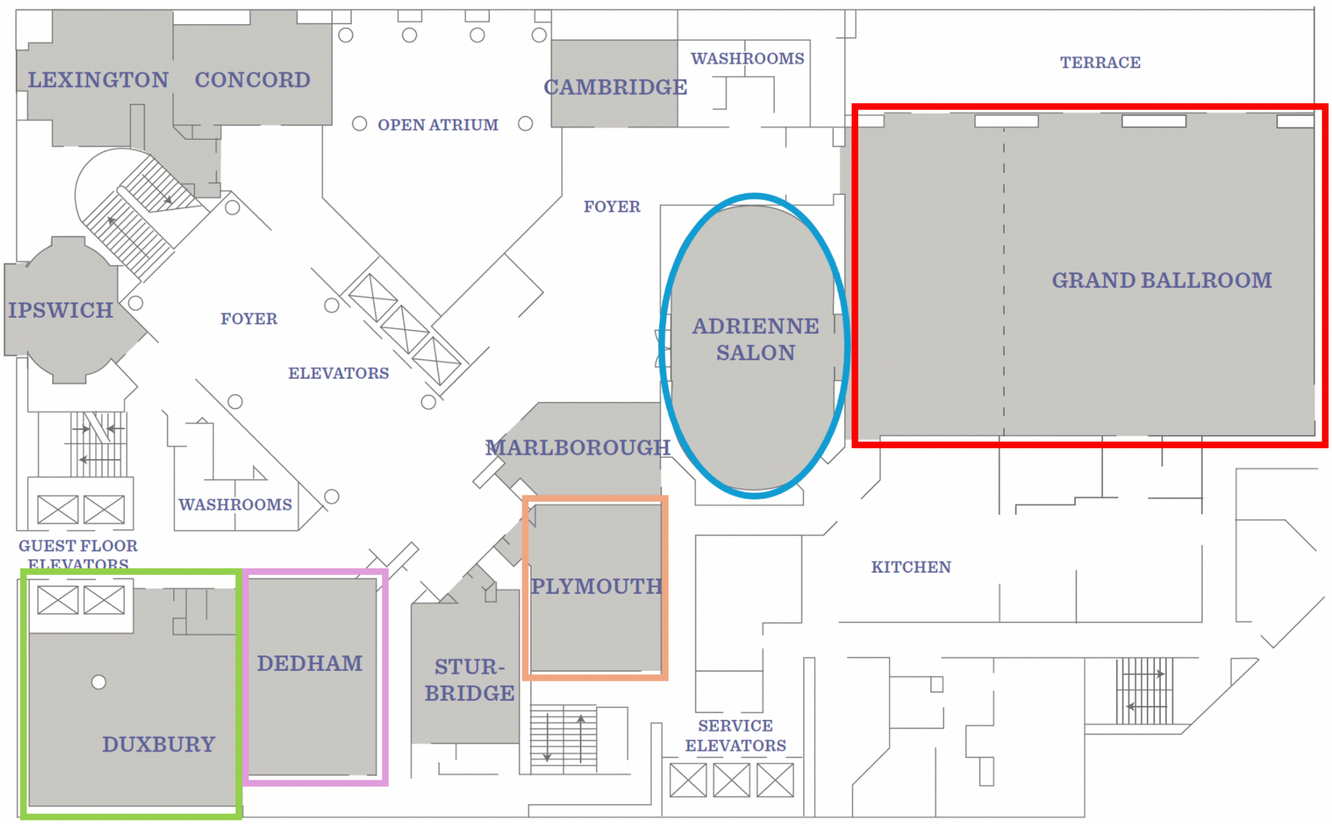
Network: Hyatt_Conference
Passcode: *AstrodynamicsBoston*

**Map of Conference Area at the Hyatt Regency**

**All conference rooms will be on the 4th floor**

**Sessions and events will take place in the following rooms:**

**Grand Ballroom**
**Adrienne Salon**
**Duxbury**
**Dedham**
**Plymouth**



## Social and Offsite Events

On **Sunday evening, Aug 10**, there will be a **welcome reception** at the Hyatt Regency Boston.

On **Monday evening, Aug 11**, we will host a reception, generously sponsored by **Draper**, followed by the presentation of the Dirk Brouwer Award to Prof. Dr. Robert D. Braun, who will deliver the **Dirk Brouwer Plenary Lecture**.

On **Tuesday evening, Aug 12**, we will hold the **Awards Dinner**. We will present the AAS Emerging Astrodynamicist Award, AAS Fellow recognitions, John V. Breakwell Student Paper Awards, **AFOSR** Travel Awards, and the Best Conference Paper Award.

On **Wednesday evening, Aug 13**, we will host a networking happy hour.

A special session on **Monday afternoon, Aug 11** will honor the **technical legacy of Cesar Ocampo**. Refreshments for the session attendees will be kindly sponsored by **Odyssey**.

Do not miss the **Poster Session** on **Wednesday afternoon, August 13**. Refreshments will be provided.

## Schedule of Events

### *Room locations subject to change; please refer to on-line program for latest updates.*

| Date | Start | End | Event | Room | Papers |
|---|---|---|---|---|---|
| 8/10/25 | 4:00 PM | 6:00 PM | Registration | 4th Floor Foyer | |
| 8/10/25 | 6:00 PM | 9:00 PM | Welcome Reception | Grand Ballroom | |
| 8/11/25 | 7:30 AM | 4:00 PM | Registration | 4th Floor Foyer | |
| 8/11/25 | 8:00 AM | 10:00 AM | Cislunar Astrodynamics I | Ballroom B | 512, 515, 523, 547, 569, 579, 616, 621 |
| 8/11/25 | 8:00 AM | 10:00 AM | Trajectory Design and Optimization I | Adrienne Salon | 504, 508, 525, 540, 558, 609, 689, 767 |
| 8/11/25 | 8:00 AM | 10:00 AM | Machine Learning and Artificial Intelligence Applied to Spaceflight I | Dedham | 513, 517, 544, 570, 584, 587, 602, 612 |
| 8/11/25 | 8:00 AM | 10:00 AM | Orbit Determination and Estimation I | Duxbury | 510, 522, 577, 578, 582, 597, 599, 828 |
| 8/11/25 | 10:30 AM | 12:30 PM | Cislunar Astrodynamics II | Ballroom B | 623, 631, 635, 647, 662, 664, 677, 725 |
| 8/11/25 | 10:30 AM | 12:30 PM | Trajectory Design and Optimization II | Adrienne Salon | 562, 580, 581, 589, 607, 611, 615 |
| 8/11/25 | 10:30 AM | 12:30 PM | Attitude Dynamics, Determination and Control I | Dedham | 516, 530, 541, 550, 641, 682, 752, 777 |
| 8/11/25 | 10:30 AM | 12:30 PM | Rendezvous, Relative Motion, and Proximity Operations I | Duxbury | 507, 532, 585, 598, 601, 604, 605 |
| 8/11/25 | 12:45 PM | 1:45 PM | Joint AAS/AIAA Committee Meeting | Duxbury | |
| 8/11/25 | 2:00 PM | 3:15 PM | Atmospheric Re-entry Guidance and Control | Dedham | 549, 592, 680, 728 |
| 8/11/25 | 2:00 PM | 3:15 PM | Orbit Determination and Estimation II | Duxbury | 872, 876, 879, 890, 923 |
| 8/11/25 | 2:00 PM | 3:15 PM | Special Session Honoring the Technical Legacy of Cesar Ocampo I | Ballroom B | 761, 787, 806, 904, 915 |
| 8/11/25 | 2:00 PM | 3:15 PM | Asteroid and Interplanetary Mission Design I | Adrienne Salon | 531, 670, 808, 905, 920 |
| 8/11/25 | 3:45 PM | 5:15 PM | Trajectory Design and Optimization III | Adrienne Salon | 529, 628, 653, 681, 703, 715 |

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|---|---|---|---|---|---|
| 8/11/25 | 3:45 PM | 5:15 PM | Orbital Dynamics, Perturbations, and Stability I | Duxbury | 642, 652, 710, 729, 734, 743 |
| 8/11/25 | 3:45 PM | 5:15 PM | Special Session Honoring the Technical Legacy of Cesar Ocampo II | Ballroom B | 571, 576, 698, 756 |
| 8/11/25 | 3:45 PM | 5:15 PM | Dynamical Systems Theory Applied to Space Flight Problems I | Dedham | 675, 686, 706, 708, 774 |
| 8/11/25 | 6:00 PM | 7:00 PM | Cocktail Reception - Sponsored by Draper | Ballroom A | |
| 8/11/25 | 7:00 PM | 8:00 PM | Brouwer Lecture: The Long-Awaited Autonomy Revolution in Deep-Space Exploration by Dr. Robert D. Braun | Ballroom B | |
| 8/12/25 | 8:00 AM | 10:00 AM | Cislunar Astrodynamics III | Ballroom B | 667, 685, 732, 750, 753, 754, 758, 875 |
| 8/12/25 | 8:00 AM | 10:00 AM | Trajectory Design and Optimization IV | Adrienne Salon | 542, 650, 695, 721, 738, 751, 833, 840 |
| 8/12/25 | 8:00 AM | 10:00 AM | Orbit Determination and Estimation III | Duxbury | 649, 673, 676, 688, 699, 700, 709, 711 |
| 8/12/25 | 8:00 AM | 10:00 AM | Satellite Constellations and Formations I | Dedham | 619, 661, 687, 713, 773, 792, 811, 817 |
| 8/12/25 | 10:30 AM | 12:30 PM | Machine Learning and Artificial Intelligence Applied to Spaceflight II | Dedham | 637, 646, 707, 726, 749, 781, 897 |
| 8/12/25 | 10:30 AM | 12:30 PM | Rendezvous, Relative Motion, and Proximity Operations II | Adrienne Salon | 614, 622, 665, 690, 717, 724 |
| 8/12/25 | 10:30 AM | 12:30 PM | Spacecraft Guidance, Navigation and Control (GNC) I | Duxbury | 551, 573, 575, 613, 660, 841 |
| 8/12/25 | 10:30 AM | 12:30 PM | Space Domain Awareness (SDA) and Space Surveillance I | Ballroom B | 501, 559, 572, 586, 595, 624, 626, 640 |
| 8/12/25 | 12:45 PM | 1:45 PM | AIAA Astrodynamics Committee Meeting | Duxbury | |
| 8/12/25 | 2:00 PM | 3:15 PM | Asteroid and Interplanetary Mission Design II | Duxbury | 608, 632, 645, 668, 669 |
| 8/12/25 | 2:00 PM | 3:15 PM | Orbit Determination and Estimation IV | Dedham | 744, 746, 805, 818, 836 |

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|---|---|---|---|---|---|
| 8/12/25 | 2:00 PM | 3:15 PM | Space Situational Awareness, Conjunction Analysis, and Collision Avoidance I | Adrienne Salon | 563, 633, 656, 666, 807 |
| 8/12/25 | 2:00 PM | 3:15 PM | Special Session on Modeling for Space Sustainability I | Ballroom B | 503, 627, 704, 741, 793 |
| 8/12/25 | 3:45 PM | 5:15 PM | Orbital Dynamics, Perturbations, and Stability II | Dedham | 527, 539, 679, 693, 825 |
| 8/12/25 | 3:45 PM | 5:15 PM | Space Situational Awareness, Conjunction Analysis, and Collision Avoidance II | Adrienne Salon | 545, 556, 557, 812, 832 |
| 8/12/25 | 3:45 PM | 5:15 PM | Special Session on Modeling for Space Sustainability II | Ballroom B | 521, 567, 618, 878, 892 |
| 8/12/25 | 3:45 PM | 5:15 PM | Dynamical Systems Theory Applied to Space Flight Problems II | Duxbury | 546, 574, 823, 846, 866, 873 |
| 8/12/25 | 6:30 PM | 9:00 PM | Awards Dinner | Grand Ballroom | |
| 8/13/25 | 8:00 AM | 10:00 AM | Cislunar Astrodynamics IV | Adrienne Salon | 759, 763, 775, 783, 794, 855, 858 |
| 8/13/25 | 8:00 AM | 10:00 AM | Trajectory Design and Optimization V | Duxbury | 697, 862, 865, 874, 882, 898, 916 |
| 8/13/25 | 8:00 AM | 10:00 AM | Machine Learning and Artificial Intelligence Applied to Spaceflight III | Plymouth | 821, 831, 848, 854, 859, 860, 867, 877 |
| 8/13/25 | 8:00 AM | 10:00 AM | Space Domain Awareness (SDA) and Space Surveillance II | Dedham | 655, 691, 719, 755, 838, 889, 906 |
| 8/13/25 | 10:30 AM | 12:30 PM | Trajectory Design and Optimization VI | Duxbury | 518, 552, 593, 603, 610, 634, 671 |
| 8/13/25 | 10:30 AM | 12:30 PM | Orbital Debris and Space Environment | Adrienne Salon | 511, 663, 684, 702, 769, 770, 835, 880 |
| 8/13/25 | 10:30 AM | 12:30 PM | Spacecraft Guidance, Navigation and Control (GNC) II | Dedham | 674, 720, 731, 764, 776, 780, 820, 844 |
| 8/13/25 | 10:30 AM | 12:30 PM | In-Space Assembly, Manufacturing, and Space Robotics | Plymouth | 553, 705, 727, 762, 801, 891 |
| 8/13/25 | 12:45 PM | 1:45 PM | AAS SFM Committee Meeting | Duxbury | |

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|---|---|---|---|---|---|
| 8/13/25 | 2:00 PM | 5:00 PM | Poster Session | Grand Ballroom | 526, 538, 554, 560, 565, 588, 591, 630, 636, 657, 678, 683, 701, 737, 739, 740, 742, 747, 748, 766, 768, 771, 782, 790, 791, 796, 799, 804, 809, 810, 815, 827, 830, 839, 842, 864, 883, 902, 907, 913, 926 |
| 8/13/25 | 3:00 PM | 4:00 PM | The Journal of the Astronautical Sciences Editorial Board Meeting | Dedham | |
| 8/13/25 | 5:00 PM | 7:00 PM | Networking Happy Hour | Grand Ballroom | |
| 8/14/25 | 8:00 AM | 10:00 AM | Cislunar Astrodynamics V | Adrienne Salon | 861, 863, 869, 870, 903, 908 |
| 8/14/25 | 8:00 AM | 10:00 AM | Trajectory Design and Optimization VII | Duxbury | 672, 716, 718, 736, 745, 798, 852 |
| 8/14/25 | 8:00 AM | 10:00 AM | Machine Learning and Artificial Intelligence Applied to Spaceflight IV | Dedham | 524, 543, 845, 888, 901, 909, 914 |
| 8/14/25 | 10:30 AM | 12:30 PM | Attitude Dynamics, Determination and Control II | Duxbury | 505, 778, 786, 814, 819, 900 |
| 8/14/25 | 10:30 AM | 12:30 PM | Rendezvous, Relative Motion, and Proximity Operations III | Dedham | 600, 730, 760, 779, 886, 893 |

Each session will have a break of 30 minutes in between. For the morning sessions (Monday to Thursday), the breaks are scheduled from 10:00 AM to 10:30 AM. For the afternoon sessions (Monday to Wednesday), the breaks are scheduled from 3:15 PM to 3:45 PM.

# Additional Technical Information

Author presentations (preferably in ppt or pdf format) will be submitted through a web-based system and are due by Friday August 8th 2025, 23:59:59 Eastern Time. Each presentation is allocated a 15 minute time slot: approximately 12 minutes for the presentation itself and 3 minutes for questions and answers as well as a transition between speakers.

Presenters shall coordinate with their Session Chairs regarding the available computing equipment, software, and media requirements for the session. Microsoft PowerPoint and PDF are the most common formats and presentation slides must be uploaded by the specified deadline.

Authors are encouraged to be in their session room 15-30 minutes prior to the start of their sessions to confirm that their presentation appears correctly. No speakers' breakfast will be served. Authors should have submitted a brief (approximately 50 words or 3 sentences) speaker's bio with their abstract submission. Session chairs shall maintain the posted schedule to allow attendees the option of joining a parallel session.

**"No-paper, no-podium" policy**
Completed preprints 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.

A final paper upload will be made available to attendees after the conference. Only final paper submissions will be included the official conference proceedings.

If the completed manuscript is not submitted 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 also acknowledges that they are 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), they acknowledge 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.

**Preprint 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. Registrants without an internet-capable portable computer, or those desiring traditional paper copies should download and print preprint manuscripts before arriving at the conference.

**Subsequent Journal Publication**

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

Journal of the Astronautical Sciences
Editor-in-Chief: Dr. Maruthi Akella, The University of Texas at Austin
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. Olivier de Weck, Massachusetts Institute of Technology
Manuscripts can be submitted via: https://mc.manuscriptcentral.com/aiaa

**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 Presentation Schedule

***Room locations subject to change; please refer to on-line program for latest updates.***

### Orbit Determination and Estimation I

Monday, 08/11/25, 8:00 AM - 10:00 AM

Session Chair(s): William Fife (Texas A&M University)

Room: Duxbury

8:00 AM - 8:15 AM

**AAS 25-510**: Weak-Signal GNSS Aided Collaborative Navigation of a Lunar PNT Constellation

Abstract: Rapid progress is being made towards the deployment of the Lunar Augmented Navigation Service (LANS): a network of lunar satellite constellations envisioned as a lunar analog to the terrestrial GNSS. LANS will initially comprise of the NASA LCRNS, ESA Moonlight, JAXA LNSS, and eventually the CSA Queqiao constellations, providing Lunanet-compatible comms-over-PNT services for lunar users. In order to provide precise PNT services, these constellations themselves must be navigated to a very high degree of accuracy. This investigation analyzes a strategy for enhancing the orbit determination accuracy of a representative lunar PNT constellation navigated via weak-signal GNSS augmented by crosslink measurements.

Author(s): Pradipto Ghosh, Johns Hopkins University Applied Physics Lab; William Fife, Johns Hopkins University Applied Physics Laboratory; Ryan Olson, Johns Hopkins University Applied Physics Laboratory; Michael Leatherman, Johns Hopkins University Applied Physics Laboratory; Shaun Stewart, Intuitive Machines

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8:15 AM - 8:30 AM

**AAS 25-522**: On Cylindrical Harmonics for Local Gravity Field Modeling

Abstract: Accurate modeling of the interior gravity field of small bodies is critical for proximity operations, yet traditional approaches often face limitations in convergence, accuracy, or computational efficiency. This work introduces a novel harmonics expansion, derived from Laplace’s equation in cylindrical coordinates, for efficient and localized gravity modeling within the exterior Brillouin sphere. The formulation leverages Fourier-Bessel functions, ensuring convergence within a prescribed cylindrical domain. Coefficients are estimated via least-squares fitting to synthetic polyhedral gravity data. Compared to conventional methods, the cylindrical harmonics approach offers improved local accuracy with fewer parameters, making it well-suited for high-fidelity gravity modeling in targeted regions.

Author(s): Giovanni Fereoli, University of Colorado Boulder; Jay McMahon, University of Colorado Boulder, CCAR

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8:30 AM - 8:45 AM

**AAS 25-577**: State Forecasting in an Estimation Framework with Surrogate Sensor Modeling

Abstract: A novel framework is proposed to estimate complex dynamical behaviors in aerospace systems with limited observational data. It combines a simplified reference dynamics model with a data-driven surrogate measurement model, leveraging their strengths to address partial observability. Numerical experiments validated the framework's efficacy in reconstructing system dynamics from partial data. The approach aims to advance state estimation methodologies in the aerospace sector by integrating data-driven techniques with traditional physics-based modeling, addressing current challenges and refining the framework's robustness through consistency analysis of the surrogate modeling approach. This enhances space situational awareness and tracking of resident space objects.

Author(s): Sriram Narayanan, The Ohio State University; Mohamed Naveed Gul Mohamed, Texas A and M University; Ishan Paranjape, Texas A&M University; Indranil Nayak, Ohio State University; Suman Chakravorty, Texas A&M University; Mrinal Kumar, The Ohio State University

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8:45 AM - 9:00 AM

**AAS 25-578**: Small Body Particle Tracking with Negative Information

Abstract: Tracking particles ejected from small bodies can help improve estimation of dynamics parameters, as demonstrated by the OSIRIS-REx mission. However, particles become unobservable as they pass through the primary body's shadow, resulting in a measurement gap. The absence of measurements is negative information and can complement traditional measurements via negative information fusion. This technique is applied to particle tracking by leveraging knowledge of the primary's shadow geometry. A Gauss Sum Filter is used and the shadow is modeled with chance constraints for accurate Gaussian Mixture splitting. The approach is compared against traditional filtering methods to demonstrated improved state estimation accuracy.

Author(s): Kian Shakerin, University of Colorado Boulder; Jay McMahon, University of Colorado Boulder, CCAR; Andrew Spielvogel, The Charles Stark Draper Laboratory

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9:00 AM - 9:15 AM

**AAS 25-582**: Discrete Parameter Flow Filtering For Sparse Tracking of Objects in Cislunar Space

Abstract: Numerous challenges exist when conducting recursive Bayesian inference for nonlinear systems---especially when informative observations are sparsely available. Although increasing the amount of available data to process is tempting, it is simply a reality that more sophisticated algorithms are required to track the exponentially increasing amount of space objects. To that end, this work develops a discrete homotopic continuation of Bayes' rule that partitions the traditional single-step update into multiple incremental updates. The method, termed discrete parameter flow, is applied with Gaussian mixture representations to achieve superior performance compared to traditional filtering schemes on a simplified scenario.

Author(s): William Fife, Texas A&M University; Kyle DeMars, Texas A&M University; Gunner Fritsch, Johns Hopkins University Applied Physics Laboratory

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9:15 AM - 9:30 AM

**AAS 25-597**: Utilizing Penumbral Transitions as Onboard Measurement Updates for Cislunar Navigation

Abstract: This paper presents a method for improving cislunar spacecraft navigation by incorporating penumbra transition detections into an extended Kalman filter (EKF). Libration points and lunar missions in the Earth–Moon system are currently faced with limited and intermittent measurement opportunities. By registering when a spacecraft enters or exits Earth and Moon shadowed penumbra regions, the proposed technique provides an additional measurement source that reduces state uncertainty. Existing spacecraft hardware like solar panels or minimally invasive additions like photo-diodes can capture these events. Preliminary simulations in the circular restricted three-body problem (CR3BP) confirm the utility of this navigation enhancement.

Author(s): James McElreath, Land, Air and Space Robotics Laboratory; Texas A&M University; Ian Down, Texas A&M University; Manoranjan Majji, Texas A&M University, College Station

9:30 AM - 9:45 AM

**AAS 25-599**: Spacecraft-to-Spacecraft Absolute and Relative Tracking Using Higher-Order Nonlinear Filtering

Abstract: This work explores spacecraft-to-spacecraft relative-absolute state estimation using only relative measurements, without ground-based tracking or known trajectories. The nonlinear cislunar environment is modeled using the Circular Restricted Three-Body Problem (CR3BP). A second-order Extended Kalman Filter (SOEKF) is implemented by truncating the Higher-Order Numerical EKF (HNEKF) after second-order terms. Two variants are tested: one with second-order dynamics only, and one with second-order terms in both dynamics and measurements. These are compared to the EKF and UKF using optical and radar measurements. Results show second-order measurement modeling is essential for accuracy and filter convergence in strongly nonlinear regimes.

Author(s): Ryan Menges, University of Colorado Boulder; Daniel Scheeres, University of Colorado Boulder

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9:45 AM - 10:00 AM

**AAS 25-828**: Guide Star Catalog Generation for Spacecraft Velocity Estimation Using the Starnav Framework

Abstract: Advancement in space technology has enabled humanity to extend its range of exploration into the depths of space. These deep space missions exhibit delayed communication with Earth that create the necessity for autonomous navigation. The StarNAV framework utilizes the relativistic perturbation of starlight to autonomously estimate the velocity of a moving observer. Accurate StarNAV estimations require star-pairs with wide inter-star angles. This issue is addressed by generating ranked catalogs of the best star-pairs for desired directions through filtration and discretization. The spacecraft can access a catalog of guide-stars for autonomously estimating its velocity in a desired direction.

Author(s): Lander Schillinger Arana, Georgia Institute of Technology; Jonathan Gutknecht, Georgia Tech; Joseph Clary, Georgia Institute of Technology; Michela Mancini, Georgia Institute of Technology; John Christian, Georgia Institute of Technology

# Machine Learning and Artificial Intelligence Applied to Spaceflight I

Monday, 08/11/25, 8:00 AM - 10:00 AM

Session Chair(s): Christopher D'Souza (NASA/JSC)

Room: Dedham

8:00 AM - 8:15 AM

**AAS 25-513**: Autonomy at Levels for Spacecraft

Abstract: Autonomy at Levels is the idea that autonomy should be embedded within and throughout a spacecraft. Using Systems Engineering methods a spacecraft is typically decomposed into systems, subsystems, assemblies, components, and so on. All these decomposition levels within all the spacecraft's systems, could and should have autonomy elements built in. As a result, the "autonomy system" is made of autonomy elements or units that are integrated, distributed and embedded within the whole spacecraft. This is like how the power system would be designed and implemented. Linking control loops and autonomy loops illustrates how to achieve Autonomy at Levels.

Author(s): Daniel Baker, AV; Jeremy Wojcik, BlueHalo, LLC; Sean Phillips, Air Force Research Laboratory

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8:15 AM - 8:30 AM

**AAS 25-517**: Text Data Processing and Information Retrieval for Space Applications

Abstract: While aerospace quantitative data analysis and modeling is quite mature, exploring information about space events through the lens of qualitative data is limited. This work explores and introduces a process in extracting insight from space related text and a way for a user to interact with the information. In addition, we examine the ability of Large Language Models (LLMs) in text data processing and interpretation. Examining text data can provide benefits such as increased context regarding events in space, a platform where users can receive specialized responses, and an opportunity to combine technical information about a satellite with news articles.

Author(s): Samuel Kwon, Advanced Space LLC; Nathan Ré, Advanced Space; Mitchell Rosen, Advanced Space, LLC

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8:30 AM - 8:45 AM

**AAS 25-544**: A Comparative Study of Optimal Control and Neural Networks in Asteroid Rendezvous Mission Analysis

Abstract: This paper compares optimal control methods and neural network-based estimators for generating pork-chop plots in asteroid rendezvous missions. A sequential convex programming-based optimal control method is implemented, enhanced by a two-step constraint relaxation strategy to handle path constraints. The neural network-based approach reduces computational time and addresses multiple local optima, though it currently has limitations in handling path constraints. Three asteroid case studies illustrate performance differences and highlight potential improvement of neural network models. Results demonstrate the neural network's effectiveness in preliminary mission design, offering rapid trajectory evaluations with low errors, thus facilitating efficient target selection in asteroid exploration.

Author(s): Zhong Zhang, Politecnico di Milano; Niccolò Michelotti, Politecnico di Milano – Department of Aerospace Science and Technology; Gonçalo Pinho, Politecnico di Milano; Francesco Topputo, Politecnico di Milano

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8:45 AM - 9:00 AM

**AAS 25-570**: Imitation Learning for Satellite Attitude Control under Unknown Perturbations

Abstract: This paper presents a novel satellite attitude control framework that integrates Soft Actor-Critic (SAC) reinforcement learning with Generative Adversarial Imitation Learning (GAIL) to achieve robust performance under various unknown perturbations. Traditional control techniques often rely on precise system models and are sensitive to parameter uncertainties and external perturbations. To overcome these limitations, we develop an SAC-based expert controller that demonstrates improved resilience against actuator failures, sensor noise, and attitude misalignments, outperforming existing benchmarks in several challenging scenarios. We then use GAIL to train a learner policy that imitates the expert's trajectories, thereby reducing training costs and improving generalization through expert demonstrations.

Author(s): Zhizhuo Zhang, Rutgers University; Hao Peng, Embry-Riddle Aeronautical University; Xiaoli Bai, Rutgers

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9:00 AM - 9:15 AM

**AAS 25-584**: Discriminative Methodology Applied to the Unscented Transform in SE(3)

Abstract: Kalman filtering techniques usually compare a known dynamic model with some process noise to an updated, noisy measurement. Both sources of noise are generally assumed to be Gaussian and are filtered to obtain a more accurate estimate. These methods assume that a relatively accurate dynamical model already exists. By including discriminative methodology to interpret differences in the predictive model and measured states over time, an incorrect model can be corrected overtime, allowing a spacecraft to learn about its environment and adapt to changing conditions. In this paper, a discriminative unscented Kalman filter (DUKF) is introduced on SE(3).

Author(s): Matthew Wittal, National Aeronautics and Space Administration; Benjamin Asher, Aegis Aerospace; Morad Nazari, Embry-Riddle Aeronautical University

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9:15 AM - 9:30 AM

**AAS 25-587**: SHAP analysis for a global thermospheric density prediction model

Abstract: Accurate thermospheric density prediction is vital for satellite operations yet challenging due to complex solar and geomagnetic influences. Traditional empirical models perform well under quiet conditions but degrade during storm periods, while physics-based methods have high computational costs. Leveraging a comprehensive satellite dataset from the 24th solar activity cycle, we further develop a global prediction model using an evidential deep learning framework that delivers consistent performance during both quiet and storm conditions, including extreme situations. To further elucidate model behavior, we employ Shapley Additive Explanations to assess input feature importance, with the results aligning well with existing physical knowledge.

Author(s): Ruochen Wang, Rutgers University; Xiaoli Bai, Rutgers

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9:30 AM - 9:45 AM

**AAS 25-602**: Developing Robust Crater-based Terrain Relative Navigation Methods Applied to Artemis 1 Flight Data

Abstract: The development of accurate surface feature detection methods enables autonomous Terrain Relative Navigation for lunar and planetary missions. This paper provides a machine learning-based workflow to develop a robust crater detection capability using crater image samples from the Lunar Reconnaissance Orbiter and simulated imagery. Through iterative training, we develop a detector that can handle the varied lighting conditions amd off-nadir crater geometry resulting from the high altitude, variable exposure conditions experienced during the Artemis 1 flight. The developed detector will then be integrated with a crater identification method and the EKF to provide translational state

estimates.

Author(s): Sofia Catalan, The University of Texas at Austin; Brandon Jones, The University of Texas at Austin; James McCabe, NASA Johnson Space Center

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9:45 AM - 10:00 AM

**AAS 25-612**: Physics-ML fusion algorithm for estimation and prediction of relative motion of an unknown, non-cooperative, and tumbling space object

Abstract: This study addresses the problem of estimation and prediction of the motion of a non-cooperative target space object by a cooperative spacecraft carrying a stereo-camera system. The proposed algorithm estimates the motion variables, inertia parameters, and map of the target using the Unscented Kalman Filter during the daytime. At nighttime, the algorithm refines the state estimates from UKF and uses data driven and physics-based models to predict the target motion. Preliminary results demonstrate that the proposed algorithm can estimate the motion, inertia parameters, and the map of the target, and predict the motion of the target for thousands of seconds.

Author(s): Rabiul Hasan Kabir, Rutgers, the State University of New Jersey; Xiaoli Bai, Rutgers

# Cislunar Astrodynamics I

Monday, 08/11/25, 8:00 AM - 10:00 AM

Session Chair(s): Anthony Genova (NASA)

Room: Ballroom B

8:00 AM - 8:15 AM

**AAS 25-512**: A Spatial Computing Framework to Design Cislunar CR3BP Spacecraft Constellations

Abstract: In this paper, we present the initial scaffold of a spatial computing framework for high-speed, iterative, and intuitive constellation design in the CR3BP model for cislunar space. The framework is implemented as a virtual-reality toolkit, building upon previous developments towards virtual-reality-based periodic orbit design. The framework provides an elegant interface system for designing a set of orbits to maximize selected spatial coverage metrics. In addition, we propose the use of a gradient-ascent optimization system for identifying optimal phasing of spacecraft between orbits.

Author(s): Eirik Mulder, Auburn University; Dhathri Harsha Somavarapu, The Aerospace Corportation; Davide Guzzetti, Auburn University

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8:15 AM - 8:30 AM

**AAS 25-515**: Constructing an Atlas of Natural Spacecraft Trajectories in an Ephemeris Model of Cislunar Space

Abstract: This paper presents a foundation for constructing an atlas of natural spacecraft motion that begins near the Moon in a point mass ephemeris model of the Earth-Moon system. These trajectories span up to 21 days subject to the point mass gravitational influences of the Earth, Moon, and Sun. Groups of geometrically distinct trajectories are automatically generated across an array of energy levels and epochs using distributed clustering. These groups of trajectories are then hierarchically visualized in a digestible manner using a dendrogram. An atlas may eventually support trajectory analysis, design, and prediction in cislunar space.

Author(s): Natasha Bosanac, University of Colorado, Boulder

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8:30 AM - 8:45 AM

**AAS 25-523**: Neural Keplerian Maps for Resonance Hopping Transport in the Earth-Moon System

Abstract: The dynamics of the Circular Restricted Three-Body Problem have been studied extensively to enable efficient transfer design in the cislunar region. One method for efficient trajectory design involves creating a Poincaré-like Map in the planar problem known as the Kepler Map. This study focuses on using deep neural networks to extend the capabilities of the Kepler map by adding impulsive maneuvers that allow a spacecraft in a relatively low-Earth orbit to efficiently reach lunar altitudes while leveraging stable and unstable manifolds of resonant trajectories.

Author(s): Shota Ito, Tokyo Metropolitan University; Nicola Baresi, University of Surrey; Dario Izzo, European Space Agency; Hironori Sahara, Tokyo Metropolitan University; Naoya Ozaki, ISAS, JAXA

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8:45 AM - 9:00 AM

**AAS 25-547**: Efficient transfers search in the three body problem leveraging quasi-periodic orbit intersections

Abstract: Given the renewed interest in the cislunar environment and the Lunar Gateway, the necessity of more efficient strategies to reach specific orbits is becoming more and more important.
This work leverages manifolds in the Three-Body Problem to retrieve an initial solution for optimizing

transfer trajectories to the Gateway. Quasi-periodic tori are generated around initial and target orbits, and analytical curves are derived by interpolation. The intersections between these curves representing the tori correspond to single-impulse transfer opportunities. An optimization algorithm refines the maneuvers, reducing fuel consumption and launch date constraints. This approach enhances mission flexibility and cost-effectiveness for lunar exploration.

Author(s): Matteo Santacesaria, Politecnico di Milano; Nathaniel Sailor, Purdue University; Andrea Capannolo, Purdue University; Andrea De Vittori, Politecnico di Milano

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9:00 AM - 9:15 AM

**AAS 25-569**: Regions of Influence of Exterior Mean-Motion Resonances in the Earth–Moon System: Bifurcations, Separatrices, and Heteroclinic Pathways

Abstract: The region beyond the Moon (within Earth's Hill sphere) hosts a complex web of exterior mean-motion resonances (MMRs) that govern the dynamics of natural and artificial bodies. We examine purely exterior 1:n resonances using a Poincare´ map at osculating orbit apogee, expressed in orbital elements. It reveals two stable asymmetric libration zones and an unstable symmetric resonance zone embedded within a broader unstable symmetric region, reflecting a bifurcation due to heightened instability. The region of influence is delineated by separatrices of unstable resonant periodic orbits. Heteroclinic connections with L2 Lyapunov orbits are explored, enabling interior-exterior transitions.

Author(s): Anjali Rawat, Virginia Tech; Bhanu Kumar, University of Michigan; Aaron J. Rosengren, University of California San Diego; Shane Ross, Virginia Tech

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9:15 AM - 9:30 AM

**AAS 25-579**: Surveilling Cislunar Space By Leveraging Non-Ballistic Periodic Solutions

Abstract: Space situational awareness in the cislunar region is most easily accomplished with space-based sensors. Ballistic orbits are frequently employed to host observing spacecraft, however, limit the possible geometries to those that are naturally ballistic. Periodic solutions with periodic maneuvers are constructed that yield improved cislunar visibility over their ballistic counterparts. Impulsive maneuvers are constructed by employing a visibility path constraint. Low-thrust maneuvers offer the potential for lower fuel requirements and more efficient engines. A cost function that maximizes visibility and minimizes fuel is optimized via indirect optimization and convex programming methods.

Author(s): Noah Sadaka, Purdue University; Liam Fahey, Purdue University; Kathleen C. Howell, Purdue University

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9:30 AM - 9:45 AM

**AAS 25-616**: Design Strategy for Long-Term Multi-Vehicle Loitering Trajectories in Multibody Environments

Abstract: Operating cislunar hubs, such as the NASA Gateway facility, necessitates constructing safe trajectories for multiple spacecraft simultaneously active in the vicinity of the hub. This investigation extends a previously introduced strategy for designing long-duration loitering trajectories in the Circular Restricted Three Body Problem for multiple visiting spacecraft. Range constraints are applied to loitering trajectories relative to the hub and to other visiting spacecraft such that safety is guaranteed while other visitors loiter, rendezvous, and depart. The utility of the loitering trajectory design strategy is then demonstrated by transitioning sample loitering scenarios into a higher-fidelity ephemeris model using various techniques.

Author(s): Mitchell Dominguez, Purdue University; Kathleen C. Howell, Purdue University

9:45 AM - 10:00 AM

**AAS 25-621**: Stable Low-Energy Prograde Earth-Moon Cycler Orbits

Abstract: We present a new class of low-energy, prograde Earth-Moon cycler orbits; natural periodic trajectories that alternately orbit the Earth and Moon, without requiring propulsion. Unlike previously studied cycler orbits, these orbits are fully ballistic, prograde, and include stable orbits. Their geometry enables potential use in space situational awareness, communications, search-and-rescue, and infrastructure development. A systematic method is introduced to design families of these cyclers with specified Earth and Moon orbit counts, revealing resonant and highly maneuverable regimes that offer new opportunities for cislunar mission design.

Author(s): Shane Ross, Virginia Tech; Michael Roberts-Tsoukkas, Virginia Tech

# Trajectory Design and Optimization I

Monday, 08/11/25, 8:00 AM - 10:00 AM

Session Chair(s): Rodney L. Anderson (Jet Propulsion Laboratory/Caltech)

Room: Adrienne Salon

8:00 AM - 8:15 AM

**AAS 25-504**: Optimal Linear Covariance Steering with Minimum Nonlinear Dynamical Errors

Abstract: Applying linear controllers to nonlinear systems requires the dynamical linearization about a reference. In highly nonlinear environments such as Cislunar space, the region of validity for these linearizations varies widely and can negatively affect controller performance if not carefully formulated. This paper presents a formulation that minimizes the nonlinear errors experienced by linear covariance controllers. The results show that the formulation proposed in this paper maintains the Gaussianity of the distribution in nonlinear simulations more effectively, thereby allowing the linear covariance controller to perform more as intended in nonlinear environments.

Author(s): Daniel Qi, Purdue University; Kenshiro Oguri, Purdue University

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8:15 AM - 8:30 AM

**AAS 25-508**: VERIFIABLE MISSION PLANNING FOR SPACE OPERATIONS

Abstract: As space missions become more complex, planning methods must maximize mission performance while rigorously enforcing safety. We develop a probabilistic approach based on a finite-horizon Markov decision process to optimize spacecraft operations planning with safety guarantees. In the model, states capture essential mission parameters, and actions represent the operational adjustments needed to meet mission objectives. By directly incorporating uncertainties from environmental conditions and spacecraft dynamics, an optimal sequence of actions is computed that maximizes expected rewards and strictly enforces safety constraints. Numerical experiments on the GRACE-FO mission demonstrate robust performance under uncertainties while providing probabilistic safety guarantees.

Author(s): Quentin Rommel, The University of Texas at Austin; Srinivas Bettadpur, The University of Texas at Austin; Himanshu Save, Center of Space Research, The University of Texas at Austin; Ufuk Topcu, The University of Texas at Austin; Michael Hibbard, Starfish Space; Pavan Shukla, The University of Texas at Austin

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8:30 AM - 8:45 AM

**AAS 25-525**: Coupled Radial Basis Functions and Cover Scheme Methods For Constrained Optimal Rendezvous and Proximity Operations

Abstract: A cover scheme method and Coupled Radial Basis Functions (CRBFs) are used to compute the optimal thrust and trajectory for a servicing satellite meeting a target spacecraft for in-space servicing via proximity operations. Local collocation is used to divide the problem domain into elements with overlapping covers to reinforce continuity. CRBFs are utilized as basis functions for approximation. This work presents the unconstrained equations for orbital relative motion, the Hill-Clohessy-Wiltshire (HCW) equations, to demonstrate the method against a standard solver. In addition, a constrained orbital relative motion problem is solved to account for an avoidance scenario, such as a neighboring spacecraft, debris, or no-fly zone.

Author(s): Bethany Hintz, University of Central Florida; Tarek Elgohary, University of Central Florida

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8:45 AM - 9:00 AM

**AAS 25-540**: Connecting Europe's spaceport to the Lunar Gateway using intermediate NRHOs.

Abstract: The ESA Explore2040 strategy aims for European lunar exploration by the 2030s, with the Argonaut program and NASA's Gateway playing key roles. Reaching the Lunar Gateway, from equatorial launch orbits, is challenging due to the required Moon position for the Earth–Moon transfer and the Gateway position for the rendezvous. This research aims to identify a lunar exploration architecture for Europe by solving the Earth-Moon transfer and Moon-to-NRHO insertion problems using an intermediate NRHO, and coupling them with the phasing problem, ensuring sustainable access to the Moon and supporting future lunar missions and crewed spaceflight.

Author(s): Marion Burnichon, Politecnico di Milano; Lorenzo Bucci, European Space Agency; Carmine Giordano, Politecnico di Milano; Francesco Topputo, Politecnico di Milano

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9:00 AM - 9:15 AM

**AAS 25-558**: Optimal Initial Lagrange Costates for Continuation Methods

Abstract: The approximate initial Lagrange costates and minimum transfer time for optimal constant thrust orbital transfers are modeled as functions of thrust acceleration and final radius. If the approximate values are close enough to allow convergence in the shooting method, the resulting control law will propagate the optimal trajectory with no approximations or arbitrary grid points. The results may be used for initial values in a continuation technique, with small changes in thrust acceleration magnitude or final orbital elements toward the desired physical values. Examples are shown for two-dimensional and three-dimensional problems with low, medium, and high thrust values.

Author(s): James Thorne, Institute for Defense Analyses (IDA)

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9:15 AM - 9:30 AM

**AAS 25-609**: Reachability-Informed Missed Thrust Design

Abstract: This work develops a novel approach to study the missed thrust problem by applying reachability results. A method to compute the missed thrust recovery margin (MTRM) utilizing controllable sets is presented and results are visualized with a heatmap. The MTRM computation is wrapped into a framework to determine a recovery region of advantageous initial conditions to target prior to a final burn sequence. Applying reachability to study robust trajectory design brings geometric insight, allowing mission designers to visualize regions of high margin and study the entire solution space at once, changing how to view the missed thrust problem.

Author(s): Robyn Natherson, University of Colorado, Boulder; Daniel Scheeres, University of Colorado Boulder

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9:30 AM - 9:45 AM

**AAS 25-689**: A MILLION-Point FAST Trajectory Optimization Solver

Abstract: One might argue that solving a trajectory optimization problem over a million grid points is preposterous. How about solving such a problem at an incredibly fast computational time? On a small form-factor processor? Algorithmic details that make possible this tri- fecta of breakthroughs are presented in this paper. The computational mathematics that deliver these advancements are: (i) a Birkhoff-theoretic discretization of optimal control problems, (ii) matrix-free linear algebra leveraging Krylov-subspace methods, and (iii) a near-perfect Birkhoff preconditioner that helps achieve O(1) iteration speed with respect to the grid size, N.

Author(s): Isaac Ross, Naval Postgraduate School; Aurya Javeed, Sandia National Laboratories; Drew Kouri, Sandia National Laboratories; Denis Ridzal, Sandia National Laboratories; John Steinman, Rice University

9:45 AM - 10:00 AM

**AAS 25-767**: Sundman-Transformed Convex Low-Thrust Trajectory Optimization in Multi-Body Systems

Abstract: With numerous near-future missions planned to the Moon, rapid and reliable trajectory design in complex multi-body models is essential. In this work, we improve the sequential convex programming (SCP) approach in multi-body systems by addressing the convergence issues in highly nonlinear regions using a Sundman transformation in the rotating-pulsating frame. Moreover, we extend previous work to solve continuous thrust problems. The efficacy of the proposed approach is shown in orbital transfers in the Sun-Earth-Moon system.

Author(s): Christian Hofmann, Massachusetts Institute of Technology; Kai Xi, Massachusetts Institute of Technology; Hakan Chunton, Massachusetts Institute of Technology; Giovanni Lavezzi, Massachusetts Institute of Technology; Ethan Burnett, Politecnico di Milano; Francesco Topputo, Politecnico di Milano; Richard Linares, Massachusetts Institute of Technology

# Rendezvous, Relative Motion, and Proximity Operations I

Monday, 08/11/25, 10:30 AM - 12:30 PM

Session Chair(s): Pradipto Ghosh (Johns Hopkins University Applied Physics Lab)

Room: Duxbury

10:30 AM - 10:45 AM

**AAS 25-507**: A guidance method for proximity operations around a tumbling target in HEO

Abstract: The increase in space debris and the new programs involving gateways around the Moon and Mars have created a surge in research on proximity operations guidance. Most works involve spacecrafts in near-circular orbits, but this is a large research gap because of the number of possible targets which are placed in highly elliptical orbits, and of future missions. In this article, an optimal sliding mode guidance is designed for proximity operations around tumbling targets in this orbital regime. The results show that the designed strategy is able to accurately track the holding points and is robust against uncertainties.

Author(s): Luca Giorcelli, Politecnico di Milano; Mauro Massari, Politecnico di Milano; Michele Maestrini, Politecnico di Milano

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10:45 AM - 11:00 AM

**AAS 25-532**: Enhancing Cislunar Operations by integrating Reinforcement Learning into Classical Relative Guidance Methods

Abstract: Growing interest in cislunar exploration and Lunar Gateway missions demands advanced guidance systems for handling the nonlinear dynamics of Near Rectilinear Halo Orbits. Communication delays necessitate autonomous operations with minimal human intervention. This work integrates Reinforcement Learning (RL) with classical relative guidance to boost efficiency, flexibility, and robustness in proximity operations. A hybrid algorithm combines ASRE for trajectory optimization, APF for path constraint management, and SMC for robust control, with the RL agent selecting configurations based on system observations. CR3BP simulations validate improvements in propellant efficiency, time-of-flight, and decision adaptability, offering a scalable, modular solution for future autonomous guidance challenges.

Author(s): Carlo Zambaldo, Politecnico di Milano; Luca Giorcelli, Politecnico di Milano; Mauro Massari, Politecnico di Milano

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11:00 AM - 11:15 AM

**AAS 25-585**: FDIR for Autonomous Space Systems for Anomalies and Cyberattacks

Abstract: Fault detection, identification, and remediation (FDIR) is a challenging task for any space system. Several different faults may all create the same symptoms or bad performance. This is compounded when the consideration of cyberattacks are added, and further made daunting when the system in question is intended to perform its tasks autonomously. A spacecraft is simulated during an RPOD maneuver during which several zero-dynamics attacks are simulated that attack the spacecraft's sensors causing the spacecraft either a faulre or auto-abort. A DUKF is used instead to identify faulty or misleading sensors, and successfully perform the docking maneuver.

Author(s): Matthew Wittal, National Aeronautics and Space Administration; Michael Czernec, Aegis Aerospace/ILS Corporation; Benjamin Asher, Aegis Aerospace

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11:15 AM - 11:30 AM

**AAS 25-598**: Second Order Cone Programming Approach for Designing Canned Breakout Maneuvers to use During Spacecraft Proximity Operations

Abstract: One consideration when designing both missions and vehicles for space proximity operations is contingency planning. One type of contingency is breakouts from the vicinity of the target spacecraft. In this paper the design of breakouts that are pre-defined and applicable at each point along an interval of a trajectory are considered. Such pre-defined breakouts are termed "canned" and must be applicable without intricate computation or dependence on certain sensors. The contribution of this paper is an approach based on second order cone programming to strategically design canned breakouts that may be subject to a large number and variety of constraints.

Author(s): Ravi Gondhalekar, Draper

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11:45 AM - 12:00 PM

**AAS 25-601**: A study of the orbit for co-orbital flying about a space station

Abstract: The co-orbital flight of a satellite or spaceship about a space station has important applications. In the co-orbital flight both the spacecraft and the space station are flying in the near-circular low Earth orbit, and the relationships among the orbital element differences play an important part in the design of the orbit for co-orbital flying. In this paper a new formulation of the relationships among the relative orbit parameters for co-orbital flight is introduced, which provides a clear perspective on the essence of the orbit for co-orbital flying and can be applied in the engineering design of co-orbital space telescope mission effectively.

Author(s): William Wang, Purdue University; Zhong-Sheng Wang, China Academy of Space Technology; James Liu, Rutgers, The State University of New Jersey

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12:00 PM - 12:15 PM

**AAS 25-604**: Shape Reconstruction and Pose Estimation of an Unknown, Noncooperative, Rotating Target Using Structure-From-Motion

Abstract: A combined simulation, image capture, and Structure-from-Motion pipeline is proposed to analyze spacecraft rendezvous and proximity operations involving a chaser and an unknown, noncooperative, rotating target. The proposed approach integrates dynamics modeling, Unreal Engine visualization, and SfM-based camera pose estimation and 3D reconstruction. The SfM estimated camera poses are used in conjunction with the known ground-truth camera poses to estimate target attitude changes. The pipeline involves extensive refinement procedures such as trajectory scaling and camera extrinsic alignment. Our results confirm that our method accurately estimates target orientation changes over time, providing valuable insights for mission planning in astrodynamics.

Author(s): Basil Khan, Rutgers University; Xiaoli Bai, Rutgers; Hadi Akbarpour, Saint Louis University; Omar Tahri, Saint Louis University

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12:15 PM - 12:30 PM

**AAS 25-605**: Analytic Osculating Relative Motion Solution Under J2 and Atmospheric Drag

Abstract: This work presents the first osculating solution to the relative motion problem, developed for low-eccentricity orbits perturbed by the gravitational J2 term and atmospheric drag. After regularizing the equations of motion using the argument of latitude, an approximate solution for the motion of each individual satellite is derived using classical perturbation theory, specifically through a power series expansion. The relative motion solution is obtained by differencing the two absolute motion solutions and then applying another power expansion. Illustrative examples demonstrate that the chosen

regularization ensures the long-term accuracy of the approximate analytical solution, even under the effects of atmospheric drag.

Author(s): Miguel Avillez, Purdue University; David Arnas, Universidad de Zaragoza

# Attitude Dynamics, Determination and Control I

Monday, 08/11/25, 10:30 AM - 12:30 PM

Session Chair(s): Maaninee Gupta (Texas A&M University)

Room: Dedham

10:30 AM - 10:45 AM

**AAS 25-516**: Zero Placement for Inverting Discrete-time Model and its Relation with Pseudo-Inverse

Abstract: Spacecraft tracking systems, such as the James Webb Space Telescope, demand high precision. Feedforward control using inverse methods can improve performance but may introduce unstable zeros in discrete-time systems, making control impractical. A prior method stabilizes the inverse by placing zeros inside the unit circle through multiple zero-order holds. This paper investigates pseudo-inverse solutions in iterative learning control, which stabilize control without explicit zero placement. By comparing zero-placement algorithms and pseudo-inverse methods, we aim to better understand their effects on system dynamics and improve feedforward control for spacecraft tracking.

Author(s): Jer-Nan Juang, National Cheng Kung Univ; Joseph Fritch, Columbia University; Richard Longman, Columbia University

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10:45 AM - 11:00 AM

**AAS 25-530**: STABLE INVERSE CONTROL FOR DISCRETE TIME SYSTEMS USING SECOND ORDER HOLDS

Abstract: Accurate trajectory tracking is essential for spacecraft control, especially when feedback bandwidth is limited. In such cases, inverse feedforward strategies are often employed. However, digital implementation using zero-order hold (ZOH) discretization can introduce instability and result in inefficient, non-smooth inputs. This paper presents a stable inversion framework based on second-order hold (SOH) discretization, which more accurately captures continuous-time system dynamics. The SOH-based approach achieves comparable tracking accuracy to ZOH while reducing the L2 norm of the input and producing smoother control signals. These benefits make SOH discretization an effective alternative for digital feedforward control in flexible spacecraft systems.

Author(s): Joseph Fritch, Columbia University; Jer-Nan Juang, National Cheng Kung Univ; Nicolas Chbat, Columbia University

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11:00 AM - 11:15 AM

**AAS 25-541**: Fault-tolerant Safety Analysis for Constrained Spacecraft Attitude using Control Barrier Functions

Abstract: Spacecraft reorientation is a critical maneuver with implications for multiple subsystems, where actuator failures can jeopardize science objectives and overall mission success. Although path-planning and adaptive control strategies have been studied, few offer formal safety guarantees under degraded actuator conditions. To address this, we propose a Control Barrier Function (CBF)-based controller that ensures safe, constraint-satisfying reorientation in the presence of actuator faults. The control strategy is embedded within a hybrid system framework to accommodate changes in actuation availability over time. This approach provides formal safety assurances and highlights the potential for robust, autonomous spacecraft attitude control under uncertain conditions.

Author(s): Sannya Amoikon, ISAE-SUPAERO; Vishala Arya, University of Colorado Boulder

11:15 AM - 11:30 AM

**AAS 25-550**: Enhanced Spacecraft Pose Estimation with Deep Learning-Based LiDAR Point Cloud Processing

Abstract: Accurate pose estimation of target spacecraft is critical for autonomous rendezvous. Classical registration algorithms on their own often fail when encountering non-rigid, articulating components like solar panels. This paper presents a hybrid pipeline that leverages a PointNet++ network for semantic segmentation of simulated LiDAR point clouds. The segmentation results are used to filter the data by removing non-rigid components. This fixed feature-centric point cloud is then registered using a G-ICP algorithm to compute a precise 6-DOF pose. Validated on a synthetic dataset, this method demonstrates improved pose accuracy, offering a more robust solution for autonomous space applications.

Author(s): Justin Schmitt, Embry-Riddle Aeronautical University; Seur Gi Jo, Embry-Riddle Aeronautical University; David Canales Garcia, Embry-Riddle Aeronautical University; Axel Garcia, MIT

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11:30 AM - 11:45 AM

**AAS 25-641**: Sun-Tracking Attitude Control Using a Single Reaction Wheel and Thrust Vector Control

Abstract: This paper proposes a sun-tracking attitude control method for interplanetary spacecraft equipped with a single reaction wheel (RW) and electric propulsion (EP). The RW can be mounted along any principal axis of the spacecraft. The EP system is equipped with a gimbal actuator so that attitude control torque can be generated. First, making use of solar radiation pressure, active stabilization of sun-pointing attitude is achieved through the control of the bias momentum. Next, thrust vector control of EP is employed in combination with the bias momentum. The developed model was partially demonstrated through on-orbit experiments in the Hayabusa2 extended mission.

Author(s): Yuki Takao, Yokohama National University; Yuya Mimasu, Japan Aerospace Exploration Agency; Yuichi Tsuda, Japan Aerospace Exploration Agency

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11:45 AM - 12:00 PM

**AAS 25-682**: RBFNN-Based Adaptive Attitude Controller with Reaction Wheel Health Estimation

Abstract: Reaction wheels are the most commonly used actuators for attitude control in spacecraft, they degrade over time due to the harsh conditions in space. We propose an adaptive controller design that simultaneously estimates the time-varying RW health degradation level while maintaining attitude tracking. In this work, we propose approximating the health degradation of RWs using a Radial Basis Function Neural Network (RBFNN) as part of a Concurrent Learning (CL)-based adaptation law.

Author(s): Morokot Sakal, Florida Institute of Technology; George Nehma, Florida Institute of Technology; Camilo Riano-Rios, Florida Institute of Technology; Madhur Tiwari, Florida Tech

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12:00 PM - 12:15 PM

**AAS 25-752**: ROBUSTNESS ANALYSIS OF ATTITUDE CONTROL SYSTEM FOR SPACECRAFT APPLICATIONS

Abstract: We propose a robustness analysis framework for spacecraft attitude control applications that can systematically handle a wide range of system nonlinearities, external disturbances, and uncertainties. It provides provable guarantees on stability and performance, to facilitate next-generation spacecraft missions with extremely high agility, dynamically varying and uncertain properties, or large deployable flexible structures. We illustrate this framework via rigorously analyzing input-output gain for systems with actuator saturation nonlinearity. The method leverages integral quadratic constraints framework which captures the effect of saturation by merging frequency-domain descriptions of the nonlinearity with time-domain dissipation arguments arising in Lyapunov stability theory.

Author(s): ABHIJIT CHAKRABORTY, Raytheon Technologies Research Center; Amit Surana, RTX Technology Research Center

12:15 PM - 12:30 PM

**AAS 25-777**: Attitude Estimation of Planar Rotations using Redundant Gyroscopes

Abstract:

Accurate heading angle estimation is crucial for autonomous robotic navigation, especially in environments where external reference signals like GPS are unavailable. Traditional methods rely on a single gyroscope to propagate the heading angle, while redundant gyros serve solely for fault detection and isolation. Though effective for fault tolerance, this setup underuses available sensor data, limiting estimation accuracy. This paper introduces two methods that fully leverage redundant gyroscope measurements to improve heading angle estimation in planar environments. Both methods maintain individual gyro bias observability, key for fault detection, using a state transformation. Simulations confirm improved accuracy and preserved fault detection capabilities.

Author(s): Andrea Rigato, The University of Texas at Austin; Renato Zanetti, The University of Texas at Austin

# Cislunar Astrodynamics II

Monday, 08/11/25, 10:30 AM - 12:30 PM

Session Chair(s): Riley Fitzgerald (Virginia Tech)

Room: Ballroom B

10:30 AM - 10:45 AM

**AAS 25-623**: Periodic Orbit Tracking in Cislunar Space: A Finite-Horizon Approach

Abstract: This paper proposes a Nonlinear Model Predictive Control (NMPC) scheme to retain a spacecraft within a family of periodic orbits near cislunar libration points. Unlike traditional methods, it optimizes trajectories within the orbit family without requiring a fixed reference. The Circular Restricted Three-Body Problem (CR3BP) models the dynamics, and orbit families are computed using the Pseudo-Arclength Continuation (PAC) method and parameterized for Multivariate Polynomial Regression (MPR). The NMPC system integrates an EKF observer for state estimation. Simulations for Lyapunov, halo, and near-rectilinear halo orbits show notable fuel savings over conventional tracking techniques.

Author(s): Mohammed Atallah, Iowa State University; Simone Servadio, Iowa State University

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10:45 AM - 11:00 AM

**AAS 25-631**: Statistical Measurement Association for Cislunar Space Leveraging Admissible Region Theory

Abstract: In cislunar space, traditional initial orbit determination techniques tend to fail due to the Too-Short Arc problem and the underlying assumption of Keplerian motion. Admissible region theory addresses this issue by taking advantage of hypothesized constraints on the range and range-rate space. Intersection theory analysis then finds a mutual point between multiple admissible regions to associate measurements and provide an initial state estimate. Our work applies these methods to cislunar space using a measurement-centric perspective, which we find susceptible to ambiguous solutions. We address this via hypothesis testing techniques, refining the solution space into a finite subset with associated uncertainties.

Author(s): Queenique Dinh, University of Colorado Boulder; Daniel Scheeres, University of Colorado Boulder; Marcus Holzinger, University of Colorado Boulder

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11:00 AM - 11:15 AM

**AAS 25-635**: OBSERVING CISLUNAR EFFECTS ON ORBITS THROUGHA HOMOTOPY-BASED UNIFIED TRANSITIONING SCHEME

Abstract: To enable long-term sustainable activity in cislunar space, understanding the ef fects on the orbits from various spatial characteristics is vital. A unified transi tioning scheme is formulated to ease transitioning trajectories from the Circular Restricted Three-Body Problem into the Higher Fidelity Ephemeris Model us ing intermediary models. Consequently, more perturbing effects are introduced into the process with each step. In this investigation, orbits are transitioned from lower-to-higher fidelity models by switching out the intermediary model. The Earth-Moon pulsation effects are analyzed using the Elliptic-Restricted Three Body Problem. Solar gravity effects are also investigated leveraging the Bicircular Restricted Four-Body Model.

Author(s): Jay Singh, Purdue University; Kathleen C. Howell, Purdue University

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11:15 AM - 11:30 AM

**AAS 25-647**: Semi-Analytical Method to Generate Linear Operators in the Circular-Restricted Three-Body Problem

Abstract: This work proposes a semi-analytical method to obtain linear operators able to capture the non-linear dynamics of the Circular-Restricted Three-Body Problem. This methodology is applied to the motion characteristic of periodic and resonant orbits and allows generating a semi-analytical approximate solution of the system. It is based on a perturbation method that allows the decomposition of the state variables into a series expansion, represented by Fourier basis functions in time. The resulting linear operator enables direct propagation and use of linear systems tools, such as Linear Quadratic Regulator control. Numerical examples demonstrate the propagation of periodic and resonant orbits, highlighting the accuracy of the approach.

Author(s): Shantanu Trivedi, Purdue University; David Arnas, Universidad de Zaragoza

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11:30 AM - 11:45 AM

**AAS 25-662**: Linear Strategies for Orbit Maintenance Design in Multi-Body Regimes With Transition Strategies to Higher-Fidelity

Abstract: Missions to the cislunar region increasingly aim to utilize trajectories derived from multi-body periodic orbits that are linearly unstable. Correspondingly, some form of stationkeeping strategy is required to maintain a spacecraft near the desired reference path. The present work examines several orbit maintenance strategies that leverage local linearization to formulate a state-feedback stationkeeping policy, while allowing feed-forward control as well. The approaches in this investigation are either derived explicitly from dynamical principles or employ convex optimization techniques to construct appropriate maneuvers. Applicability of these approaches in, and transition strategies to, higher-fidelity force models are also explored.

Author(s): Dale Williams, Purdue University; Kathleen C. Howell, Purdue University

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11:45 AM - 12:00 PM

**AAS 25-664**: Optimal Impulsive Control of Cislunar Relative Motion using Reachable Set Theory

Abstract: This work presents the first application of the state-of-the-art Koenig-D’Amico reachable set theory solver to the chaotic Circular-Restricted Three-Body Problem (CR3BP) dynamics of relative motion in the cislunar regime. The dynamics of a system of two spacecraft in the CR3BP are formulated as a Linear Time-Variant system, allowing the solver to find an optimal impulsive control maneuver plan. This methodology demonstrates robust and accurate performance for over different CR3BP orbits, reconfiguration scenarios, and control windows. It also exhibits the computational efficiency to be used on-board spacecraft, enabling the safe, effective, and efficient operation of cislunar Distributed Space Systems.

Author(s): Matthew Hunter, Stanford University; Walter Manuel, Stanford University; Simone D'Amico, Stanford University

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12:00 PM - 12:15 PM

**AAS 25-677**: Networks of Periodic Orbits in the Earth--Moon System Through a Regularized and Symplectic Lens

Abstract: In this investigation, using numerical continuation, Kustaanheimo-Stiefel regularization, and a novel "symplectic toolkit", we carry out an extensive numerical study of periodic orbit families for the Earth-Moon CR3BP. Near the Moon we investigate prograde, retrograde, and Halo orbits, discovering previously-unknown orbit families linking them together through bifurcations and singularities -- also confirming a 1968 conjecture of Broucke. Earth prograde and retrograde orbits are also studied, finding infinite chains linking 1:2N and 1:2N+1 resonant orbits. These connections provide insights into the global network structure of families of periodic orbits, identifying orbit families near others of interest for mission design.

Author(s): Bhanu Kumar, University of Michigan; Agustin Moreno, University of Heidelberg

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12:15 PM - 12:30 PM

**AAS 25-725**: A Study on the Application of the Short Period Orbit Family for Optical Cislunar Surveillance

Abstract: This work aims to provide an initial analysis on the viability of short periodic trajectories about $L_4$ and $L_5$ to house an observational constellation able to observe and track objects following direct transfer trajectories between the Earth and the Moon. Specifically, the impact of exclusion angles and illumination of targets are analyzed for this region of interest and potential orbits for these observer constellations are identified and evaluated. A study of trajectory insertion costs is also included to show the feasibility of these orbits for constellation design.

Author(s): Brian Baker-McEvilly, Embry-Riddle Aeronautical University; Andrew Binder, Purdue University; David Canales Garcia, Embry-Riddle Aeronautical University; David Arnas, Universidad de Zaragoza

# Trajectory Design and Optimization II

Monday, 08/11/25, 10:30 AM - 12:30 PM

Session Chair(s): James Thorne (Institute for Defense Analyses (IDA))

Room: Adrienne Salon

10:45 AM - 11:00 AM

**AAS 25-562**: Comet Interceptor: Mission Feasibility and Guidance Strategy for a Pristine Comet Encounter

Abstract: Comet Interceptor, ESA's first F-class mission, aims to study a pristine comet entering the inner Solar System for the first time. Launching in 2029 with ARIEL, it will wait in a quasi-Halo orbit around Lagrange Point 2 for up to 4 years to intercept a suitable target. Two transfer strategies—direct or Moon-assist—maximize reachability. A trio of spacecraft will conduct a high-speed flyby, with probes released for multi-point observations. Mission analysis, including navigation and targeting uncertainties, confirms feasibility. Backup targets and a robust operational plan ensure an 80% success probability within current mission constraints.

Author(s): Jose Manuel Sanchez Perez, ESA; Ignacio Acedo, GMV GmbH @ ESA-ESOC; Laurent Beauregard, Telespazio Germany GmbH @ ESA-ESOC

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11:00 AM - 11:15 AM

**AAS 25-580**: Grid Search Pruning for Solving Gravity-Assist Problems with the Genetic Algorithm

Abstract: This paper presents a ballistic grid search pruning strategy to initialize the Genetic Algorithm (GA) for the multiple-gravity assist problem. The method reduces the computational burden on the GA and helps prevent it from getting trapped in local minima. The grid search time complexity is mitigated using initial guesses from the ballistic Lambert solutions and a GA selection operator. The concept is analyzed on the Cassini-2, Messenger (Reduced), and Rosetta trajectory optimization problems from the ESA GTOP database. The results show the ability to prune the design space a priori, leading to the GA converging near the known optimal solution.

Author(s): David Knapick, Iowa State University; Simone Servadio, Iowa State University

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11:15 AM - 11:30 AM

**AAS 25-589**: Effective Design of NRHO Recovery Trajectories via Iterative Convex-Bayesian Optimization Framework

Abstract: This paper proposes a trajectory optimization framework for the Bicircular Restricted Four-Body Problem, combines a sequential convex programming approach with Bayesian optimization to design an effective return trajectory. The proposed framework considers not only the control acceleration but also the transition time and NRHO insertion phase angle as design variables, aiming to minimize fuel consumption in the event of a PLSB maneuver failure.

Author(s): Yuki Matsumoto, Japan Aerospace Exploration Agency; Ryo Nakamura, Japan Aerospace Exploration Agency; Takahiro Sasaki, Japan Aerospace Exploration Agency; Satoshi Ueda, Japan Aerospace Exploration Agency

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11:30 AM - 11:45 AM

**AAS 25-607**: Pontryagin-Bellman Differential Dynamic Programming for Robust Low-Thrust Trajectory Optimization Under Uncertainty

Abstract: We propose a new approach for solving nonlinear constrained stochastic optimal control problems, with an emphasis on low-thrust trajectory design under uncertainty. The method incorporates Pontryagin's Minimum Principle into the Differential Dynamic Programming framework, yielding a Pontryagin-Bellman Differential Dynamic Programming (PDDP) algorithm. PDDP simultaneously designs an optimal reference trajectory and correction policy that minimize state distribution. Optimization relies on a null-space trust-region method, solving a series of quadratic subproblems derived from first- and second-order sensitivities, while constraints are handled via mathematical programming. Preliminary results show the method effectively designs robust trajectories under imperfect state knowledge, dynamics modeling, and maneuver execution errors.

Author(s): Yanis Sidhoum, Purdue University; Kenshiro Oguri, Purdue University

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11:45 AM - 12:00 PM

**AAS 25-611**: Optimal Statistical Moment Steering for Controlling Non-Gaussian Distributions

Abstract: This paper presents a method of controlling a non-Gaussian distribution in nonlinear environments with optimized linear gains. This paper utilizes Conjugate Unscented Transformation to quantify the higher-order statistical moments. The formulation focuses on controlling and constraining the sigma points associated with the uncertainty quantification, which would thereby reflect the control of the entire distribution. The method is compatible with sequential convex programming, and is applied to problems in astrodynamics.

Author(s): Daniel Qi, Purdue University; Kenshiro Oguri, Purdue University; Puneet Singla, The Pennsylvania State University; Maruthi R. Akella, The University of Texas at Austin

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12:00 PM - 12:15 PM

**AAS 25-615**: Low-Thrust Trajectory Optimization for the Moon-Enabled Sun Occultation Mission Concept

Abstract:

This study investigates the feasibility of a Moon-enabled Sun occultation mission to observe the solar corona, normally obscured by the Sun's brightness. The con- cept involves positioning a spacecraft behind the Moon to block the incident light coming from the solar disk. Low-thrust propulsion is analyzed to assess its suit- ability for such a mission. The mission geometry includes lunar flybys to modify the orbit, enabling the spacecraft to pass through designated occultation zones. A multi-arc approach is employed to optimize the full trajectory while accounting for mission constraints.

Author(s): Alesia Herasimenka, University of Surrey; Nicola Baresi, University of Surrey

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12:15 PM - 12:30 PM

**AAS 25-581**: Pathfinding Challenges with the Genetic Algorithm for the Multiple-Gravity-Assist Problem

Abstract: This paper presents a genetic-based method to determine optimal flyby sequences in a single optimization loop. The Hidden Genes Genetic Algorithm (HGGA) is challenged as the number of flybys increases. As genetic generations increase, the number of function evaluations of longer flyby sequences rapidly decreases. A new method is proposed here that fairly evaluates every sequence in every generation. Numerical results for benchmark problems are presented and compared to solutions in the literature. The results presented in this paper demonstrate the capability of the proposed method compared to matching known optimal solutions.

Author(s): David Knapick, Iowa State University; Simone Servadio, Iowa State University

# Orbit Determination and Estimation II

## Monday, 08/11/25, 2:00 PM - 3:15 PM

## Session Chair(s): Kyle DeMars (Texas A&M University)

## Room: Duxbury

2:00 PM - 2:15 PM

**AAS 25-872**: Uncertainty Quantification Using Directional Splitting and Gaussian Mixture Models with Applications to Orbital Dynamics

Abstract: A novel adaptive algorithm is proposed to propagate forward in time an arbitrary distribution through nonlinear dynamics forced by white noise. The new scheme employs Gaussian Mixture Models and automatically refines the number of components to better encompass the effects of the nonlinear dynamics. The refinement is done in directions that suffer from both high nonlinearity and high uncertainty. An orbital uncertainty quantification numerical example is provided to validate the effectiveness of the proposed methodology.

Author(s): Renato Zanetti, The University of Texas at Austin; Kyle DeMars, Texas A&M University; Derek Tuggle, Draper Laboratory; Kristen Michaelson, University of Texas at Austin; Maaninee Gupta, Texas A&M University

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2:15 PM - 2:30 PM

**AAS 25-876**: Probabilistic Angles-Only Initial Orbit Determination Using a Spaceborne Multi-Sensor Network

Abstract: In this paper, a probabilistic initial orbit determination algorithm using angle-only relative measurements from satellites in a mega-constellation to track space debris is presented. The simulation environment consists of satellite mega-constellation and thousands of space debris objects propagated using a high-fidelity numerical propagator. A passive radar is simulated to generate measurements of azimuth and elevation angles of space debris in the satellite's local frame and then fed to the multi-sensor CAR-MHF IOD algorithm. The algorithm fuses the measurements across satellites, pruning orbit candidates using statistical tools. Final hypotheses undergo weighted batch least squares, yielding accurate six-state estimates for Kalman filter tracking initialization.

Author(s): Chinmay Gaikwad, Embry Riddle Aeronautical University; Filipe Senra, Embry-Riddle Aeronautical University; Hao Peng, Embry-Riddle Aeronautical University

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2:30 PM - 2:45 PM

**AAS 25-879**: A Robust Method for Initial Orbit Determination Using Range-Swept Seeding and Full-State Differential Correction

Abstract: This paper presents a robust method for initial orbit determination (IOD) and is ideal for high-eccentricity orbits, where classical techniques often fail. It uses a two-observation orbit estimator (so2rv) to seed a full-state differential correction routine that then operates on all three (or more) observations. The range parameter in so2rv is automatically adjusted to yield increasingly better orbits. Unlike Lambert or f/g series approaches, this method avoids numerical instability near apogee and is effective under poor observation geometry. Empirical validation shows consistent success where conventional IOD fails, making it highly suitable for space surveillance and orbit cataloging applications.

Author(s): Daniel Parrott, Tycho Tracker

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2:45 PM - 3:00 PM

**AAS 25-890**: A Numerical Comparison of the UDU^T and P Covariance Forms of the Extended Kalman Filter

Abstract: Specific implementations of the Extended Kalman Filter (EKF) are often characterized by their treatment of the error-covariance. The UDUT decomposition and the accompanying time and measurement update algorithms guarantee that an error-covariance matrix which is initially positive definite will remain positive definite. Using the Ansys Orbit Determination Tool Kit application as a reference, we describe the integration of the UDUT algorithms into the EKF and compare the performance of processing error-covariance in UDUT form versus processing error-covariance in undecomposed P form.

Author(s): Andrew Goetz, AGI; James Woodburn, AGI

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3:00 PM - 3:15 PM

**AAS 25-923**: Partial State Gaussian Mixture Fusion for Distributed Navigation and Tracking

Abstract: In space-based tracking systems, uncertainties in the spacecraft navigation state and the target state are linked and should be considered jointly.
In distributed tracking systems, where multiple agents exchange information about the target state, the correlations between the ego-state and the target state present a challenge and opportunity.
This paper presents a conservative multi-sensor fusion algorithm for combining non-Gaussian beliefs while preserving known correlations between the target and ego-state.
The proposed approach is scalable to large sensor networks, as it requires no knowledge of data pedigree, and does not require that an agent estimate any other agent's ego-state.

Author(s): Simone Semeraro, School of Aeronautics and Astronautics, Purdue University; Keith LeGrand, Purdue University; Jackson Kulik, Utah State University

# Special Session Honoring the Technical Legacy of Cesar Ocampo I

Monday, 08/11/25, 2:00 PM - 3:15 PM

Session Chair(s): Ryan Russell (The University of Texas at Austin), Bonnie Prado Pino (Odyssey Space Research L.L.C.)

Room: Ballroom B

2:00 PM - 2:15 PM

**AAS 25-915**: Complete Kepler Propagator Including Second-Order Sensitivities

Abstract: The well-known universal Kepler formulation is revisited with the goals of fast runtime, robust convergence, and accurate sensitivity computation across the global domain. A new initial guesses strategy and high-order partial derivatives of Kepler's time equation are exploited to converge in 1 or 2 iterations for the ellipse and hyperbola cases, respectively. The state propagation and state transition matrix and tensor are computed with a new version of Pitkin's algorithm that includes both time and anomaly as independent variables. The result is a fully quadratic relative motion model and is useful for a variety of navigation and mission design applications.

Author(s): Ryan Russell, The University of Texas at Austin

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2:15 PM - 2:30 PM

**AAS 25-904**: Exact Impulsive to Time-Optimal Finite Burn Conversion with Costate Estimation

Abstract: An automated method is described that converts a single impulsive maneuver to an exact time-optimal finite-burn maneuver for a thrust limited, constant exhaust velocity rocket engine. The motivation of the present study is the necessity to convert a multi-impulse trajectory to an optimal finite burn trajectory via an automated procedure. A parameter finite burn model is solved first using a direct method and its solution is then used to estimate the parameters needed to solve the optimal-time finite-burn problem using the indirect method. An extended adjoint-control transformation that uses second time derivatives for the thrust direction unit vector is used for estimating the costates.

Author(s): Cesar Ocampo, Odyssey Space Research; Bharat Mahajan, Odyssey Space Research LLC

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2:30 PM - 2:45 PM

**AAS 25-787**: Advanced Modeling Techniques for Analyzing Space Debris Fragmentation and Evolution

Abstract: The increasing presence of space debris poses significant challenges to orbital sustainability, necessitating advanced modeling techniques for long-term analysis. This research presents a computational framework for analyzing the evolution of debris generated by object fragmentation in orbit, incorporating realistic debris scenarios. The framework enables forward and backward propagations utilizing N-body symplectic integrators, facilitating a comprehensive assessment of collision risks and debris evolution. The study examines long-term population dynamics across various orbital regimes, evaluating the accuracy of symplectic methods in complex fragmentation environments. This approach enhances understanding of orbital debris and informs mitigation strategies for sustainable space operations.

Author(s): Juan F Puerta Ibarra, Universidad de Antioquia; Bonnie Prado Pino, Odyssey Space Research L.L.C.; Nicolas Muñoz Galeano, Universidad de Antioquia

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2:45 PM – 3:00 PM

**AAS 25-761**: Time Sensitive Departures in Near Rectilinear Halo Orbits

Abstract: Satellites in a Near Rectilinear Halo Orbit can utilize unstable manifolds for departure to heliocentric orbits at their end of life. These orbits are highly sensitive to dispersions due to navigation uncertainties and maneuver execution errors. Additionally, uncertainties due to orientation can cause varying effects of solar radiation pressure and out-gassing events can occur after a satellite is no longer operational. This paper characterizes how operators can minimize time of contact with their satellites post departure while avoiding collisions with other celestial bodies and spacecraft in the orbit used by Earth Moon's 9:2 NRHO resonance.

Author(s): Marielle Pellegrino, Odyssey Space Research; Christopher Foster, Odyssey Space Research, LLC.; Cesar Ocampo, Odyssey Space Research/NASA-JSC

# Asteroid and Interplanetary Mission Design I

Monday, 08/11/25, 2:00 PM - 3:15 PM

Session Chair(s): Jason Leonard (KinetX)

Room: Adrienne Salon

2:00 PM - 2:15 PM

**AAS 25-531**: 2- 3- and N-body Orbit Propagators for Rapid Optical Data processing

Abstract: This paper presents methods for building 2-, 3-, and N-body orbit propagators optimized for near-real-time optical data processing with a focus on orbits beyond geosynchronous Earth orbit (xGEO). Theory and equations of motion for multi-body orbit propagation are well established, but practical guidance on constructing accurate and efficient propagators is scarce. Because xGEO spacecraft and some of the 1.4 million cataloged asteroids can exhibit similar brightness and motion in the field of view (FOV) of optical sensors, effectively distinguishing between them requires not only a solid understanding of the underlying physics but also practical know-how in building and using these propagators.

Author(s): Gim Der, DerAstrodynamics; William Mandeville, Intrack Radar Technologies; Timothy McLaughlin, Pine Park Engineering; Jeremy Kolansky, Intrack Radar Technologies

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2:15 PM - 2:30 PM

**AAS 25-670**: Dragonfly Phase C Mission Design and Navigation

Abstract: Dragonfly is the fourth mission in NASA's New Frontiers program. Dragonfly is a relocatable octocopter lander that will explore Titan, Saturn's largest moon. The Johns Hopkins Applied Physics Laboratory (JHUAPL) designs, builds, and operates the spacecraft and performs the Mission Design role, while NASA's Jet Propulsion Laboratory (JPL) performs the Navigation role. Dragonfly will launch in 2028 and arrive at Titan in 2034, with surface operations extending through 2038. This paper describes the state of the Mission Design and Navigation (MDNav) work through mission critical design review in April, 2025.

Author(s): Jacob Englander, Johns Hopkins Applied Physics Laboratory; Donald Ellison, The Johns Hopkins University Applied Physics Laboratory; Jesse Greaves, NASA/CalTech Jet Propulsion Labotatory; Noble Hatten, Johns Hopkins University Applied Physics Laboratory; Brian Kennedy, NASA / Caltech JPL; Mark Jesick, Jet Propulsion Laboratory; Daniel Lubey, Jet Propulsion Laboratory, California Institute of Technology; Maria McQuaide, JHU Applied Physics Laboratory; Duane Roth, Jet Propulsion Laboratory; Mau C. Wong, JPL

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2:30 PM - 2:45 PM

**AAS 25-808**: Preliminary mission Analysis for a Mars sample return mission

Abstract: In recent years the most challenging and prominent deep space mission would be a Mars sample return (MSR) mission. According to the previous plan, the joint NASA-ESA MSR mission will have its orbiter launched in 2027 and the lander launched in 2028, and it is expected that the Mars sample return will be accomplished by 2033. According to the public release, China space is making an endeavor to achieve Mars sample return by 2031 or 2033. This paper introduces the main considerations in the preliminary mission analysis of a proposed MSR mission.

Author(s): Zhong-Sheng Wang, China Academy of Space Technology; Baiyi Tian, China Academy of Space Technology; Jie Dong, China Academy of Space Technology; William Wang, Purdue University

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2:45 PM - 3:00 PM

**AAS 25-905**: Autonomous Optical Navigation for Unknown Asteroids with Irregular Horizons

Abstract: This paper develops an enhanced horizon-based Optical Navigation (OpNav) method by using image stacking and artificial limb smoothing methods to overcome the elliptical horizon assumption while maintaining computational efficiency suitable for onboard usage. This method improves navigation accuracy for irregular asteroid horizon geometries. Monte Carlo simulations validate that navigation errors remain bounded within analytically derived covariances across various asteroid models (Bennu, Itokawa, Arrokoth, and 67P). Using a sequential Extended Kalman Filter (EKF) framework, the state and radius are estimated. Rotation rate and shape ratio parameters are also estimated. The framework is tested in flyby scenarios with a covariance-aware controller that dynamically adjusts maneuvers with evolving estimation accuracy and covariance.

Author(s): Aditya Arjun Anibha, Purdue University; Kenshiro Oguri, Purdue University; Jacopo Villa, Laboratory for Atmospheric and Space Physics

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3:00 PM - 3:15 PM

**AAS 25-920**: Optical Navigation and Characterization Strategy of Asteroid Justitia during the EMA Approach Phase

Abstract: Upon flying by 6 main-belt asteroids, the Emirates Mission to the Asteroid Belt (EMA) will rendezvous and perform proximity operations around a seventh target, asteroid 269 Justitia, in 2034. In this work, we present the strategy and vision-based algorithms for optical navigation and characterization of Justitia during the approach phase, including techniques for pole estimation, shape reconstruction, and surface-relative navigation. The proposed algorithms are robust to challenging surface lighting, are agnostic to the target appearance, and leverage geometric quantities, such as the asteroid limb and visual features, significantly increasing the level of automation in optical-navigation procedures.

Author(s): Jacopo Villa, Laboratory for Atmospheric and Space Physics; Mohamed Almashjari, UAE Space Agency; Jay McMahon, University of Colorado Boulder, CCAR; Jeremy Knittel, Laboratory for Atmospheric and Space Physics (LASP)

# Atmospheric Re-entry Guidance and Control

## Monday, 08/11/25, 2:00 PM - 3:15 PM

## Session Chair(s): Maaninee Gupta (Texas A&M University)

## Room: Dedham

2:00 PM - 2:15 PM

**AAS 25-549**: Robust Sampling-Based Covariance Steering for Aerocapture Guidance

Abstract: Aerocapture is a maneuver where a spacecraft dives through the atmosphere of a planet to reduce its velocity and prepare for orbital insertion. Uncertainties in the entry state and atmospheric density increase the risk of aerocapture. This work develops a robust sampling-based covariance steering algorithm designed for aerocapture guidance. Our algorithm leverages sampled nonlinear trajectories to improve evaluation of the $\Delta V$ required for aerocapture and address nonlinearities caused by the aerocapture dynamics and atmospheric disturbances. We perform Monte Carlo simulations on aerocapture at Mars and demonstrate a 5-15% reduction in the 99th-percentile and worst-case $\Delta V$ required for aerocapture.

Author(s): Alex Rose, MIT; Christopher Jewison, Draper; Jonathan How, MIT

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2:15 PM - 2:30 PM

**AAS 25-592**: Integrated Post-Mission Trajectory Generation for Reusable Unmanned Space Vehicles Using Sequential Convex Optimization

Abstract: Reusable space vehicles have recently attracted a lot of attention due to there advantage of being able to carry out various space missions multiple times. This paper presents an integrated approach to post-mission trajectory generation for reusable unmanned space vehicles (ReUSVs). The method defines two phases from post-mission maneuver, which are a de-orbit phase, which identifies an atmospheric “re-entry region,” and a return-flight phase that navigates from atmospheric entry to a specified landing site. Sequential convex optimization is employed to iteratively solve trajectory optimization problems, reducing computational cost. This framework provides a systematic and efficient solution for ReUSV missions.

Author(s): Jaewon Kim, Seoul National University; Sangmin Lee, Seoul National University; Jong-Min Park, Seoul National University; Youdan Kim, Seoul National University; Chandeok Park, Yonsei University; Mingu Kim, Hansung University; Jongho Park, Kookmin University; Suwon Lee, Kookmin University; Seokwon Lee, Chung-Ang University

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2:30 PM - 2:45 PM

**AAS 25-680**: Dynamical Models for Spacecraft Landings in Low-gravity Environments using Polynomial Chaos

Abstract: Landings on the surface of small solar-system bodies (SSB) are incredibly valuable in terms of scientific return, however there is also a high risk assosciated to them as seen for the Philae and MINERVA probes. One of the main problems is the complex modelling of the interaction between the lander and the surface of the SSB. This work presents novel ways of combining high fidelity simulations with data-driven methods like polynomial chaos to obtain dynamical models of the spacecraft-surface interactions. These models can then be used to perform sensitivty and reliability analyses, and be used for retrieving surface properties afterwards.

Author(s): Iosto Fodde, Politecnico di Milano; Lucia Francesca Civati, Politecnico di Milano; Alessia Cremasco, Politecnico di Milano; Fabio Ferrari, University of Bern

2:45 PM - 3:00 PM

**AAS 25-728**: Rapid Mission Design: Exploring Methods of Sequential Transfer Learning for Earth Re-Entry Guidance and Control

Abstract: Traditional transfer learning is a method of machine learning in which the neural network can learn from previously trained neural networks. Thus, the neural network can be fully trained with much less data and time than traditional machine learning requires. Sequential Transfer Learning can be described as applying transfer learning iteratively to missions with parameters that vary increasingly in a certain direction within the design space. Thus, missions that may be well outside of the original mission's design space for the traditional transfer learning will still benefit from reduction in required data as well as training time.

Author(s): Benjamin Mitchell, University of Central Florida; Tarek Elgohary, University of Central Florida

# Special Session Honoring the Technical Legacy of Cesar Ocampo II

Monday, 08/11/25, 3:45 PM - 5:15 PM

Session Chair(s): Ryan Russell (The University of Texas at Austin), Bonnie Prado Pino (Odyssey Space Research L.L.C.)

Room: Ballroom B

4:00 PM - 4:15 PM

**AAS 25-698**: Fast Optimization of Low-Thrust Spiral Trajectories to Cislunar Space

Abstract: End-to-end optimized low-thrust trajectories from a Geostationary Transfer Orbit (GTO) to a Lunar Near Rectilinear Halo Orbit (NRHO) can be difficult design due to the computational complexity of trajectory, the varied sensitivity through multiple dynamic regimes, and the imposition of mission specific eclipse constraints. The approach presented aims to simplify the optimization problem into a series of computationally efficient surrogate models which can more quickly compute the values relevant to identifying the optimal end-to-end solution. The optimal solution to the simplified problem can then either be reconstructed in high-fidelity, or used as an initial guess for high-fidelity optimization.

Author(s): Steven McCarty, NASA Glenn Research Center

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4:15 PM - 4:30 PM

**AAS 25-576**: A History of Copernicus: the origin, development, and evolution of JSC's spacecraft trajectory design and optimization system

Abstract: This paper describes the history of the Copernicus spacecraft trajectory design and optimization system, a software tool originally developed at the University of Texas at Austin, and then later at the NASA Johnson Space Center. For twenty years, Copernicus has been a workhorse tool for advanced mission design at \acs{JSC}. During this time, the tool has been under constant development and has evolved significantly. The origin and development of the software is detailed, how it has been used, and some lessons learned and future possibilities are also presented.

Author(s): Jacob Williams, NASA Johnson Space Center; Juan Senent, Jet Propulsion Laboratory; Ravishankar Mathur, Intuitive Machines; Shaun Stewart, Intuitive Machines

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4:30 PM - 4:45 PM

**AAS 25-571**: INTERPOLATION OF PERIODIC ORBIT FAMILIES IN THE RESTRICTED THREE BODY PROBLEM

Abstract: The restricted three body problem is an important preliminary dynamics model for spacecraft subject to multibody gravity. Periodic solutions, analogous to elliptical solutions in the two-body problem, are natural waypoints and destinations. Solutions are generally not analytic and require sophisticated numerical methods to obtain. Here, a method is presented to efficiently parameterize periodic orbits and families. The result is a Cartesian six-state functionally dependent on newly defined phase and family parameters. The smooth and continuous functions and their partial derivatives are fast to compute and are useful for a variety of mission design and navigation applications. Several examples are presented.

Author(s): Jad Bourjeili, University of Texas at Austin; Ryan Russell, The University of Texas at Austin

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4:45 PM - 5:00 PM

**AAS 25-756**: Characterizing Jettison Maneuvers along Artemis Mission Trajectories

Abstract: This study explores the responsible jettison and disposal of cislunar spacecraft serving the Artemis program. Employing simplified four-body dynamics, the current analysis characterizes the

dynamics of jettisoned objects along the outbound and return legs of a fast transit from Earth to the Gateway NRHO. Additionally, the long-term behavior of objects jettisoned from the NRHO itself are considered from a four-body perspective. The robustness of the resulting trajectories is characterized, and placement, characteristics, and limitations of cleanup burns are explored to effectively maintain long-term Earth evasion.

Author(s): Diane Davis, NASA Johnson Space Center; Liam Fahey, Purdue University; Stephen Scheuerle, NASA Johnson Space Center; Kathleen C. Howell, Purdue University

# Orbital Dynamics, Perturbations, and Stability I

Monday, 08/11/25, 3:45 PM - 5:15 PM

Session Chair(s): Casey Heidrich (University of Colorado Boulder)

Room: Duxbury

3:45 PM - 4:00 PM

**AAS 25-642**: Generalized Terminator Orbits around Asteroids under Oblique Solar Radiation

Abstract: Terminator orbits are a promising solution for stable station-keeping around asteroids under strong solar radiation pressure (SRP). However, conventional designs require the orbital plane to be perpendicular to the sun direction and assume SRP acts purely in the radial direction, which imposes geometric constraints on spacecraft operations. In this study, we extend the terminator orbit theory from the cannonball model to the flat-plate model, capturing the attitude-dependent effects of oblique solar radiation. The resulting generalized terminator orbits remain frozen while accommodating arbitrary spacecraft orientations. This framework also provides a theoretical bridge between basic cannonball dynamics and advanced solar sailing schemes.

Author(s): Shota Kikuchi, National Astronomical Observatory of Japan; Daniel Scheeres, University of Colorado Boulder

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4:00 PM - 4:15 PM

**AAS 25-652**: MATHEMATICA Verification of the DSST Zonal Harmonics Long- and Short-Period Terms

Abstract: The Draper Semi-Analytical Satellite Theory (DSST) includes comprehensive models for an artificial Earth satellite's mean element and short-period motions. The theory was constructed using traditional pencil and paper techniques. The resulting algorithms were programmed as Fortran 77 subroutines for inclusion in the GTDS orbit determination program. The objective of the current effort is to construct the core DSST algorithms using a modern, general-purpose computer algebra system, MATHEMATICA. This system will put the current algorithms on a more sustainable basis and support the development of future extensions. A derivation in MATHEMATICA of the zonal harmonic long and short-period terms is presented.

Author(s): Juan Félix San-Juan, University of La Rioja; Miguel Alonso, University of La Rioja; Paul J. Cefola, University at Buffalo (SUNY)

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4:15 PM - 4:30 PM

**AAS 25-710**: Solution for Frozen Orbits Under the Effects of Zonal, Sectorial, and Tesseral Gravitational Harmonics

Abstract: A novel approach is provided to find an analytical approximate second-order closed-form solution for frozen orbits under the effect of zonal, sectoral, and tesseral perturbations. This result is produced by finding an analytical solution for osculating orbital elements describing a satellite under the same perturbations and setting the secular variation of these equations to zero. The solutions found are applied to the mass distributions of the Earth and the Moon to verify their accuracy and limitations.

Author(s): India Hutson, Purdue University; David Arnas, Universidad de Zaragoza

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4:30 PM - 4:45 PM

**AAS 25-729**: Advanced Analytical Characterization of Lunar Frozen Orbits: A Generalized Framework Including Multiple Gravitational Harmonics

Abstract: A new analytical method is developed for identifying lunar frozen orbits, based on long-period canonical transformations rather than the traditional use of Lagrange Planetary Equations. This approach allows frozen orbit conditions to be derived directly from the Hamiltonian structure. Unlike earlier analytic theories, which typically included only the J2 harmonic and third-body effects, the proposed framework incorporates multiple higher-order lunar gravitational harmonics. The method also generalizes to orbital configurations such as circular and equatorial orbits, offering a more complete analytical formulation for frozen orbit characterization.

Author(s): Grigory Nikitin, Texas A&M University; Kyle T. Alfriend, Texas A&M University

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4:45 PM - 5:00 PM

**AAS 25-734**: Lunar satellite analytic theory with complete gravity and third-body perturbations

Abstract: Artificial satellite theories for the Moon differ in important aspects from the similar theories for Earth because of more uneven nature of lunar gravity, strong third-body perturbations, and no atmospheric drag. In this work, a fully analytic theory for lunar satellites is developed using generalized formulae that enable inclusion of spherical harmonics up to an arbitrary degree and order. The complete gravity and third-body disturbing functions are together considered as the dominant perturbation to the Keplerian Hamiltonian, which is then fully normalized up to second order by constructing three canonical transformations for averaging out the short-, medium-, and long-period terms.

Author(s): Bharat Mahajan, Odyssey Space Research LLC

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5:00 PM - 5:15 PM

**AAS 25-743**: Artificial Frozen Orbits Around Small Bodies via Solar Sailing

Abstract: Frozen orbits are useful for achieving periodic orbits around small bodies, but conventional frozen orbits are typically restricted to the terminator or ecliptic planes. This paper proposes artificial frozen orbits (AFOs) around small bodies by actively controlling perturbations caused by solar radiation pressure (SRP). Semi-analytical solutions for the AFOs are derived by incorporating the dynamic variations of SRP using averaged Gauss variational equations. The control laws for the sail steering angles are expressed in terms of Fourier series. The results reveal several types of AFOs that deviate from the terminator and ecliptic planes, exhibiting variable orbital radii and eccentricities.

Author(s): Yuki Takao, Yokohama National University; Shota Kikuchi, National Astronomical Observatory of Japan

# Trajectory Design and Optimization III

Monday, 08/11/25, 3:45 PM - 5:15 PM

Session Chair(s): Kenshiro Oguri (Purdue University)

Room: Adrienne Salon

3:45 PM - 4:00 PM

**AAS 25-628**: A General Gaussian Steering Framework Leveraging Nonlinearity Constraints

Abstract: Gaussian steering has been proposed as a means of constructing--a priori--a feedback law to control the mean and covariance of state dispersions. The primary astrodynamics application is the ability to develop correction maneuvers for a spacecraft that are robust to modeled uncertainties. An additional goal for Gaussian steering is that robustness to uncertainties is claimed as a result of a successful optimization and not as a product of Monte Carlo verification. To that end, this paper develops a general Gaussian steering framework where the system's nonlinearity is accounted for. The generalized aspect stems from the ability to use either analytical linearization or quadrature.

Author(s): William Fife, Texas A&M University; Kyle DeMars, Texas A&M University; Jackson Kulik, Utah State University

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4:00 PM - 4:15 PM

**AAS 25-653**: Flight Dynamics Operation Results from the Extended Mission of Korea Pathfinder Lunar Orbiter

Abstract: The Korea Pathfinder Lunar Orbiter (KPLO) successfully completed its nominal mission in 2023 and entered an extended mission in 2024 to continue lunar exploration. This paper presents flight dynamics operational results from both phases, including orbit design and maneuver execution for orbit maintenance, collision avoidance, and orbital adjustments. The results demonstrate the effectiveness of KPLO's orbit operations under real-world challenges and provide valuable insights for future lunar missions.

Author(s): Jun Bang, Korea Aerospace Research Institute; Jonghee Bae, Korea Aerospace Research Institute; SeungBum Hong, Korea Aerospace Research Institute; Young-Joo Song, Kyung Hee University

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4:15 PM - 4:30 PM

**AAS 25-681**: Trajectory Dispersion Analysis for the IM-2 Mission

Abstract: The IM-2 mission trajectory design process included dispersion analysis performed by KinetX and Intuitive Machines personnel. MIRAGE-based Monte Carlo analysis performed by KinetX during the mission design effort provided assurance that the maneuver plan was effective at delivering the spacecraft to the target orbit within $\Delta V$ limits. Similar analyses performed during the mission operation provided flight controllers with continued insight into the potential outcome of each trajectory maneuver. A Copernicus-based Monte Carlo developed at Intuitive Machines provides an analysis verification opportunity employing the actual maneuver planning software. This paper describes the trajectory dispersion analyses performed for IM-2 using both toolsets.

Author(s): James Moore, Intuitive Machines; Andrew Levine, KinetX Aerospace; Daniel Wibben, KinetX, Inc.; Jason Leonard, KinetX; Ravishankar Mathur, Intuitive Machines; Timothy Roorda, Intuitive Machines

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4:30 PM - 4:45 PM

**AAS 25-703**: IM-2 Trajectory Design and Maneuver Planning

Abstract: Intuitive Machines' second mission to the Moon landed on the Mons Mouton plateau in the Lunar South Pole region in early 2025. Drawing on lessons learned from IM-1, we crafted Design Reference Mission (DRM) trajectories and maneuver planning scenarios for IM-2. We discuss the design for each planned maneuver and how we implemented the maneuver targeting operationally. We detail the in-flight trajectory performance, which includes a comparison of the flight reconstruction Best Estimate Trajectory to both the pre-flight DRM and in-flight operator-generated maneuver plans.

Author(s): Timothy Roorda, Intuitive Machines; Daniel Greer, Intuitive Machines; James Moore, Intuitive Machines; Daniel Wibben, KinetX, Inc.; Andrew Levine, KinetX Aerospace; Jason Leonard, KinetX; Ravishankar Mathur, Intuitive Machines; Shaun Stewart, Intuitive Machines

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4:45 PM - 5:00 PM

**AAS 25-715**: Catching Payloads with Tethers: Optimal Control for Payload Reference Trajectory Generation

Abstract: Momentum exchange tethers offer a promising alternative to traditional propulsion systems, particularly for transiting cislunar space, where high fuel costs make conventional Earth-departure maneuvers costly. This work applies a continuum of optimal control strategies to address this challenge: beginning with minimum energy control, converting it to thrust-constrained minimum fuel control using a continuation homotopy method, and concluding with impulsive maneuver solutions. Numerical results highlight trade-offs between fuel usage and time-of-flight across each formulation, resulting in a spectrum of feasible trajectories demonstrating the potential for momentum exchange systems to support sustained, fuel-efficient operations throughout the Earth-Moon system.

Author(s): Andrew Binder, Purdue University; Abdulrahman Abdrabou, Purdue University; David Arnas, Universidad de Zaragoza

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5:00 PM - 5:15 PM

**AAS 25-529**: Using Motion Primitives to Generate Initial Guesses for Trajectories to Sun-Earth L2

Abstract: This paper focuses on generating initial guesses for a spacecraft trajectory from an Earth-Moon L1 Lyapunov orbit to a Sun-Earth L2 Lyapunov orbit. To generate this initial guess, a motion primitive approach to trajectory design is employed. Motion primitives are generated as fundamental building blocks of motion in each of the Earth-Moon and Sun-Earth circular restricted three-body problems. A sequence of these primitives is then generated by searching a motion primitive graph that captures their sequential composability within and between dynamical models. This sequence is used to extract an initial guess for a transfer.

Author(s): Natasha Bosanac, University of Colorado, Boulder

# Dynamical Systems Theory Applied to Space Flight Problems I

Monday, 08/11/25, 3:45 PM - 5:15 PM

Session Chair(s): Nicola Baresi (University of Surrey)

Room: Dedham

3:45 PM - 4:00 PM

**AAS 25-675**: Local Orbital Elements with Halo Orbits

Abstract: Local orbital elements (LOEs) are coordinates defined about a Lagrange point in cislunar space that simplify the form of the dynamics and provide geometric insights. The primary limitation of LOEs is the exclusion of halo orbits; hence, resonant local orbital elements (RLOEs) are developed to re-incorporate these orbits into the LOE framework. In this work, we review the relevant resonant normal form theory used to construct RLOEs. Orbits can be simply generated from RLOEs via suitable Poincaré sections; further, orbits can be corrected numerically by a single shooting method (periodic orbits) or a modified flow map parameterization method (quasi-periodic orbits).

Author(s): Luke Peterson, University of Texas at Austin; Ethan Dennis, CU Boulder; Daniel Scheeres, University of Colorado Boulder

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4:00 PM - 4:15 PM

**AAS 25-686**: Analytical Orbital Shell Design for Scalable Slotting in Low Earth Orbit

Abstract:  While existing approaches to orbital slotting and minimum space occupancy designs offer partial solutions, they often rely on computationally expensive numerical optimization or conservative safety margins, limiting scalability and adaptability. This paper introduces an analytical framework for designing perturbation-resilient orbital shells, explicitly accounting for zonal harmonics. Unlike prior numerical methods, this approach provides a closed-form expressions for radial distance as a function of latitude, enabling direct analysis of shell geometry and thickness through linearized covariance propagation. By analytically modeling shell sensitivity to variations in orbital elements and uncertainty, we provide a traceable method to optimize inter-shell separation and minimize overlap.

Author(s): Mahhad Nayyer, Purdue University; David Arnas, Universidad de Zaragoza

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4:15 PM - 4:30 PM

**AAS 25-706**: The Topology of Spatial Minimoon Transit

Abstract: Minimoons are intriguing scientific targets and an easily accessible option for missions from Earth.  Understanding the envelope of their possible behavior is an essential step in designing potential missions to minimoons because the trajectory of a particular minimoon may not necessarily be known a priori, and a rapid response may be required.  We introduce the use of isolating neighborhoods here as an approach for obtaining a rigorous understanding of the behavior of minimoons in the low-energy regimes that are of interest.  The topology of these trajectories are analyzed as well as characteristics such as transit duration and Earth close approaches.

Author(s): Rodney L. Anderson, Jet Propulsion Laboratory/Caltech; Robert Easton; Martin Wen-Yu Lo, Jet Propulsion Laboratory

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4:30 PM - 4:45 PM

**AAS 25-708**: Persistence of Restricted Three-Body Problem Normal Form Structures in Higher-Fidelity Models

Abstract: Analytical normal form expansions of the Circular Restricted Three-Body Problem (CR3BP)

recast the six-dimensional synodic flow into lower-dimensional analogs via local integrals of motion. These action variables greatly clarify the phase-space structure, yet their utility in higher-fidelity ephemeris models remains untested. In this investigation, the persistence of CR3BP action variables is assessed in dynamical models with quasi-periodic gravitational forces. The results of KAM theory suggest that the underlying invariant tori should survive as slightly deformed, quasi-periodic analogues, providing quasi-integrals of motion. The variations in these quasi-integrals of motion is quantified, and their potential in providing insights in more realistic contexts is evaluated.

Author(s): Juan-Pablo Almanza-Soto, Purdue University; Kathleen C. Howell, Purdue University

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4:45 PM - 5:00 PM

**AAS 25-774**: Cis-lunar Space Object Maneuver Identification through Innovation in Reduced Order Modal Space

Abstract: Innovation-based methods built on full-state filters are often computationally intensive and could struggle in the highly nonlinear dynamical environments especially in the case of strategically executed maneuvers “invisible” to observer spacecraft. In this paper, we introduce a data-driven, reduced-order framework that combines Proper Orthogonal Decomposition and Extended Dynamic Mode Decomposition to extract an orthogonal modal basis for measurement predictions. An Extended Kalman Filter operating identifies maneuvers driven by sharp spikes in the filter innovation projected onto the modal subspace. By leveraging modal compression, our approach delivers significant improvements in computational efficiency while maintaining accuracy of impulsive maneuver detection.

Author(s): Kevin Alvarado, Rensselaer Polytechnic Institute; Hadley Earl, RPI; Sandeep Singh, Rensselaer Polytechnic Institute

# Orbit Determination and Estimation III

Tuesday, 08/12/25, 8:00 AM - 10:00 AM

Session Chair(s): Simone Servadio (Iowa State University)

Room: Duxbury

8:00 AM - 8:15 AM

**AAS 25-649**: Improvement of orbital uncertainty realism through a statistically-based covariance scaling method

Abstract: In the Least Square (LS) framework, orbital uncertainty is computed from the known measurements uncertainty, commonly provided as a general feature of a sensor. Thus, poor modeling of sensor's properties can yield unrealistic covariances. The square of the Weighted Root Mean Square (WRMS) of the residuals, often used to roughly assess the quality of an estimation, is sometimes used to scale the output covariance with its square value. This study aims at assessing the suitability of this apparently empricial method by adressing it in a theoretical way, since it shows significant covariance realism improvement on simulated data.

Author(s): Yvan Gary, Centre National d'Etudes Spatiales; Emmanuel Delande, Centre National d'Études Spatiales

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8:15 AM - 8:30 AM

**AAS 25-673**: Libration Point Orbit Determination Sensitivity Analysis With Varying Track Location

Abstract: Orbit determination of libration point orbits near the moon is often performed using range and range-rate measurements. Using a site located at the center of the Earth to not bias measurements to a specific ground location. Measurements are taken and put through a batch least squares process to estimate the orbit. The orbit is then separated into independent tracks located along itself. Using each track separately, the effectiveness of the batch least squares estimation of the orbit is examined using the maximum value of the covariance.

Author(s): Tate Crawford, Texas A&M University - Land, Air, and Space Robotics Laboratory; James McElreath, Land, Air and Space Robotics Laboratory; Texas A&M University; Manoranjan Majji, Texas A&M University, College Station

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8:30 AM - 8:45 AM

**AAS 25-676**: IM-2 Ground Navigation Performance from pre-Launch Analysis Through Mission Operations and Post-Flight Reconstruction

Abstract: Intuitive Machines (IM) launched their second (IM-2) Nova-C class lunar lander, Athena, aboard a SpaceX Falcon 9 on February 27, 2025 at 00:16:30 UTC as part of NASA’s Commercial Lunar Payload Services program. The ground navigation for IM-2 was conducted by KinetX, Inc. as prime with IM’s Orbit Determination team shadowing. Post-launch operations were nominal for IM-2 with precise delivery to the intended pre-departure orbit. This paper will focus on providing a complete picture of the Ground Navigation Team’s efforts from pre-launch analysis through mission operations and finalizing everything with a post-flight Best Estimate Trajectory.

Author(s): Jason Leonard, KinetX; Jeroen Geeraert, KinetX Inc.; Michael Salinas, KinetX Aerospace; Joel Fischetti, KinetX Aerospace; Kevin Pipich, KinetX, Inc.; Andrew Levine, KinetX Aerospace; Daniel Wibben, KinetX, Inc.; Donald Kuettel, Intuitive Machines; Shen Ge, Intuitive Machines; Samuel Welsh, Intuitive Machines; Shaun Stewart, Intuitive Machines; Daniel Brack, Intuitive

Machines; Mitra Farahmand, Intuitive Machines

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8:45 AM - 9:00 AM

**AAS 25-688**: The Scarabaeus open-source navigation tool: preliminary results and real measurements

Abstract: This paper introduces Scarabaeus, an open-source software package designed for interplanetary navigation. Developed with modularity and flexibility in mind, the software is capable of handling a wide range of mission scenarios, from interplanetary cruises to planetary and small-body flybys and rendezvous, with functionalities for orbit determination and navigation performance analysis. This work presents the software architecture and main capabilities along with preliminary analyses, showcasing real measurement processing capabilities with previously flown missions and the preliminary results from the first navigation training exercises. These demonstrate the tool's potential for contributing to the advancement of precise navigation technologies for deep space applications.

Author(s): Jay McMahon, University of Colorado Boulder, CCAR; Mattia Pugliatti, University of Colorado Boulder; Giovanni Fereoli, University of Colorado Boulder; Santhosh Pattamudu-Manoharan, University of Colorado Boulder; Zachary Ellis, University of Colorado Boulder; Annalise Cabra, University of Colorado Boulder; Mohamed Almashjari, UAE Space Agency; Mohamed Kuleib, United Arab Emirates Space Agency; Wendy Frank, Laboratory for Atmospheric and Space Physics; Jeremy Knittel, Laboratory for Atmospheric and Space Physics (LASP)

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9:00 AM - 9:15 AM

**AAS 25-699**: Unexpected Observations on the Accuracy of Linear Covariance Analysis and Track Association

Abstract: This paper presents two unexpected findings related to the accuracy of linear covariance propagation in astrodynamics. First, higher-dimensional state distributions experience a more rapid deviation from Gaussianity than lower dimensional marginal distributions; in particular, 6-dimensional states diverge from Gaussian behavior significantly faster than 2- or 3-dimensional states. This effect is quantified, and the paper provides information on its underlying causes. Second, it was found that increasing the initial covariance can, in some cases, reduce the non-Gaussianity of the propagated distribution. This counterintuitive behavior is examined in detail, and possible explanations are discussed.

Author(s): Alexandra Nelson, Utah State University; Jackson Kulik, Utah State University

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9:15 AM - 9:30 AM

**AAS 25-700**: ORBIT LINEAR COVARIANCE ANALYSIS IN A SEQUENTIAL FILTER ARCHITECTURE

Abstract: Linear covariance analysis is commonly used to estimate the state error-covariance response along a nominal trajectory. During linear covariance analysis, the computationally expensive integration of the non-linear orbit trajectory is performed once, with relevant information saved to allow efficient evaluation of the covariance response to various measurement schedules. We describe an implementation of linear covariance analysis in a sequential estimation framework which accommodates process noise and eliminates dependence on fit span. These characteristics differentiate the sequential algorithm from the commonly used batch-weighted least-squares approach and result in a more detailed covariance response at the expense of additional computation time.

Author(s): James Woodburn, AGI; Andrew Goetz, AGI

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9:30 AM - 9:45 AM

**AAS 25-709**: Cislunar Domain Multi-Target Search and Estimation Strategies After Long Sensor Shutoffs

Abstract: In this work, we extend a method for minimal-assumption probabilistic initial orbit

determination (IOD) and orbit determination (OD) to track multiple objects in cislunar space. This IOD framework involves kinematically fitting polynomials through thousands of measurements providing a full-position estimate. Then, an association is performed between observations and target estimates based on the Bayesian likelihood function. After the association step, a nonlinear filtering framework is used to reduce the covariance of the target estimates over time. This combined framework, along with autonomous search and recovery (ASR), is demonstrated for long sensor shutoff scenarios.

Author(s): Ishan Paranjape, Texas A&M University; Suman Chakravorty, Texas A&M University

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9:45 AM - 10:00 AM

**AAS 25-711**: Gaussian Mixture Square Root Filters for Cislunar Angles-Only Relative Orbit Determination

Abstract: Precise and robust relative orbit determination is critical for tasks such as autonomous spacecraft rendezvous, docking, and formation flying. Angles-only techniques, which rely on angular measurements from optical sensors, offer an alternative in scenarios where traditional range measurements are unavailable or impractical. However, challenges arise due to the nonlinear nature of line-of-sight measurements and complex dynamics in environments like the Earth-Moon three-body system. This work investigates the use of Square Root Unscented Kalman Filters (SRUKF) and their Gaussian Mixture extension (GMSRUKF) for angles-only relative orbit estimation in Near Rectilinear Halo Orbit regimes. The filters are evaluated across cases with varying initial uncertainty, measurement dropout, and relative orbit geometry.

Author(s): Andrea Lopez, University of Colorado Boulder; Jay McMahon, University of Colorado Boulder, CCAR; Hanspeter Schaub, University of Colorado

# Trajectory Design and Optimization IV

Tuesday, 08/12/25, 8:00 AM - 10:00 AM

Session Chair(s): Matthew Shaw (Lockheed Martin Corporation)

Room: Adrienne Salon

8:00 AM - 8:15 AM

**AAS 25-721**: Jacobian Coloring for Multi-Impulse Cislunar Trajectory Optimization

Abstract: This study introduces a multi-shooting, multi-impulse trajectory optimization framework for cislunar missions, combining complex-step sensitivity analysis, Jacobian coloring, and impulse regularization to enhance NLP solver efficiency. By exploiting sparsity patterns in Jacobian matrices, the method reduces computational costs during gradient calculations, achieving a 2× speedup compared to standard approaches. Applied to Earth-Moon southern halo orbit transfers, the framework optimizes an 18-node trajectory with a total Δv of 197.78 m/s, demonstrating improved convergence and precision in multi-body dynamical environments. The integration of these techniques enables faster, more robust optimization of complex space missions.

Author(s): Koya Yamamoto, Texas A&M University; Ehsan Taheri, Auburn University; John L. Junkins, Texas A&M University

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8:15 AM - 8:30 AM

**AAS 25-738**: NRHO Transfer for Crewed Mission with Continuous Launch Window and Free-return Trajectory in Off-nominal Case

Abstract: The construction of Gateway has been progressing on the Artemis Program. A crewed transfer mission to Gateway is also scheduled in the near future. In crewed missions, countermeasures against off-nominal events, such as launch delay and maneuver failure are an extremely important consideration. In this study, a recovery plan using the Perilune Rendezvous Method (PRM) is proposed. In this method, the launch window can be set up every day. Furthermore, in the case of maneuver failure, the spacecraft can return to the Earth or Gateway by extending the time of flight. This method can contribute the safe transfer to Gateway for astronauts.

Author(s): Junji Kikuchi, Japan Aerospace Exploration Agency (JAXA); Satoshi Ueda, Japan Aerospace Exploration Agency

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8:30 AM - 8:45 AM

**AAS 25-833**: Trajectory Correction Maneuver Placement Using Gradient-Based Global Optimization

Abstract: Trajectory correction maneuvers (TCMs) are necessary for most deep-space missions to correct for a wide variety of error sources encountered during flight. Common techniques for choosing the locations of these maneuvers are often based on a combination of Monte Carlo data and a mission designer's intuition. This paper presents a fast, analytic approach for optimizing TCM placement that accounts for navigation uncertainties, maneuver execution errors, and mission operational constraints. Linear-covariance-based models combined with gradient-based global optimization are shown to be able to optimize both the number and locations of TCMs along trajectories rapidly and reliably.

Author(s): Galen Savidge, Advanced Space; Sai Chikine, Advanced Space

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8:45 AM - 9:00 AM

**AAS 25-840**: Trajectory Planning and Optimization for a CubeSat Deployed from a LEO Carrier Satellite

Abstract: This work presents a maneuver planning and trajectory optimization framework for deploying a small “client” satellite from an on-orbit “carrier.” Starting from an idle orbit, the carrier maneuvers, deploys the client, and returns to its original orbit. After deployment, the client completes the maneuver to its mission orbit. A MATLAB-based planner analytically calculates maneuvers and their associated costs, and a GPOPS-II trajectory optimizer finds optimal maneuver/deployment sequences. These frameworks support a Multidisciplinary Design Optimization study regarding in-space assembly and the Orbital Locker project at the Massachusetts Institute of Technology.

Author(s): Garrett Siemen, Massachusetts Institute of Technology, US Space Force; Kerri Cahoy, Massachusetts Institute of Technology; James Dingley, Massachusetts Institute of Technology

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9:00 AM - 9:15 AM

**AAS 25-542**: Neural Approximators for Low-Thrust Trajectory Transfer Cost and Reachability

Abstract: This paper employs neural networks to predict fuel-optimality and trajectory feasibility, two critical metrics in low-thrust mission design. The applicability of the Scaling Law for approximating low-thrust trajectories is first demonstrated, followed by the construction of the largest open-access dataset using the proposed homotopy ray method. By transforming the data into a self-similar space, the networks generalize across arbitrary inclination angles and semi-major axes without retraining for new mission scenarios. The models achieve high accuracy and are further validated on a third-party dataset. They are also applied to a multi-flyby asteroid trajectory optimization problem, yielding the best-known solution.

Author(s): Zhong Zhang, Politecnico di Milano; Francesco Topputo, Politecnico di Milano

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9:15 AM - 9:30 AM

**AAS 25-751**: Comparison of Chemical and Stored-Energy Electric Propulsion for Responsive Spacecraft Maneuvers

Abstract: Stored-energy electric propulsion is a potential in-space propulsion architecture where electrical energy is stored over time onboard the spacecraft and then discharged through the electric propulsion system for small, responsive maneuvers (e.g., collision avoidance). The purpose of this paper is to quantify requirements on the propulsion and energy storage systems such that stored-energy electric propulsion would lead to a lower overall system mass fraction than that of a chemical system. We have developed an analytical formulation that identifies the critical energy density and optimal specific impulse for stored-energy electric propulsion to be viable for future mission designs with both single and multiple maneuvers.

Author(s): Oliver Jia-Richards, University of Michigan

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9:30 AM - 9:45 AM

**AAS 25-650**: TRAJECTORY CANDIDATES TO INCLINED SUN-EARTH L4

Abstract: This manuscript analyzes six trajectory candidates for a mission targeting the inclined Sun-Earth L4 point with $10^\circ$ and $14.5^\circ$ inclination about the ecliptic plane. The trajectory designs considered include chemical-based phasing trajectories, electric-based phasing trajectories, and gravity-assist trajectories utilizing multiple Earth and Mars flybys with both chemical and electric propulsion systems. The analysis assumes spacecraft masses of 3.5 tons for chemical propulsion and 1.5 tons for electric propulsion missions with a maximum thrust level of $200mN$.

Author(s): Jinsung Lee, Satellite Technology Research Center / Korea Advanced Institute of Science and Technology; Jaemyung Ahn, Korea Advanced Institute of Science and Technology; Daniel Scheeres, University of Colorado Boulder; Gunhee Yi, Korea Advanced Institute of Science and Technology; Sunghong Park, Korea Astronomy and Space Science Institute; Kyungsuk Cho, Korea

Astronomy and Space Science Institute; Arik Posner, NASA Headquarters / SMD / Heliophysics Division

9:45 AM - 10:00 AM

**AAS 25-695**: SMEX Mission Design: Stable, Eccentric Trajectory for Deep Space-Looking Ultraviolet Telescope

Abstract: A mission proposed against the 2025 NASA Astrophysics Small Explorer Announcement of Opportunity requires a stable, low-ΔV, high-Earth orbit trajectory design that enables long exposure ultraviolet imaging of distant galaxies with minimal interference from Earth. Using previous cislunar trajectory design approaches as inspiration, we propose a mission design that enters a stable, lunar resonant orbit using a direct lunar transfer and lunar flyby trajectory, resulting in a stable, lunar resonant orbit using less than 200 m/s of ΔV over two years of operational lifetime.

Author(s): Sydney Bonbrest, Trusted Space; Erin Griggs, Trusted Space, Inc.

# Cislunar Astrodynamics III

## Tuesday, 08/12/25, 8:00 AM - 10:00 AM

## Session Chair(s): Powtawche Valerino (NASA Marshall Space Flight Center)

## Room: Ballroom B

8:00 AM - 8:15 AM

**AAS 25-685**: Generating local linear operators in the circular restricted three-body problem

Abstract: This work introduces a methodology to define linear operators to locally approximate nonlinear systems. This is done by creating a linear mapping between basis functions in the state of the system, with basis functions in time, represented by Taylor series expansions. That way, it is possible to create not only local linear approximations of the differential equation of the system, but also its integrated linear state transition matrix in closed-form. Applications to orbital propagation and navigation in the circular restricted three-body problem are provided to show the performance and capabilities of the proposed technique.

Author(s): David Arnas, Universidad de Zaragoza

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8:15 AM - 8:30 AM

**AAS 25-732**: Transfers from NRHO to DRO Using Solar Sails at Varying Solar Angles

Abstract: The resurgence of lunar exploration necessitates the expansion of space situational awareness into cislunar space. Orbital debris generated in the cislunar environment often evolves along complex and chaotic trajectories. This research focuses on moving debris generated from the 9:2 Southern L2 NRHO out to the 70,000 km DRO using BCR4BP dynamics. Fitting a hypothetical debris removal spacecraft with a solar sail can greatly reduce the required delta-v. It was found that the delta-v for transfers can vary greatly based on the starting angle of the Sun with respect to the fixed Earth-Moon system, down to less than 300 m/s.

Author(s): Peter Lie, California Polytechnic State University Aerospace Engineering; Kira Abercromby, California Polytechnic State University

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8:30 AM - 8:45 AM

**AAS 25-750**: Orbital Transfer in the Cislunar Space Using Virtual Target with Adaptive Step Size Strategy

Abstract: This study investigates a discrete-time control strategy for orbital transfer between a halo orbit and a butterfly orbit in cislunar space, aiming to address the practical limitations of real-world spacecraft, including actuation and onboard computational constraints. A virtual target following approach is employed, where a proportional-derivative (PD) controller computes thrust commands to guide the spacecraft toward a moving target along the desired trajectory. A fixed sampling interval is initially used, but it results in terminal inaccuracy due to limited control authority. To improve convergence, an adaptive sampling scheme is introduced, yielding enhanced terminal accuracy and thrust feasibility under practical conditions.

Author(s): Priyanjali Shukla, Indian Institute of Science, Bangalore; Ishfaq Zahoor Bhat, Indian Institute of Science,Bangalore; Debasish Ghose, Indian Institute of Science

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8:45 AM - 9:00 AM

**AAS 25-753**: Performance Evaluation of Observer Spacecraft on Cislunar Orbits

Abstract: This paper investigates space-based observers tracking a target spacecraft in cislunar space,

with both on periodic orbits (e.g., halo or axial). Visibility is evaluated using two criteria: apparent magnitude—affected by distances and relative orientations of the Sun, observer, and target—and occlusion by the Sun, Earth, and Moon. A cannonball model estimates apparent magnitude. Simulations show that visibility duration varies with initial conditions. A strategy is proposed to optimize the observer's relative position to enhance visibility, supported by numerical results over different time horizons.

Author(s): Ishfaq Zahoor Bhat, Indian Institute of Science,Bangalore; Debasish Ghose, Indian Institute of Science

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9:00 AM - 9:15 AM

**AAS 25-754**: Adaptive Keep-Out Zones For Cislunar Orbital Debris Mitigation

Abstract: Our work investigates the formulation of adaptive keep-out zones to mitigate debris conjunction with a given cislunar orbit. We present a baseline deterministic strategy for defining the maximum radial distance from which a debris particle could impact the orbit within a given time horizon, and explore local variations in this distance along the orbit. We develop a probabilistic formulation of the keep-out zone based on the velocity profile of debris particles, leveraging the eigen-directions of the invariant manifolds along the orbit to develop a sampling distribution for debris velocities. The characteristics and relative efficacy of the two presented approaches are discussed.

Author(s): Arjun Chhabra, Princeton University; Amlan Sinha, Princeton University; Ryne Beeson, Princeton University

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9:15 AM - 9:30 AM

**AAS 25-758**: PRELIMINARY DESIGN OF THE LUNAR DATA NETWORK CONSTELLATION UNDER OPERATIONAL CONSIDERATIONS

Abstract: Intuitive Machines will launch and operate the first United States based Lunar Communication and Positioning, Navigation and Timing constellation starting in 2026. This paper describes the design considerations for the constellation's orbits under the performance requirements for coverage and quality of service. Additionally, the outbound Ballistic Lunar Transfer trajectory for the constellation's first satellite will be presented together with an overall Delta-V budget assessment.

Author(s): Daniel Brack, Intuitive Machines; Timothy Roorda, Intuitive Machines; Ravishankar Mathur, Intuitive Machines; Shaun Stewart, Intuitive Machines; Mark Hartigan, Georgia Institute of Technology; Juan Crenshaw, NASA; Michael Volle, a.i. solutions, Inc.; Grant Ryden, NASA

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9:30 AM - 9:45 AM

**AAS 25-667**: Dynamics-Informed Cislunar Orbit Transfer Design using Resonant Normal Form Representations

Abstract: The resonant normal form of the dynamics in the circular restricted three-body problem (CR3BP) pro-
vides an elegant way to characterize motion near libration points by providing some local orbital ele-
ment analogs in their vicinity. Making use of the orbital element-like properties of the resonant normal
form coordinates, this paper introduces a fuel-optimal two-burn orbit transfer design scheme for periodic
quasiperiodic tori and their corresponding stable and unstable manifolds without needing to precompute and store them as a locus of trajectories.

Author(s): Kaushik Rajendran, Purdue University; Kenshiro Oguri, Purdue University

9:45 AM - 10:00 AM

**AAS 25-875**: Initial Results on Navigation Performance of a Cislunar Constellation based on ER3BP

Abstract: In this paper, the performance of a GPS-like navigation constellation based on multi-revolution elliptic Halo (ME-Halo) orbits is presented. Designed in the elliptic restricted three-body problem (ER3BP), these artificial orbits account for Earth-Moon orbital eccentricity and require continuous low-thrust control within acceptable $\Delta V$ budgets. Constellation orbits are represented by a simplified trigonometric series, facilitating ephemeris broadcasts. Navigation performance is assessed through idealized pseudorange measurements processed by an Extended Kalman Filter (EKF), highlighting advantages of formulations in the Earth-Moon synodic frame. Preliminary Position Dilution of Precision (PDOP) results confirm favorable navigation performance, especially at distances further away from Earth.

Author(s): Filipe Senra, Embry-Riddle Aeronautical University; Chinmay Gaikwad, Embry Riddle Aeronautical University; Hao Peng, Embry-Riddle Aeronautical University

# Satellite Constellations and Formations I

## Tuesday, 08/12/25, 8:00 AM - 10:00 AM

## Session Chair(s): Iosto Fodde (Politecnico di Milano)

## Room: Dedham

8:00 AM - 8:15 AM

**AAS 25-619**: Efficient Commissioning of Cis-Lunar Constellations: The Role of the Lunar Staging Orbit (LSO)

Abstract: As humanities presence around the Moon expands, so too does the need for satellite infrastructure. This includes constellations of orbiting assets for communication, position, navigation, and timing, as well as space situational awareness. The proposed solution to this problem herein is an orbital transfer vehicle (OTV). An OTV thrives with delivering multiple payloads to multiple destinations that would otherwise require several individual launches and mission plans. This paper defines the lunar staging orbit (LSO) as a method for an OTV to efficiently commission a constellation of eight communication spacecraft into four separate, elliptical frozen lunar orbits.

Author(s): Benjamin Asher, Aegis Aerospace; Sarah Reese, Aegis Aerospace

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8:15 AM - 8:30 AM

**AAS 25-661**: Differential drag-based control of a leader-follower spacecraft formation via attitude maneuvers

Abstract: Small satellites like CubeSats lower mission costs and are usually deployed in constellations or formation flights. Often propulsionless, they rely on passive orbital control, mainly using differential drag achieved through attitude maneuvers. This work develops an attitude-based differential drag control algorithm for relative positioning between two small satellites in a virtual leader and real follower formation flight. We propose a controller designed with the integrator backstepping technique, which, in a closed loop with the rotational dynamics, results in the asymptotic stability of the closed-loop system equilibrium points. A numerical simulation assesses the effectiveness and accuracy of the control strategy.

Author(s): Alessio Bocci, UiT The Arctic University of Norway; Raymond Kristiansen, UiT The Arctic University of Norway; José Juan Corona-Sánchez, UiT The Arctic University of Norway

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8:30 AM - 8:45 AM

**AAS 25-687**: Autonomous Space-Based Wildfire Monitoring: Dynamic Scheduling of Maneuverable Satellites with CNN-Based Detection

Abstract: Wildfires are a potentially devastating natural process occurring more frequently in recent years, causing increased loss of life and destruction of infrastructure. Satellites in low Earth orbit can provide crucial information regarding active wildfires through onboard sensors, additionally providing the capability to detect wildfires by applying algorithms or artificial intelligence to acquired data. This paper combines a convolutional neural network and a reconfigurable Earth observation satellite scheduling problem to enable the autonomous detection of wildfires and subsequent scheduling to gather observations of the detected wildfires. The experimentation indicates that autonomous detection and scheduling are useful for obtaining information on wildfires.

Author(s): Brycen Pearl, West Virginia University; Joshua Warner, West Virginia University; Hang Woon Lee, West Virginia University

8:45 AM - 9:00 AM

**AAS 25-713**: A Geometrical Perspective of 2D Lattice Flower Constellations Using Linear Toroidal Maps

Abstract: This work focuses on the definition and study of satellite constellations from a geometrical perspective using linear toroidal representations in right ascension of the ascending node and mean anomaly. This enables the description of all possible uniform distributions of satellites, providing an alternative proof that 2D Lattice Flower Constellations generate every possible uniform distribution in this space of configuration. This result is used to identify constellation parameters directly from relative distributions. Additionally, since ground-tracks are linear trajectories in this representation, this enables the study of coverage directly on this map, allowing the reduction of computational time for coverage applications.

Author(s): Sarah DeVito, Purdue University; David Arnas, Universidad de Zaragoza

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9:00 AM - 9:15 AM

**AAS 25-773**: Heliocentric Mutually Orbiting Groups: Parametrization, Phasing Maneuvers, and Orbital Insertion

Abstract: This paper considers heliocentric Mutually Orbiting Groups (MOGs), a type of planar satellite formation used in distributed interplanetary communications and space-based gravitational wave detectors. We parametrize MOGs by their semi-major axis, eccentricity and number of satellites, and derive fuel-optimal maneuvers for phasing within them. We develop three orbital insertion strategies and analyze the tradeoffs between their $\Delta V$ costs and time of flight. Finally, we model deployment using performance estimates of the launch vehicle and satellites' propulsion systems. Our results demonstrate the feasibility of reconfigurable planar heliocentric MOGs of varying sizes centered anywhere between 0.5 and 5AU from the Sun.

Author(s): Jules Pénot, Massachusetts Institute of Technology; Hamsa Balakrishnan, Massachusetts Institute of Technology

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9:15 AM - 9:30 AM

**AAS 25-792**: Cislunar Constellation Design for Relayed Communications in a Competitive Environment

Abstract: The Cislunar environment will grow increasingly competitive in coming years, and the problem of ensuring secure, robust communication between ground stations and the Earth will become ever the more important. In this effort, competing communications constellations will be defined \textit{a priori}. A multi-objective genetic algorithm (MOGA) will be used to optimize a constellation of Cislunar satellites for the purpose of relaying communications from hypothetical lunar ground stations, with a particular focus on avoiding interception by a competing constellation.

Author(s): Jeremy Dening, University at Buffalo; Chris Nebelecky, University at Buffalo/CUBRC; Chase Murray, University at Buffalo; Dowon Lee, University at Buffalo

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9:30 AM - 9:45 AM

**AAS 25-811**: Mission Design and Flight Dynamics Operations for the Starling Swarm Technology Demonstration

Abstract: The NASA Starling mission, launched in July 2023, represents a significant advancement in demonstrating the capabilities of small satellite swarms to operate autonomously in low Earth orbit (LEO). Starling, which consists of four 6U CubeSats, has validated critical technologies necessary for future multi-satellite missions, including autonomous formation flying and optical-based navigation. The mission successfully maintained precise formations using GPS-based orbit determination and the

Starling Flight Dynamics System (FDS) to manage maneuvers and ensure operational success. This abstract provides a comprehensive overview of the Starling's flight dynamics, covering formation requirements, orbit determination, maneuver planning, and operational tools.

Author(s): Nahum Alem, NASA Ames Research Center; Ted Hendriks, Metis Technology Solutions; Jose Alvarellos, ASRC Federal/ NASA Ames Research Center; Paul Levinson-Muth, Millennium Engineering and Integration; Andres Dono, NASA Ames Research Center / Millennium Engineering and Integration

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9:45 AM - 10:00 AM

**AAS 25-817**: Analysis of Unknown Satellite Families for Large-Scale Constellations Using UMAP and HDBSCAN

Abstract: This study presents a framework that integrates advanced machine learning and orbital mechanics to classify and analyze satellite constellations using Two-Line Element (TLE) data. TLE data is transformed into 15-dimensional Reduced Orbital Parameter Vectors (ROPV) to capture dynamical orbit geometry. Uniform Manifold Approximation and Projection (UMAP) reduces the data to a lower-dimensional embedding, preserving local neighborhood relationships validated by the Trustworthiness index. Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN) identifies operational clusters validated by the the Density-Based Cluster Validation (DBCV) index. The methodology is demonstrated using case studies of the GPS, OneWeb, and Starlink satellite constellations.

Author(s): Caden Matthews, The University of Oklahoma; Diogo Merguizo Sanchez, The University of Oklahoma

# Machine Learning and Artificial Intelligence Applied to Spaceflight II

Tuesday, 08/12/25, 10:30 AM - 12:30 PM

Session Chair(s): Stephen West (Space Exploration Engineering)

Room: Dedham

10:30 AM - 10:45 AM

**AAS 25-637**: Enhancing Fault Resilience in RL-Based Satellite Autonomous Task Scheduling

Abstract: This paper investigates strategies to enhance the fault resilience of deep reinforcement learning (DRL) policies for agile Earth-observing satellite scheduling, with a focus on reaction wheel (RW) faults. These faults can trigger safe mode operations, leading to missed imaging opportunities. Prior work has demonstrated that policies trained exclusively under nominal conditions exhibit limited resilience to such faults. To address this limitation, this study examines training in mixed nominal and fault environments, augmenting the observation space with fault information, and applying recurrent neural networks (RNNs) to utilize temporal observation history.

Author(s): Yumeka Nagano, University of Colorado, Boulder; Hanspeter Schaub, University of Colorado

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10:45 AM - 11:00 AM

**AAS 25-646**: Adaptive Data-Driven Summary of Natural Motion in Cislunar Space

Abstract: This paper introduces an adaptive clustering framework for summarizing planar trajectories by their geometry in the Earth-Moon circular restricted three-body problem. First, a coarse grid of initial states is defined using the hypersurface formed by maxima in the curvature along a trajectory. Their trajectories are generated and clustered by geometry. New initial conditions are then sampled to balance 1) global exploration, using the curvature of the hypersurface, and 2) local exploitation, using the change in the total absolute curvature along trajectories and null cluster assignments. This process is repeated to adaptively generate a data-driven summary of a complex solution space.

Author(s): Miguel Rebelo, University of Colorado Boulder; Natasha Bosanac, University of Colorado, Boulder

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11:15 AM - 11:30 AM

**AAS 25-707**: Heading Estimation in Planetary Navigation Using Recurrent Neural Networks and Kalman Filtering

Abstract: Landing a spacecraft autonomously on a planetary surface is crucial for NASA's road map to the Moon and Mars. Heading estimation, fundamental to navigation becomes challenging with limited visibility, surface feature maps and noisy data. This paper introduces a novel method by leveraging machine learning techniques and Kalman filter for velocity- and acceleration-based heading estimation on planetary surface by utilizing real-world Blue Origin rocket IMU data. The goal is to improve traditional heading estimation and its reliability by using recurrent architecture of the Long Short-Term Memory (LSTM) networks, efficient for non-linear dynamic and complex systems.

Author(s): Khushboo Patel, Embry-Riddle Aeronautical University; Troy Henderson, Embry-Riddle Aeronautical University

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11:30 AM - 11:45 AM

**AAS 25-726**: Reinforcement Learning For Autonomous Strip Imaging Task Scheduling In Super-Agile Satellites

Abstract: This paper investigates the use of Deep Reinforcement Learning (DRL) to address the scheduling problem for strip imaging tasks in the context of Super-Agile Earth-Observing Satellites (SAEOS). Strip imaging enables continuous data collection along extended ground paths, making it essential for monitoring elongated features as well as broad areas decomposed into adjacent strips. The problem is formulated as a Partially Observable Markov Decision Process (POMDP), and a DRL-based approach is proposed to derive an on-board decision-making policy. The DRL agent learns scheduling strategies that fulfill user-defined objectives, optimize transitions between tasks, and manage onboard ressources while adapting to real-time mission dynamics.

Author(s): Anaïs Cheval, AVS Laboratory, University of Colorado Boulder; Hanspeter Schaub, University of Colorado

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11:45 AM - 12:00 PM

**AAS 25-749**: Multi Modal Deep Learning for Terrain Relative Navigation Near Lunar South Pole

Abstract: As human exploration of the Moon and Mars advances, Terrain Relative Navigation (TRN) is vital for precise, autonomous landings. However, shadowed regions like Shoemaker Crater pose challenges due to poor lighting and sensor noise. This work proposes a Cascading Multi-Modal CNN that fuses visual, depth, and thermal data—generated via thermophysical modeling from high-resolution lunar DTMs—to improve lander localization. Using hierarchical classification and joint regression, the model enhances resilience under difficult conditions. Results show that combining sensing modalities significantly outperforms single-sensor methods, especially in extreme environments like the lunar south pole.

Author(s): Nathan Nguyen, Rensselaer Polytechnic Institute; Ickbum Kim, Rensselaer Polytechnic Institute; Sandeep Singh, Rensselaer Polytechnic Institute

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12:00 PM - 12:15 PM

**AAS 25-781**: DreamSat-2.0: Towards a General Single-View Asteroid 3D Reconstruction

Abstract: To enhance asteroid exploration and autonomous spacecraft navigation, we introduce DreamSat-2.0, a pipeline that benchmarks three state-of-the-art 3D reconstruction models—Hunyuan-3D, Trellis-3D, and Ouroboros-3D—on custom spacecraft and asteroid datasets. Our systematic analysis, using 2D perceptual (image quality) and 3D geometric (shape accuracy) metrics, reveals that model performance is domain-dependent. While models produce higher-quality images of complex spacecraft, they achieve better geometric reconstructions for the simpler forms of asteroids. New benchmarks are established, with Hunyuan-3D achieving top perceptual scores on spacecraft but its best geometric accuracy on asteroids, marking a significant advance over our prior work.

Author(s): Santiago Díaz, Universidad Politécnica de Madrid; Xinghui Hu, Massachusetts Institute of Technology; Josiane Uwumukiza, Wellesley College; Giovanni Lavezzi, Massachusetts Institute of Technology; Victor Rodriguez-Fernandez, Universidad Politécnica de Madrid; Richard Linares, Massachusetts Institute of Technology

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12:15 PM - 12:30 PM

**AAS 25-897**: Action Chunking with Transformers for Image-Based Spacecraft Guidance and Control

Abstract: We present an imitation learning approach for spacecraft guidance, navigation, and control (GNC) that achieves high performance from limited data. Using only 100 expert demonstrations, equivalent to 6,300 environment interactions, our method, which implements Action Chunking with Transformers (ACT), learns a control policy that maps visual and state observations to thrust and torque commands. ACT generates smoother, more consistent trajectories than a meta-reinforcement learning (meta-RL) baseline trained with 40 million interactions. We evaluate ACT on a rendezvous task: in-orbit docking with the International Space Station (ISS). We show that our approach achieves

greater accuracy, smoother control, and greater sample efficiency.

Author(s): Alejandro Posadas-Nava, MIT ARCLab; Richard Linares, Massachusetts Institute of Technology; Roberto Furfaro, ; Andrea Scorsoglio, University of Arizona; Luca Ghilardi, University of Arizona

# Rendezvous, Relative Motion, and Proximity Operations II

Tuesday, 08/12/25, 10:30 AM - 12:30 PM

Session Chair(s): Matthew Givens (Advanced Space)

Room: Adrienne Salon

10:30 AM - 10:45 AM

**AAS 25-614**: Solving Optimal Feedback Control Problems for Spacecraft Rendezvous via Physics-Informed Neural Networks

Abstract: This study proposes a PINN-based algorithm for deriving optimal feedback controls in continuous-thrust spacecraft rendezvous problems. The proposed algorithm is built upon a generating function approach to define canonical transformations, where the main idea is to approximate these generating functions with neural networks. The PINN framework is utilized to satisfy the Hamilton-Jacobi partial differential equations associated with canonical transformations. Numerical simulations validate the effectiveness of the algorithm, demonstrating high accuracy in satisfying terminal constraints under various boundary conditions. These results confirm its capability to successfully derive optimal feedback controls on nonlinear systems.

Author(s): Kwanyeong Kim, Yonsei University; Chandeok Park, Yonsei University

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10:45 AM - 11:00 AM

**AAS 25-622**: Long-Duration Station-Keeping Strategy for Cislunar Spacecraft Formations

Abstract: This paper demonstrates a novel guidance and control strategy for cislunar near-rectilinear halo orbit formation-keeping applied to high-fidelity dynamics. Bounded relative motion is constructed about long-duration ephemeris trajectories with osculating invariant circles to form quasi-periodic relative orbits. State-of-the-art absolute control strategies are paired with a simple and effective relative control feedback law. Finally, a control barrier function is implemented to ensure recursively passively-safe bounded relative motion under feedback in the presence of possible missed maneuver events for the duration of the formation flight. The strategy is verified in high-fidelity simulation environments through Monte Carlo trials.

Author(s): Ethan Foss, Stanford University; Yuji Takubo, Stanford University; Simone D'Amico, Stanford University

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11:15 AM - 11:30 AM

**AAS 25-665**: Constant-Direction Optimal Low Thrust Control for Spacecraft Rendezvous Hovering Phases

Abstract: Optimal low-thrust control with a constant thrust direction presents a challenging problem in spacecraft proximity operations. This study considers a constant thrust direction defined in the radial-transverse-normal frame of the active spacecraft and formulates the optimal control problem using inertial dynamics. The energy-optimal control problem is addressed analytically, enabling efficient selection of a favorable constant direction that meets mission requirements. Based on the selected direction and the corresponding energy-optimal solution, the fuel-optimal control problem is solved efficiently as a nonlinear programming problem.

Author(s): Chuncheng Zhao, Politecnico di Milano; Michele Maestrini, Politecnico di Milano; Pierluigi Di Lizia, Politecnico di Milano

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11:30 AM - 11:45 AM

**AAS 25-690**: Spacecraft relative motion with respect to a spinning chief body frame

Abstract: Relative motion between spacecraft is often modeled in the Hill frame for its analytical simplicity and intuitive orbital geometry. However, this frame is not ideal for missions involving body-fixed constraints, such as collision avoidance with spinning targets. This paper presents analytical solutions for relative motion in the body frame of a rotating chief, deriving geometrically meaningful invariants that clarify trajectory behavior. The study considers bounded and drifting motion, assuming initial alignment with the Hill frame and constant rotation about each principal axis (radial, along-track, and cross-track). Resonant (spin rate equal to the orbital rate) and non-resonant rotation cases are analyzed.

Author(s): Afrah Ghedira, University of Colorado Boulder; Hanspeter Schaub, University of Colorado

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11:45 AM - 12:00 PM

**AAS 25-717**: Multi-Vehicle Guidance for Formation Flight on Libration Point Orbits

Abstract: The multiple spacecraft guidance problem for proximity flight in libration point orbit is considered. A nonlinear optimal control problem with continuous-time path constraints enforcing minimum separation between each spacecraft is formulated. The path constraints are enforced via an isoperimetric reformulation, and the problem is solved via a sequential convex programming. The proposed approach does not necessitate specific dynamic system structures to provide continuous-time guarantees for minimum separation within a fuel-optimal solution. The optimal control problem is deployed within a model predictive control scheme and demonstrated in the ephemeris model dynamics for rendezvous loitering and formation flying applications.

Author(s): Yuri Shimane, Georgia Institute of Technology; Purnanand Elango, University of Washington; Avishai Weiss, MERL

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12:00 PM - 12:15 PM

**AAS 25-724**: Optimal In-Space Servicing Assignments in Low Earth Orbit

Abstract: The purpose of this work is to propose a mathematical framework for identifying the optimal assignments available for multi-satellite servicing systems where a fleet of servicers has to rendezvous a receptor satellite constellation under a time a fuel constraint. To this end, this work leverages the natural differential dynamics that appear between servicers and receptors under orbital perturbations to identify both individual low fuel cost maneuvering strategies for each assignment, and a global optimum of the system using the Munkres algorithm. Servicing reachability, time and fuel budget constraint tradeoffs, sensitivity analysis and examples of application are also included.

Author(s): Elizabeth Howard, Purdue University; David Arnas, Universidad de Zaragoza

# Space Domain Awareness (SDA) and Space Surveillance I

Tuesday, 08/12/25, 10:30 AM - 12:30 PM

Session Chair(s): Casey Heidrich (University of Colorado Boulder)

Room: Ballroom B

10:30 AM - 10:45 AM

**AAS 25-501**: Optimized Radial Basis Functions with Adaptive Sampling Strategy for Orbital Uncertainty Propagation

Abstract: Orbital uncertainty propagation of Resident Space Objects (RSOs), a challenging area in astrodynamics, is central to applications such as Space Situational Awareness (SSA), mission design, and collision avoidance. In this context, the recently introduced uncertainty quantification method using Liouville's theorem and radial basis function approximation is advanced by the inclusion of optimization of approximation parameters and adaptive sampling to refine the probability density function (PDF) approximation. Leveraging the mesh-free adaptability of radial basis functions, the curse of dimensionality is mitigated by optimizing the shape parameter associated with each dimension. The method is applied for the uncertainty propagation of an Earth-bound satellite.

Author(s): Pugazhenthi Sivasankar, University of Central Florida

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10:45 AM - 11:00 AM

**AAS 25-559**: Gaussian Mixture Reachability Approximation Methods for Persistent Space Object Tracking

Abstract: Reachability over-approximation methods show promise for greatly improving sensor revisit times for spacecraft tracking at significantly reduced computational cost. In this work, we consider tracking and reacquisition problems for which the initial set is bounded by nonlinear admissible region constraints. A Gaussian mixture approximation is employed to transform the problem into a series of reachability sub-problems. The resulting reachable set over-approximation is combined into overall area coverage metrics. These metrics inform sensor revisit times for follow-on observation of uninitialized detections.

Author(s): Casey Heidrich, University of Colorado Boulder; Marcus Holzinger, University of Colorado Boulder

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11:00 AM - 11:15 AM

**AAS 25-572**: Visibility Informed Covariance Analysis for Cislunar Transfer Trajectories

Abstract: This work introduces a visibility-informed covariance analysis framework for assessing the observability of cislunar transfer trajectories from Earth-Moon Lagrange points (L3, L4, L5) to Earth orbit. By modeling spacecraft dynamics in the circular restricted three-body problem and simulating ground-based optical observations, this methodology evaluates how lunar phase and Earth's rotation affect visibility and state uncertainty. A grid of initial observation epochs is used to identify optimal windows for trajectory tracking. The results inform space domain awareness (SDA) planning and highlight the importance of trajectory selection and timing in ensuring observability, safety, and effective monitoring of cislunar missions.

Author(s): Evangelina Evans, University of Colorado at Boulder; Daniel Scheeres, University of Colorado Boulder; Marcus Holzinger, University of Colorado Boulder

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11:15 AM - 11:30 AM

**AAS 25-586**: Effects of a New Global Thermospheric Density Prediction Model on Satellite Orbit Propogations

Abstract: There is a critical need for accurate orbit predictions for conjunction assessment, but neutral mass atmospheric density fluctuations make this difficult. Yiran et al. recently proposed a global thermospheric density prediction framework that demonstrates high-accuracy density predictions. We implement this framework in orbit simulations under two space weather conditions to investigate its performance. We compare the results against standard empirical models and assess the proposed model's accuracy using known satellite orbits. We also evaluate the computational time performance of this model relative to current standard empirical models.

Author(s): Jacen Nisbet, Rutgers, the State University of New Jersey; Ruochen Wang, Rutgers University; Xiaoli Bai, Rutgers

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11:30 AM - 11:45 AM

**AAS 25-595**: Information-Theoretic Sensor Tasking for Optimal Space Object Custody

Abstract: Increased congestion across orbital regimes and the growing heterogeneity of sensor networks demand adaptive tasking strategies to ensure effective space domain awareness. This work presents an information-theoretic sensor scheduling method that maximizes the expected Kullback-Leibler divergence between prior and posterior state distributions. Measurements are evaluated at a common reference time to enable consistent prioritization across asynchronous observations and sensing modalities. The approach is demonstrated in two scenarios: single-target, single-observer in cislunar space and multitarget, multi-observer in low Earth orbit. These examples highlight the method's flexibility and scalability, making it well-suited for complex surveillance problems in increasingly dynamic and distributed space environments.

Author(s): Brighton Smith, Texas A&M University; Kyle DeMars, Texas A&M University

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11:45 AM - 12:00 PM

**AAS 25-624**: Cislunar Maneuvering Low-Thrust Spacecraft Tracking with Adaptive Optimal Control Estimation

Abstract: Tracking maneuvering cislunar spacecraft is a difficult task due to the highly nonlinear dynamical environment, great distances, and frequent observation gaps. If optimal control is assumed, it is possible to predict the future control of a spacecraft given observations of the start of a maneuver. This idea is applied to construct an optimal control interacting multiple model estimator (OCIMM) by including the costate as an estimation variable. The OCIMM can significantly reduce the mean absolute estimation error compared to a traditional IMM during observation gaps and periods of rapidly changing control through its ability to predict the future control.

Author(s): Darin Lin, Purdue University; Kenshiro Oguri, Purdue University

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12:00 PM - 12:15 PM

**AAS 25-626**: CONSTELLATION DESIGN AND TASKING VIA TWO STAGE OPTIMIZATION USING LINEAR PROGRAMMING AND GRADIENT DESCENT

Abstract: Expanding infrastructure and traffic in the region between the Earth and Moon necessitates comensurate commitments in monitoring and surveillance architectures. Space-based architectures are particularly useful as are not subject to atmospheric occlusion and are dynamic. However, optimizing a dynamic architecture presents challenges. This work presents a formulation for optimizing the placement of space assets via a two stage optimization scheme. The first stage leverages first order methods to optimize asset placements in a continuous space, while the second stage optimizes asset-to-

demand allocation via the well known assignment problem.

Author(s): Malav Patel, Georgia Institute of Technology; Koki Ho, Georgia Institute of Technology

12:15 PM - 12:30 PM

**AAS 25-640**: Fast Autonomous Lost-in-space Catalog-based Optical Navigation (FALCON)

Abstract: Space environment sustainability requires in-orbit monitoring of resident space objects while ensuring autonomous navigation for active satellites to support safe and reliable operations. This paper proposes an innovative space-based positioning, navigation, and monitoring system called Fast-Autonomous-Lost-in-space-Catalog-based-Optical-Navigation. Observer satellites obtain bearing angle measurements to visible targets, match them to an onboard catalog, and estimate their state via batch and sequential orbit determination. This enables GNSS independent lost-in-space orbit determination and simultaneous catalog refinement. The methodology is tested in the NASA-Starling mission scenario displaying promising matching and navigation performances under uncertainties, paving the way to new strategic capabilities for resilient optical navigation.

Author(s): Antonio Rizza, Stanford University; Justin Kruger, Space Rendezvous Laboratory, Stanford University; Mike Timmerman, Stanford University; Simone D'Amico, Stanford University

# Spacecraft Guidance, Navigation and Control (GNC) I

Tuesday, 08/12/25, 10:30 AM - 12:30 PM

Session Chair(s): Simone Servadio (Iowa State University)

Room: Duxbury

10:30 AM - 10:45 AM

**AAS 25-551**: Optimal asteroid selection in deep space navigation

Abstract: An optimization-based asteroid selection procedure for image-based deep space optical navigation is presented. The importance of observation geometry in beacon-based navigation is outlined and an optimization objective that captures this idea is presented. Then a genetic algorithm is used to select the optimal set of five to six asteroids that minimizes the predicted RMS spacecraft position error. An Earth-Mars interplanetary transfer is considered for illustration, whereby main belt asteroids are considered as navigation beacons. We present our optimal selection procedure as part of a full navigation filter design, which follows a triangulation procedure performed using the selected asteroids.

Author(s): Man Jun Koh, Korea Advanced Institute of Science and Technology; Natnael S. Zewge, Korea Advanced Institute of Science and Technology (KAIST); Hyochoong Bang, Korea Advanced Institute of Science and Technology (KAIST)

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10:45 AM - 11:00 AM

**AAS 25-573**: Sequential Sparse Regression and Model Predictive Control for Small Body Missions

Abstract: A sparse regression approach to identify dominant nonlinear dynamics governing spacecraft motion near asteroids is proposed. Unlike traditional orbit determination algorithms that rely on predefined force models and ground-based processing, this method adaptively selects the most influential terms from onboard measurements alone. The resulting nonlinear model is well-suited for efficient linearization inside of a model predictive controller due to the parsimonious structure of the reconstructed dynamics. This framework offers a computationally lightweight and accurate alternative for system identification in the context of autonomous station-keeping and control in highly perturbed and uncertain gravitational environments typically found in small-body missions.

Author(s): Kevin Lewis, Purdue University; Andrea Capannolo, Purdue University

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11:00 AM - 11:15 AM

**AAS 25-575**: Adaptive Sliding Mode Control Barrier Functions for Multiple State Constraints

Abstract: This paper presents a robust safety filter for spacecraft control systems with multiple state constraints, based on Adaptive Sliding Mode Control Barrier Functions (ASMCBFs).  In this research, we extend the framework by introducing a soft-min-based formulation that enables the system to satisfy multiple safety constraints without conflict, by smoothly approximating the minimum value of each individual CBF. The effectiveness of the proposed method is verified through two simulation scenarios, one involving multiple obstacle avoidance and another combining obstacle avoidance with a line-of-sight (LOS) cone constraint.

Author(s): Jihyeok Kim, Yonsei University; Hancheol Cho, Yonsei University

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11:15 AM - 11:30 AM

**AAS 25-613**: COASTING TIME DETERMINATION FOR ANTI-BALLISTIC MISSILE GUIDANCE DURING EXO-ATMOSPHERIC FLIGHT

Abstract: A coasting time determination algorithm is proposed during the midcourse guidance for high-altitude defense systems in multi-stage launch vehicles. The coasting phase, which occurs between stage separations and before the ignition of the next stage engine, provides additional degrees of freedom for midcourse guidance, contributing to improved target interception. The proposed algorithm calculates the optimal coasting time in three-dimensional space, incorporating the concept of zero-effort at burnout. The effectiveness of the algorithm is demonstrated through numerical simulation, offering a robust solution against the uncertainties in thrust magnitude in an exo-atmospheric interception scenario.

Author(s): Youngjun Lee, Seoul National University; Seokwon Lee, Chung-Ang University; Youdan Kim, Seoul National University

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11:30 AM - 11:45 AM

**AAS 25-660**: INS/LIDAR TIGHTLY COUPLED RELATIVE NAVIGATION DESIGN FOR COOPERATIVE SPACECRAFT MISSION

Abstract: In this paper, we propose a cooperative relative navigation algorithm using point cloud data from LiDAR sensors in various space mission scenarios. Assuming a cooperative scenario where the position and attitude of the target are obtained, we derive a distance measurement equation based on the point cloud geometry structure and propose a navigation algorithm that is robust to the measurement deteriorations. Based on this, a tightly coupled extended Kalman Filter incorporating the INS model is designed, which robustly combines the proposed measurement model in more sparse environments.

Author(s): Dongyeon Park, Konkuk University; Yeontak Song, Konkuk University; Hyunseok Choi, Konkuk University; Minwhan Kim, Konkuk University; Sangkyung Sung, Konkuk University

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11:45 AM - 12:00 PM

**AAS 25-841**: Linear Quadratic Gaussian Weighting Matrices for Output Covariance Assignment in Nonlinear Systems

Abstract: This paper solves the time-varying output covariance assignment problem under stochastic disturbances and measurement errors via a finite-horizon optimal control framework. A time-varying Linear Quadratic Gaussian (LQG)-equivalent controller enables such assignment despite model uncertainties, by means of tailored control weight sequences. A systematic algorithm computes these time-varying output weights, shown to be Lagrange multipliers for the covariance constraints. The approach is demonstrated on a short-horizon attitude control problem with strict covariance requirements. The numerical results highlight its potential for broader application to guidance and control tasks in nonlinear dynamical systems.

Author(s): Vishala Arya, University of Colorado Boulder

# Orbit Determination and Estimation IV

Tuesday, 08/12/25, 2:00 PM - 3:15 PM

Session Chair(s): Ryne Beeson (Princeton University)

Room: Dedham

2:00 PM - 2:15 PM

**AAS 25-744**: Stellar Occultations in Support of the LUMIO Orbit Determination

Abstract: The LUMIO mission, scheduled for launch in 2027, aims to observe lunar meteoroid impact flashes from a quasi-Halo orbit around the Earth-Moon L2 point. This study explores the use of stellar occultation measurements to enhance LUMIO's orbit determination accuracy, particularly during science observation windows when traditional optical measurements are less effective. By including simulated occultation events the spacecraft position uncertainty is significantly improved, particularly along the transverse and normal components, which were reduced by up to 53% during science cycles. This approach demonstrates the potential of stellar occultations to complement radiometric data, improving navigation accuracy for deep space missions.

Author(s): Davide Banzi, University of Bologna; Riccardo Lasagni Manghi, Alma Mater Studiorum - Università di Bologna; Marco Zannoni, University of Bologna

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2:15 PM - 2:30 PM

**AAS 25-746**: Direction of Motion-Based Optical Navigation Using Deep Learning: Methods and Results from Dawn at Vesta

Abstract: Direction of motion (DoM) observables, extracted from landmarks tracked across successive image pairs, provide valuable constraints for spacecraft orbit determination. Unlike state-of-the-art optical navigation techniques, this method is independent from a priori knowledge of the target's shape or landmark catalogs, making it suitable for uncharted bodies exploration. In this study, deep learning techniques are integrated into the navigation framework to detect and match keypoints across successive acquisitions, enabling DoM estimation. By using real data from NASA's Dawn mission at Vesta, we demonstrate that DL-derived DoM observables, when combined with radio-tracking data, can enhance trajectory reconstruction in scenarios with limited tracking coverage.

Author(s): Anna Maria Gargiulo, Sapienza University of Rome; Shyam Bhaskaran, Jet Propulsion Laboratory; Nicholas Bradley, Jet Propulsion Laboratory; Andrew Vaughan, NASA / Caltech JPL; Daniel Lubey, Jet Propulsion Laboratory, California Institute of Technology; Declan Mages, Jet Propulsion Laboratory; Simone Andolfo, Sapienza University of Rome; Tommaso Torrini, Sapienza University of Rome; Antonio Genova, Sapienza University of Rome

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2:30 PM - 2:45 PM

**AAS 25-805**: Covariance Prediction Validation and Perturbation Recovery for a Crewed Station in A Near Rectilinear Halo Orbit

Abstract: NASA's Gateway program will build a crew-tended station in a Near Rectilinear Halo Orbit (NRHO) by the Moon to support cislunar and heliocentric operations. The state estimate of the Gateway is processed in a linearized navigation filter. In this paper, linearized filter covariance predictions are compared against empirically sampled nonlinear state errors from a Monte Carlo analysis to validate covariance propagation methods. Through a mission timeline there are multiple Rendezvous, Proximity Operations, and Docking (RPOD) events which require a maximum state estimation error for success. This paper will also explore the recovery behavior of the state estimate after RPOD events.

Author(s): Clark Newman, a.i. solutions, Inc.; Diane Davis, NASA Johnson Space Center

2:45 PM - 3:00 PM

**AAS 25-818**: Fast Second-Order Covariance Propagation Based on the Canonical Polyadic Decomposition

Abstract: Covariance analysis provides an efficient method to propagate uncertainty in dynamical systems. Linear covariance propagation is used extensively in spacecraft navigation; however, in more nonlinear systems, the linear assumption provides an inadequate approximation for covariance propagation. Higher-order covariance propagation methods employing differential algebra or state transition tensors can be limited by their increased computational costs. We present a technique for second-order covariance propagation of an initial Gaussian distribution by employing the canonical polyadic decomposition of the moment tensors associated with a Gaussian distribution. This methodology significantly decreases the computational complexity of moment propagation.

Author(s): Braden Hastings, Utah State University; Jackson Kulik, Utah State University

3:00 PM - 3:15 PM

**AAS 25-836**: Quantifying Volume Changes from Covariance Propagation

Abstract: In a Hamiltonian dynamical system the volume associated with a highest density region containing a given probability mass is exactly conserved. Similarly, the volume of covariance ellipsoids are conserved under linear covariance propagation in these systems. In this work, we quantitatively explore the non-conservation of volume associated with ellipsoids arising from higher-order and unscented propagation of the covariance. Along the way, we compare the volume preservation of the unscented transform based on different whitening transformations and parameters. Finally, we note a novel family of conserved quantities related to the state transition tensors.

Author(s): Jackson Kulik, Utah State University; Keith LeGrand, Purdue University

# Space Situational Awareness, Conjunction Analysis, and Collision Avoidance I

## Tuesday, 08/12/25, 2:00 PM - 3:15 PM

## Session Chair(s): Brandon Jones (The University of Texas at Austin)

## Room: Adrienne Salon

2:00 PM - 2:15 PM

**AAS 25-807**: Monte Carlo Conjunction Analysis Using Importance Sampling and Taylor Polynomial Expansion

Abstract: This paper introduces a fast and accurate method for estimating satellite collision probabilities in rare-event scenarios. It combines multivariate Taylor polynomial expansions, generated using generalized dual numbers, with cross-entropy-based importance sampling to efficiently propagate uncertainties in orbital conjunctions. The surrogate models replace costly numerical integrations by approximating the nonlinear state evolution, while importance sampling biases the sample distribution toward high-risk regions, reducing computational cost. The method is tested across 53 real-world cases from NASA's CARA dataset, demonstrating significant gains in accuracy and efficiency over brute-force Monte Carlo, offering a scalable solution for high-fidelity conjunction risk assessment.

Author(s): Shripad Sant, University of Central Florida; Ryan Ketzner, University of Central Florida; Tarek Elgohary, University of Central Florida

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2:15 PM - 2:30 PM

**AAS 25-563**: Relative dynamic model selection to maximise evasive manoeuvres effectiveness

Abstract: This work examines how the relative dynamic model selection influences the performance of evasive manoeuvres in orbital pursuit–evasion games. Various linear, nonlinear, and perturbed models are assessed in terms of global and local fidelity, computational cost, observability, and suitability for real-time implementation based on State Dependent Riccati Equation control. Simulations within a zero-sum game framework reveal key trade-offs between modelling accuracy and onboard feasibility; responsiveness and robustness; observability and system complexity. Crucially, despite their lower theoretical efficiency, some models exhibit superior integration within the control architecture. Findings highlight that model selection critically shapes engagement outcomes in autonomous space defence scenarios.

Author(s): Filippo Mascellani, Politecnico di Milano; Laura Oliva, Politecnico di Milano; Michele Maestrini, Politecnico di Milano; Luigi De Maria, Politecnico di Milano

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2:30 PM - 2:45 PM

**AAS 25-633**: Multiple-Model Adaptive Estimation for Dynamic Parameters in LEO Population Evolutionary Models

Abstract: MOCAT-SSEM is a source-sink predictive model for population of objects in Low Earth Orbit (LEO). MOCAT-SSEM is faster than its Monte-Carlo counterpart but less accurate due to using parameterized constants for determining collisions between objects. Previous work applied Kalman Filtering to obtain new initial estimates for these parameters. Other methods such as estimation smoothing and multiple-model adaptive estimation (MMAE) provide more robust estimates. In this paper we apply estimation smoothing via Fraser-Potter (FP) and Rauch-Tung-Streibel (RTS) algorithms and MMAE to obtain the optimal initial guess for these collision parameters and provide comparison between the original and new SSEM model.

Author(s): Erin Ashley, Iowa State University; Simone Servadio, Iowa State University

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2:45 PM - 3:00 PM

**AAS 25-656**: Warning Time Optimisation of Low-Thrust Satellite Collision Avoidance through a Backward Sweep

Abstract: The increasing density of space debris necessitates frequent and efficient collision avoidance manoeuvres (CAMs) for operational satellites. This work presents a novel methodology that determines the latest possible thrust initiation time of low-thrust CAMs through a backward sweep, offering a balance in accuracy and computational efficiency, making it suitable for on-board usage. In particular, this work dynamically tracks the time of maximum danger as a function of the control input, and leverages this to find the latest possible time at which a thrust arc can be initiated while safely avoiding a collision between an operational satellite and a non-cooperative object.

Author(s): Frank de Veld, Inria, Université Côte d'Azur; Roberto Armellin, Te Punaha Atea - Space Institue, The University of Auckland; Zeno Pavanello, The University of Auckland

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3:00 PM - 3:15 PM

**AAS 25-666**: QUANTIFYING THE COLLISION RISK OF LARGE DEPLOYMENTS OF SPACE OBJECTS DURING THE COLA GAP

Abstract: Shortly after deployment, there exists a gap in the ability to protect both the newly deployed space object(s) and existent space objects from unintentional collisions. This work models this “COLA Gap” for multi-satellite, rideshare launches and attempts to quantify the collision risk associated with this gap that is unknowingly accepted by satellite operators. This work has found that roughly 20% of the total number of conjunctions remain unidentified due to this COLA Gap effect. Some conjunctions have a collision probability high enough to trigger remediation criteria while intra-launchmanifest conjunctions would also remain unidentified during real world operations.

Author(s): Andrew Abraham, The Aerospace Corporation

# Special Session on Modeling for Space Sustainability I

Tuesday, 08/12/25, 2:00 PM - 3:15 PM

Session Chair(s): Miles Lifson (The Aerospace Corporation)

Room: Ballroom B

2:00 PM - 2:15 PM

**AAS 25-503**: Virtual Environment for Space Traffic Analysis

Abstract: The near-Earth space environment will soon see a significant increase in resident space objects (RSOs). To ensure the sustainable growth of this future environment will require the development of right-of-way guidelines and other policies that minimize collision risk while not being overburdensome. The Virtual Environment for Space Traffic Analysis (VESTA) was developed to address this challenge, and is designed to explore future scenarios with many tens of thousands of objects, with varying maneuvering guidelines and tracking accuracies, and corresponding meta-data. This talk will cover the capabilities of VESTA and discuss preliminary results surrounding future anticipated collision risk, compliance, and more.

Author(s): Brian Gunter, Georgia Institute of Technology; Mariel Borowitz, Georgia Institute of Technology; Alaric Gregoire, Georgia Institute of Technology; Clifford Stueck, Georgia Institute of Technology; John Jozsa, Georgia Institute of Technology

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2:15 PM - 2:30 PM

**AAS 25-627**: The sustainability of the LEO orbit capacity via Risk-driven active debris removal

Abstract: The growing space debris population in Low Earth Orbit (LEO) jeopardizes orbital sustainability, necessitating efficient risk assessment and active debris removal (ADR). This study develops and optimizes a risk-driven ADR framework by evaluating risk indices to prioritize high-criticality debris. We assess existing models and introduce enhancements to improve predictive accuracy. Advanced Monte Carlo simulations using the Monte Carlo Orbital Capacity Assessment Tool (MOCAT) simulate 200-year orbital evolution under varied intervention scenarios. Results emphasize a refined risk index integrating static and dynamic parameters to rank debris effectively. Optimized target selection enhances space safety and ensures LEO's long-term viability.

Author(s): Yacob Biniam Medhin, Aerospace Engineering Department Iowa state University; Simone Servadio, Iowa State University

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2:30 PM - 2:45 PM

**AAS 25-704**: Leveraging Machine Learning for Modeling Space Object Density Evolution

Abstract: Anthropogenic space-object proliferation demands fast, high-fidelity forecasts of orbital congestion. We introduce MOCAT-ML, a machine-learning surrogate of the MIT Orbital Capacity Tool that couples convolutional and recurrent layers to model the spatiotemporal evolution of debris density. Trained on an extensive library of physics-based simulations, the network reproduces long-term trends and non-linear feedbacks while requiring minimal computational resources. This capability enables interactive scenario exploration, rapid policy evaluation, and operational decision-making, offering a practical path toward sustainable space-traffic management. This project code is available at https://github.com/ARCLab-MIT/mocat-ml.

Author(s): Sumiyajav Sarangerel, MIT ARCLab; Sergio Sanchez-Hurtado, Universidad Politécnica de Madrid; Enrico Zucchelli, Massachusetts Institute of Technology; Victor Rodriguez-Fernandez, Universidad Politécnica de Madrid (UPM); Giovanni Lavezzi, Massachusetts Institute of Technology;

Di Wu, Embry-Riddle Aeronautical University; Richard Linares, Massachusetts Institute of Technology

2:45 PM - 3:00 PM

**AAS 25-741**: Enhancing Space Debris Integrated Assessment Models to support transdisciplinary policy modelling in LEO

Abstract: This paper presents advancements to an integrated assessment model linking orbital debris dynamics with economic decision-making, with the goal of informing the development of effective, incentive-based space sustainability strategies. The physical model, MOCAT-SSEM, now incorporates eccentricity to more accurately capture orbital evolution and fragmentations, particularly for non-circular debris and rocket bodies. The economic module, OPUS, can now model launch demand for multiple satellite types with distinct physical and financial profiles. Together, these enhancements enable better simulations of launch behaviour, collision risk, and policy outcomes. Early results show these improvements enhance model fidelity.

Author(s): Indigo Brownhall, University College London; Giovanni Lavezzi, Massachusetts Institute of Technology; Mark Moretto, North Carolina State University; Daniel Kaffine, University of Colorado Boulder; Miles Lifson, The Aerospace Corporation; Akhil Rao, Middlebury College; Michele Marino, University College London (UCL); Richard Linares, Massachusetts Institute of Technology; Santosh Bhattarai, University College London (UCL)

3:00 PM - 3:15 PM

**AAS 25-793**: A Data-Driven Approach to Estimate LEO Orbit Capacity Models

Abstract: Utilizing the Sparse Identification of Nonlinear Dynamics algorithm (SINDy) and Long Short-Term Memory Recurrent Neural Networks (LSTM), the population of resident space objects, divided into Active, Derelict, and Debris, in LEO can be accurately modeled to predict future satellite and debris propagation. This proposed approach makes use of a data set coming from a computational expensive high-fidelity model, the MOCAT-MC, to provide a light low-fidelity counterpart that provides accurate forecasting in a small time frame.

Author(s): Braden Stock, Iowa State University; Maddox McCarthy, Iowa State University; Simone Servadio, Iowa State University

# Asteroid and Interplanetary Mission Design II

Tuesday, 08/12/25, 2:00 PM - 3:15 PM

Session Chair(s): Rohan Sood (The University of Alabama)

Room: Duxbury

2:00 PM - 2:15 PM

**AAS 25-608**: Nuclear Thrust Sheet Spacecraft Design and Mission Optimization for Deep Space Exploration

Abstract: The Thin-Film Nuclear Engine Rocket (TFINER) utilizes ~10micron thick sheets of radioisotope fuel for propulsion. A substrate placed on one side selectively absorbs the alpha decay emissions to generate thrust with potential final velocities of ~100km/s or more. The physics driving the optimization of the sheet layers along with the spacecraft design are described. The resulting system performance is quantified and compared against other technologies. Mission design and planning aspects (rendezvous targeting, communications, etc.) are discussed. Finally, requirements for missions such as a rendezvous with the interstellar object ‘Oumuamua are reviewed including optimizations that leverage the Oberth maneuver.

Author(s): Ian Claypool, Draper; James Bickford, Draper; Thomas Palazzo, Draper; Brian Casel, Draper; Ronald McNabb, Draper

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2:15 PM - 2:30 PM

**AAS 25-632**: BRANCH MERGE AND BOUND ALGORITHM FOR INTERPLANETARY MISSION DESIGN

Abstract: A new framework is presented for automating the search for interplanetary multiple gravity assist trajectories with deep space maneuvers. Branching is achieved with a global reachability analysis for low $\Delta v$ options following a flyby. Merging
the arrival trajectories at each flyby, and bounding the results with Pareto sorts leads to a dramatic reduction in the search space. The new merging step exploits well-known principles of dynamic programming and allows for efficient pruning of non-optimal trajectories. The process is automated and returns globally optimal Pareto fronts of trajectories between any two planets.

Author(s): William Brandenburg, The University of Texas at Austin Department of Aerospace Engineering and Engineering Mechanics; Ryan Russell, The University of Texas at Austin; Matthew Shaw, Lockheed Martin Corporation

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2:30 PM - 2:45 PM

**AAS 25-645**: Interplanetary Missions Enabled by Advanced Electrospray Propulsion

Abstract: Missions returning to the Moon provide opportunities for interplanetary exploration from vehicles deployed along an Earth-Moon transfer trajectory. Using an advanced electrospray propulsion system on a small spacecraft bus, we present a set of four rideshare spacecraft trajectories deployed from a single primary Earth to Moon transfer. The propulsion system and core spacecraft features are introduced in this paper. The spacecraft proceed to Mars, Venus, and a pair of asteroid encounters, all starting from a single rideshare opportunity. The trajectory designs are all presented with maneuver profiles and associated data.

Author(s): Darrel Conway, Thinking Systems, Inc.; Darren Garber, NXTRAC

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2:45 PM - 3:00 PM

**AAS 25-668**: Uranus Orbiter and Probe: System Capture and Orbital Operations

Abstract: The 2022 Planetary Science Decadal Survey: Origins, Worlds, and Life, recommended the Uranus Orbiter and Probe concept to be the next Planetary flagship-class mission. The characteristics of the Uranus system, and its distance from Earth, present unique challenges in terms of orbital capture, atmospheric probe delivery, and system science orbiter activities. This paper presents a Uranus system capture trade study, which poses the end-to-end capture, probe delivery, and tour initialization sequence as a multi-agent optimization problem. Additionally, the accommodations required to establish a successful science tour concept of operations using an RTG-powered spacecraft at 20 au are discussed.

Author(s): Donald Ellison, The Johns Hopkins University Applied Physics Laboratory; Noble Hatten, Johns Hopkins University Applied Physics Laboratory; Jacob Englander, Johns Hopkins Applied Physics Laboratory; Zachary Putnam, Johns Hopkins Applied Physics Laboratory

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3:00 PM - 3:15 PM

**AAS 25-669**: Robust Access to Uranus via Solar Electric Propulsion

Abstract: The 2022 Planetary Science Decadal Survey, Oceans, Worlds, and Life (OWL), recommended a Uranus Orbiter and Probe (UOP) as the next Planetary flagship-class mission. However, OWL called for a 2031 launch and a Jupiter gravity assist, which are not compatible with realistic expectations of when UOP might be funded. In this work, we present a means of reaching Uranus in any launch year by use of a solar electric propulsion transfer stage followed by chemical capture. The design presented here can be implemented with today's technology and includes a detailed sensitivity analysis.

Author(s): Jacob Englander, Johns Hopkins Applied Physics Laboratory; Donald Ellison, The Johns Hopkins University Applied Physics Laboratory; Noble Hatten, Johns Hopkins University Applied Physics Laboratory

# Space Situational Awareness, Conjunction Analysis, and Collision Avoidance II

Tuesday, 08/12/25, 3:45 PM - 5:15 PM

Session Chair(s): Brandon Jones (The University of Texas at Austin)

Room: Adrienne Salon

3:45 PM - 4:00 PM

**AAS 25-812**: Different Operational Categories of Covariance for Satellite Conjunction Assessment

Abstract: Modern conjunction assessment techniques depend heavily on the calculation of probabilities of collision, which in turn is dependent on the positional and velocity covariance information provided with ephemeris data. Traditionally, covariances provided by satellite operators for conjunction screening by other operators have only included known committed maneuver information. However, as more operators adopt rapid maneuver cadences, there is a growing need to provide covariances which statistically incorporate potential future maneuvers. Herein, we will discuss techniques to incorporate potential maneuvers, assess the realism of augmented covariances, and compare common conjunction assessment metrics from the various techniques presented.

Author(s): William Hudnut, Iridium Communications, Inc.; Ryan Shepperd, Iridium

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4:00 PM - 4:15 PM

**AAS 25-832**: A Novel Orbit-bundle Based Approach Toward Conjunction Assessment in Cislunar Space

Abstract: The current work offers a novel orbit-bundle based approach towards conjunction assessment in cislunar space. Existing literature is devoted towards extending the best practices of collision avoidance in Low Earth Orbits to deep space using the NASA MADCAP process. However, higher uncertainties in the accurate determination of Collision Probability, and the chaotic nature of the cislunar regime, where executing a single Collision Avoidance Manoeuver (CAM) might not be sufficient, suggest that newer approaches to conjunction assessment, tailored towards the cislunar regime, are needed. The current work is a contribution in that direction.

Author(s): Ishfaq Zahoor Bhat, Indian Institute of Science,Bangalore; Madhav Nakani, IISC; Debasish Ghose, Indian Institute of Science

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4:15 PM - 4:30 PM

**AAS 25-545**: Demonstration of an Efficient Method for Uncued Ground-Based Passive Optical LEO Object Detection

Abstract: The rapid increase in number of objects in low-Earth orbit (LEO) presents new challenges to space domain awareness (SDA). We present a LEO space surveillance concept consisting of a network of low-cost, commercial-off-the-shelf (COTS) optical cameras to provide cost-efficient LEO SDA solutions. To push the sensitivity of the system, we have developed an efficient track-before-detect technique that can rapidly generate uncued detections of objects fainter than the single-frame sensitivity limit. We present the development and on-sky demonstration of a single-aperture prototype, demonstrating the LEO surveillance capabilities of low-cost cameras when coupled with advanced and efficient detection algorithms.

Author(s): Tam Nguyen, University of Maryland; Roman Geykhman, MIT Lincoln Laboratory; David Ewing, MIT Lincoln Laboratory; Luis Kimzal, MIT Lincoln Laboratory; Jonathan Birge, MIT Lincoln Laboratory

4:30 PM - 4:45 PM

**AAS 25-556**: Advancing Star Elimination Methods for Improved Resident Space Object Detection in Space Situational Awareness

Abstract: This paper examines the process of identifying RSOs in optical imagery, focusing specifically on a proposed method for removing stars from the data to enable the accurate linking of RSO-related data points across frames. This is to be accomplished through star catalog comparison. The method holds the potential for estimating an expected value of objects in a frame, which builds groundwork to automated threshold setting within the algorithm. The goal of this work is the refinement of the method, an exploration on the required threshold definition, and ultimately the verification of the star catalog comparison method for various image collects.

Author(s): Evan Pavetto-Stewart, Embry-Riddle Aeronautical University; Alan Lovell, Embry-Riddle Aeronautical University; Carolin Sophie Pech, Embry-Riddle Aeronautical University

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4:45 PM - 5:00 PM

**AAS 25-557**: A Refined Approach to Resident Space Object Identification in Unresolved Optical Space Imagery via Streak Detection

Abstract: To identify resident space objects (RSOs) in optical space imagery, the primary issue is distinguishing RSOs from stars and other objects (or aberrations) that may be present. For this purpose, an algorithm was developed in previous work that can distinguish RSOs from other objects using a streak detection method. In this paper, the authors present further refinements to this algorithm with the aim of making it more accurate and robust for a wider range of input images. Results generated by the algorithm are displayed that demonstrate the improvements made to the code.

Author(s): Carolin Sophie Pech, Embry-Riddle Aeronautical University; Alan Lovell, Embry-Riddle Aeronautical University; Evan Pavetto-Stewart, Embry-Riddle Aeronautical University

# Special Session on Modeling for Space Sustainability II

Tuesday, 08/12/25, 3:45 PM - 5:15 PM

Session Chair(s): Timothy Murphy (The Aerospace Corporation)

Room: Ballroom B

3:45 PM - 4:00 PM

**AAS 25-521**: Initial Verification and Validation of Space Environment Pathway Reference Scenarios

Abstract: The Aerospace Corporation and academic partners have developed a set of six reference scenarios for the future space environment, known as the Space Environment Pathways (SEPs). Each scenario contains documented assumptions and publicly available launch inputs to support modeling. Here, the SEPs are used as inputs to several space environment models and modeling approaches. These include a Monte Carlo Evolutionary Space Environment Model (MOCAT-MC), a source-sink model (MOCAT-SSEM), and two space traffic coordination simulators (VESTA AND SSTME). This effort is intended to test usability of the SEPs, to verify all necessary information is provided, and to compare model outputs.

Author(s): Miles Lifson, The Aerospace Corporation; Santosh Bhattarai, University College London (UCL); Indigo Brownhall, University College London; Petra Chow, The Aerospace Corporation; Brian Gunter, Georgia Institute of Technology; John Jozsa, Georgia Institute of Technology; Giovanni Lavezzi, Massachusetts Institute of Technology; Brendan Mindiak, The Aerospace Corporation; Timothy Murphy, The Aerospace Corporation; Clifford Stueck, Georgia Institute of Technology; Greg Wilburn, The Aerospace Corporation; Enrico Zucchelli, Massachusetts Institute of Technology

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4:00 PM - 4:15 PM

**AAS 25-567**: Monte Carlo Analysis of Servicing and Debris Removal in LEO

Abstract: This paper highlights that different technologies and strategies for active debris removal (ADR) are likely to lead to different performance for the overall population of space objects in LEO. Using a 100-year time horizon and incorporating detailed representations of current and planned satellite constellations, this study uniquely evaluates ADR strategies to provide insights for sustainable space operations. This analysis is enabled through the MIT Orbital Capacity Analysis Tool - Monte Carlo (MOCAT-MC), an open-source simulation framework modeling ADR missions and servicing-related collision risks. The results demonstrate potential informed ADR policies to reduce debris proliferation and enhance space sustainability.

Author(s): Seth Cornelius, Space Enabled Research Group, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology; Jacqueline Smith, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology,; Daniel Jang, Massachusetts Institute of Technology - Lincoln Laboratory; Enrico Zucchelli, Massachusetts Institute of Technology; Di Wu, Embry-Riddle Aeronautical University; Giovanni Lavezzi, Massachusetts Institute of Technology; Scott Dorrington, Industrial Sciences Group ; Richard Linares, Massachusetts Institute of Technology; Danielle Wood, Massachusetts Institute of Technology

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4:15 PM - 4:30 PM

**AAS 25-618**: Economic Impact and Feasibility of Active Debris Removal: Initial Results from the OPUS Integrated Assessment Model

Abstract: The past decades have seen a substantial increase of satellites in LEO, creating potential for exponential debris growth without direct action. This paper investigates how active debris removal (ADR) affects space sustainability and the space economy. Orbital Propagators Unified with Economic

Systems (OPUS) integrated assessment model augmented with ADR simulated the space environment and economic actors, applying economic and sustainability metrics inclusive of policy considerations. Cost and funding models are investigated. ADR is shown to induce a lower replacement launch rate than removal rate. ADR improves space sustainability but must be cheaper than current estimates to improve LEO's economic welfare.

Author(s): Sammie Graff, North Carolina State University; Miles Lifson, The Aerospace Corporation; Mark Moretto, North Carolina State University; Indigo Brownhall, University College London; Zack Donohew, University of Colorado Boulder; Ian Christensen, Secure World Foundation; Daniel Kaffine, University of Colorado Boulder; Joey Kilpatrick, University of Colorado Boulder

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4:30 PM - 4:45 PM

**AAS 25-878**: Reinforcement Learning for Sustainable Launching in the LEO Environment

Abstract: Can AI/ML method find a better launching pattern with a long-time horizon space sustainability in mind? We are proposing the first RL environment for studying sustainable space development. So far we have shown that it is possible to introduce learning-based method to control chaotic space environment for sustainable development through training PPO agent. We are enhancing the system by adjusting key parameters and refining the AI/ML agent's decision-making process through both hyperparameter tuning and infrastructure adjusting.

Author(s): Di Wu, Embry-Riddle Aeronautical University; Charles Harmon, Massachusetts Institute of Technology; Enrico Zucchelli, Massachusetts Institute of Technology; Peng Mun Siew, Massachusetts Institute of Technology; Richard Linares, Massachusetts Institute of Technology

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4:45 PM - 5:00 PM

**AAS 25-892**: Integrating Policy, Modeling, and Socioeconomic Factors in MOCAT-SSEM for LEO Environmental Sustainability

Abstract: While space debris mitigation efforts have improved, they remain insufficient to prevent further debris accumulation. To address this challenge, the authors propose a novel framework combining the MIT Orbital Capacity Assessment Tool Source-Sink Evolutionary Model (MOCAT-SSEM) with the Environment-Vulnerability-Decision-Technology (EVDT) framework. MOCAT-SSEM characterizes the low-Earth orbit environment, whereas EVDT incorporates socioeconomic impacts of orbital congestion and simulates feedback control actions and logic tied to policy and active debris removal. This integrated approach aims to provide an open-source model that allows users to input different policy interventions and understand the impact of those interventions on satellite behavior.

Author(s): Maya Harris, Massachusetts Institute of Technology; Isabella Vesely, Massachusetts Institute of Technology; Giovanni Lavezzi, Massachusetts Institute of Technology; Richard Linares, Massachusetts Institute of Technology

# Dynamical Systems Theory Applied to Space Flight Problems II

Tuesday, 08/12/25, 3:45 PM - 5:15 PM

Session Chair(s): Rodney L. Anderson (Jet Propulsion Laboratory/Caltech)

Room: Duxbury

3:45 PM - 4:00 PM

**AAS 25-823**: Quadrature, Statistical Metrics, and Goodness-of-Fit for Folded, Gauss, and von Mises Product Distributions

Abstract: Normal form theory can produce local orbital elements at special solutions of the circular restricted three-body problem for the purpose of local dynamical systems analysis and development of new space situational awareness methods. The new orbital element set, an action-angle coordinate system, and the local stability structure of the special solutions gives rise to a natural definition of a generalized Bernoulli distribution, that is a mixture of a product distribution consisting of Folded, Gaussian, and von Mises components. This paper focuses on the definition, theory, and demonstration of quadrature approaches and goodness-of-fit metrics and criteria for this new distribution class.

Author(s): Ryne Beeson, Princeton University

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4:00 PM - 4:15 PM

**AAS 25-846**: Numerical Jordan Form Construction and Applications to Astrodynamics

Abstract: Increasingly, the Circular Restricted Three Body Problem (CR3BP) is employed as a useful medium-fidelity dynamical model for multi-body mission design, particularly within the cislunar region. The CR3BP is a time-autonomous, Hamiltonian system when formulated in a rotating frame, and the monodromy matrix associated with CR3BP periodic orbits is defective. In this investigation, approaches for numerically producing the Jordan form of a CR3BP monodromy matrix are examined and applied to the analysis of standard and bifurcating orbits within the CR3BP.

Author(s): Dale Williams, Purdue University; Andrew Langford, Purdue University; Kathleen C. Howell, Purdue University

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4:15 PM - 4:30 PM

**AAS 25-866**: Local Normal Form Analysis of Hamiltonian Periodic Orbits under First-Order Perturbations

Abstract: This paper presents an application of Hamiltonian Perturbation Theory (HPT) to analyze the persistence of periodic orbits in globally non-integrable dynamical systems under external perturbations. By leveraging the local integrability of the tangent bundle around periodic orbits, a systematic framework is developed to extend classical HPT techniques beyond their traditional domain of globally integrable systems. The approach applies Jordan Normal Form decompositions of monodromy matrices to construct canonical coordinate systems where perturbation effects can be analyzed using classical techniques. The methodology is demonstrated through detailed analysis of pitchfork bifurcations under symmetry-breaking perturbations, revealing how the canonical transformation framework predicts the emergence of cusp catastrophe structures.

Author(s): Andrew Langford, Purdue University; Kathleen C. Howell, Purdue University

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4:30 PM - 4:45 PM

**AAS 25-873**: An Ephemeris Caching System Enabling Multibody Dynamics Capabilities in Systems Tool Kit

Abstract: The Ansys Systems Tool Kit requires high-fidelity ephemerides to construct its Solar System environment. For this, the SPICE and DE systems produced by the Navigation and Ancillary Information Facility (NAIF) and Solar System Dynamics (SSD) groups, respectively, are leveraged. This paper explores a bespoke system implemented in the STK codebase that functions to cache and serve data from the JPL ephemerides. These data are made available to various algorithms within a multibody dynamics simulation architecture. Beyond providing the motivation for such a mechanism, an in-depth examination of the caching system along with characterizations of its performance and validity are offered.

Author(s): Cody Short, AGI; Mari Kinzly, AGI; James Woodburn, AGI; Marisa Exnicious, Ansys Government Initiatives (AGI); Linda Kay-Bunnell, AGI, an Ansys Company

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4:45 PM - 5:00 PM

**AAS 25-546**: Rapid Computation and Identification of Rotational Invariant Curves On the Keplerian Map

Abstract: Chaotic trajectories are often overlooked in the study of cislunar motion due to their ergodic behaviour. However, the long-term evolution of chaotic trajectories is restricted by dynamical barriers. These barriers correspond to quasi-periodic trajectories, which shield neighbourhoods of the cislunar environment. We rapidly compute invariant curves tied to the quasi-periodic trajectories with an analytical approximation of a periapsis map, the Keplerian map. For specified energies, we identify barriers that bound the Earth-centric radii of chaotic trajectories. Chaotic trajectories propagated using a point-mass ephemeris model are then used to validate the invariant curves as barriers to transport.

Author(s): Oliver Boodram, University of Colorado Boulder; Damennick Henry, University of Colorado at Boulder; Daniel Scheeres, University of Colorado Boulder

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5:00 PM - 5:15 PM

**AAS 25-574**: On the Concept of Conditional Barrier Structures in the Circular Restricted Three-Body Problem

Abstract: The zero velocity curve and the zero velocity surface are examples of barrier structures that place bounds on the motion and govern transport phenomena at the very fundamental level. Our recent work deduced that states on the barrier structures separating the regions of possible and impossible motion globally minimize an energy function. The present paper explores the role of local energy minimizers in the circular restricted three-body problem. It is demonstrated that structures locally minimizing the energy function also play the role of barriers within a conditioned range that the local minimizer is regarded as the global minimizer.

Author(s): Kenta Oshima, Suwa University of Science

# Orbital Dynamics, Perturbations, and Stability II

Tuesday, 08/12/25, 3:45 PM - 5:15 PM

Session Chair(s): Matthew Givens (Advanced Space)

Room: Dedham

3:45 PM - 4:00 PM

**AAS 25-825**: Changing the Independent Variable of State Transition Matrices

Abstract: The state transition matrix (STM) is ubiquitous in space flight mechanics. Applications include navigation, guidance, trajectory design, and relative motion. Time regularization is commonly used to reduce nonlinearity of the state evolution. However, a regularized STM computed with the new independent time-like variable is fundamentally different than the time-based STM. While regularization benefits the dynamics implementation, many applications require the time-based STM. Here, a mapping is derived to transform a regularized STM and its second-order extension to their time-based counterparts. The mapping is analytic and requires only the equations of motion and the regularized STM and its second order extension.

Author(s): James Leith, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin

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4:15 PM - 4:30 PM

**AAS 25-679**: Characterizing the Influence of Stochastic Forces on the Dynamics around Non-spherical Bodies.

Abstract: Within astrodynamics and celestial mechanics there are various systems which cannot be modelled by just a purely deterministic system but have to include stochastic processes. These can be, for example, movements of spacecrafts through small space debris clouds or the dynamics of moonlets within rings. This work investigates how the dynamics in complex environments including various types of perturbations and stochastic processes can be characterised using novel methods based on polynomial chaos and stochastic dynamics indicators. A specifc use case of the motion around non-spherical bodies is used to test this new methodology.

Author(s): Iosto Fodde, Politecnico di Milano; Lucia Francesca Civati, Politecnico di Milano; Fabio Ferrari, University of Bern

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4:30 PM - 4:45 PM

**AAS 25-693**: On the resonant dynamics of particles in non-symmetric potentials

Abstract: The dynamics around irregularly shaped asteroids often exhibit chaotic behavior, yet stable regions can exist where periodic or resonant motion occurs, shaping the long-term evolution of ejecta, dust, or debris. This work focuses on the role of the asteroid’s non-symmetric gravitational potential, with an application to the Didymos primary. It examines capture mechanisms driven by perturbations relevant to particles, such as solar radiation pressure and dissipative collisions, through the use of resonance analysis, Poincaré maps, Hamiltonian models, and dynamical indicators, to explore the conditions under which transient or long-term trapping can occur.

Author(s): Lucia Francesca Civati, Politecnico di Milano; Iosto Fodde, Politecnico di Milano; Fabio Ferrari, University of Bern

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4:45 PM - 5:00 PM

**AAS 25-527**: Stabilizing the LISA Cartwheel Formation

Abstract: LISA, the first space-based gravitational wave observatory, will open the millihertz frequency band to direct observation. Its three-spacecraft cartwheel formation requires extreme orbital stability without station-keeping. This study refines the mission's navigation strategy, optimizing SEP transfer, cartwheel injection, and disturbance modelling. A combination of SEP guidance and micro-propulsion correction mitigates injection dispersions, ensuring compliance with corner angle requirements. While line-of-sight velocities slightly exceed mission requirements under conservative assumptions, further refinements are expected to improve stability. These results reinforce LISA's robust orbit design, ensuring its ability to detect signals from supermassive black hole mergers and other astrophysically significant sources.

Author(s): Waldemar Martens, European Space Agency; Francesco Cavallo, Telespazio Germany GmbH for ESA; Nicola Baresi, University of Surrey

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5:00 PM - 5:15 PM

**AAS 25-539**: Consistent Modeling of Third-Body Perturbations with Ephemeris Data

Abstract: A common approach to calculating the perturbing acceleration due to third-bodies relies on the "indirect method" and ephemeris data. This method captures the direct gravitational forces on the spacecraft and includes a term that accounts for the mutual gravitation between bodies. In this study, the consistency (level of agreement between a trajectory propagated in two reference frames) of the indirect method using ephemeris data is compared to an approach that directly incorporates the frame center acceleration in the dynamics. The results show that the latter method produces more consistent trajectories than the indirect method (up to five orders of magnitude).

Author(s): Bryan Cline, University of Illinois Urbana-Champaign; Robyn Woollands, University of Illinois at Urbana-Champaign

# Machine Learning and Artificial Intelligence Applied to Spaceflight III

Wednesday, 08/13/25, 8:00 AM - 10:00 AM

Session Chair(s): Ryne Beeson (Princeton University)

Room: Plymouth

8:00 AM - 8:15 AM

**AAS 25-821**: Learning Orbital Uncertainty with Quantified Error Bounds for Conjunction Analysis

Abstract:

Orbital state uncertainty evolves over time according to the Fokker–Planck partial differential equation (FP-PDE). We approximate its time-dependent probability density function with physics-informed neural networks (PINNs) and, drawing on our earlier theory, construct continuous-time error bounds for these approximations. Specialized training strategies tame the vast state–time domain of orbital dynamics, overcoming key challenges in training PINNs with quantified error bounds. Leveraging these error bounds, we propose three methods for computing rigorous upper bounds on conjunction event probabilities. Numerical experiments validate these guarantees and suggest paths toward potential improvements.

Author(s): Chun-Wei Kong, University of Colorado Boulder; Morteza Lahijanian, Universtiy of Colorado Boulder; Jay McMahon, University of Colorado Boulder, CCAR

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8:15 AM - 8:30 AM

**AAS 25-831**: Risk-Sensitive Reinforcement Learning for Designing Robust Low-Thrust Interplanetary Trajectories

Abstract: Recently, SmallSats have gained momentum for interplanetary missions due to their cost-effectiveness, rapid development, and ability to perform complex tasks. However, these benefits come with trade-offs, as limited budgets often require the use of less reliable components, increasing the likelihood of control execution errors. While Reinforcement Learning shows promise in designing robust trajectories, existing methods depend on prior knowledge of these errors, limiting generalization. We propose Risk-Sensitive Reinforcement Learning to train policies robust to unknown disturbances. Our algorithm, RS-PPO, extends Proximal Policy Optimization by incorporating risk into its objective and is evaluated on an Earth-to-Mars transfer under various control execution errors.

Author(s): Aarun Srinivas, University of Maryland - College Park; John Martin, University of Maryland

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8:30 AM - 8:45 AM

**AAS 25-848**: Fast Learning of Non-Cooperative Spacecraft 3D Models through Primitive Initialization

Abstract: To enable 3D Gaussian Splatting (3DGS) in space, this work contributes: (1) a CNN-based primitive initializer for 3DGS using monocular images; (2) a pipeline capable of training with noisy or implicit pose estimates; and (3) an analysis of initialization variants that reduce training cost of precise 3D models. A comparison is performed between different variants of the CNN-based primitive initalizer that demonstrate a significant reduction in the cost to train 3DGS even under noisy pose supervision.

Author(s): Pol Francesch Huc, Stanford University; Emily Bates, Stanford University; Simone D'Amico, Stanford University

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8:45 AM - 9:00 AM

**AAS 25-854**: Detecting Orbital Anomalies In Space Object Behavior Using Recurrent Neural Networks

Abstract: Overpopulation of the Near-Earth environment is a matter of particular concern for the whole space sector, prompting the need for a comprehensive Space Domain Awareness (SDA). Identification of maneuvering activities, especially focusing on anomalous behaviors, is key to enhance object catalog maintenance and construct behavioral profiles, known as Patterns of Life (PoL). Leveraging large availability of TLE datasets, this work explores an anomaly detection tecnique to identify deviations from the nominal orbital behaviors. This capability is fundamental to uncover suspicious and potentially dangerous activities, supporting a more reliable space environment.

Author(s): Gaetano Calabro', Politecnico di Milano; Riccardo Cipollone, Look Up Space; Pierluigi Di Lizia, Politecnico di Milano

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9:00 AM - 9:15 AM

**AAS 25-859**: Sensor Selection for State Estimation in Cislunar Space Using Information Gain Metrics

Abstract: The renewed surge of interest in lunar exploration has motivated advances in autonomous spacecraft navigation within the cislunar regime. Indeed, navigation in the cislunar trajectories poses unique challenges, including complex dynamics and varying sensor observability. This paper presents an information-gain-based sensor selection method within an extended Kalman filter that autonomously selects between navigation modalities, such as Earth- and Moon-referenced optical navigation. The approach facilitates robust, ground-independent navigation by autonomously selecting the most informative sensing modality for improved state estimation. Simulation results demonstrate improved accuracy compared to fixed-modality and heuristic switching strategies.

Author(s): Naveen Senthil, Georgia Institute of Technology; Tara Mina, Georgia Institute of Technology; John Christian, Georgia Institute of Technology

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9:15 AM - 9:30 AM

**AAS 25-860**: Multi-Phase Spacecraft Trajectory Optimization via transformer-based Reinforcement Learning

Abstract: Autonomous spacecraft control across mission phases—such as orbit-raising, station-keeping, and rendezvous—remains a critical challenge due to the need for adaptive policies that generalize across dynamically distinct regimes. While reinforcement learning (RL) has shown promise in individual astrodynamics tasks, existing approaches often require separate policies for distinct mission phases. This work introduces a transformer-based RL framework that unifies multi-phase trajectory optimization through a single policy architecture, leveraging the transformer's inherent capacity to model extended temporal contexts. Our framework replaces conventional recurrent networks with a transformer encoder-decoder structure, enabling the agent to maintain coherent memory across mission phases.

Author(s): Amit Jain, MIT; Victor Rodriguez-Fernandez, Universidad Politécnica de Madrid; Richard Linares, Massachusetts Institute of Technology

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9:30 AM - 9:45 AM

**AAS 25-867**: Characterization of Neural Ordinary Differential Equations for Astrodynamics Applications

Abstract: This work investigates the potential of neural ordinary differential equations (neural ODEs) for modeling spacecraft dynamics. As a proof of concept, we evaluate their ability to learn accelerations in canonical astrodynamics problems, including the planar two-body and circular

restricted three-body problems. We characterize the strengths, limitations, and practical caveats of the approach, assessing both accuracy and generalization across datasets of varying complexity. Results demonstrate that neural ODEs have potential as accurate, data-driven surrogates for traditional models, offering a flexible approach to modeling complex dynamics in support of improved space mission design and analysis.

Author(s): Sarah Wielgosz, University of Maryland; John Martin, University of Maryland; Huan Xu, University of Maryland, College Park

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9:45 AM - 10:00 AM

**AAS 25-877**: Navigating the unknown: data-driven image processing and simplified renderings for Small Body Flybys

Abstract: Flybys of small celestial bodies present a unique set of challenges for optical navigation due to their irregular shapes, unpredictable properties, and varying illumination conditions. Traditional centroiding algorithms, while robust and efficient, are often limited in accuracy when applied to highly irregular shapes. Moreover, unknown prior information on material properties, makes it difficult to design the appropriate rendering setup for testing. In order to address both challenges, this work investigates the adoption of a simplified rendering pipeline using procedural small body generation and domain randomization to create a large and diverse set of shapes to robustly train data-driven universal center-finding algorithms. Preliminary results demonstrate the potential for these data-driven methods

Author(s): Mattia Pugliatti, University of Colorado Boulder; Jay McMahon, University of Colorado Boulder, CCAR

# Space Domain Awareness (SDA) and Space Surveillance II

Wednesday, 08/13/25, 8:00 AM - 10:00 AM

Session Chair(s): Natasha Bosanac (University of Colorado, Boulder)

Room: Dedham

8:00 AM - 8:15 AM

**AAS 25-655**: Reconstruction of Orbital Manoeuvres Using a Bi-Fidelity Optimal Control Based Estimator

Abstract: This work presents a bi-fidelity particle filter adaptation of an existing manoeuvre reconstruction algorithm based on optimal control theory. Leveraging the accuracy of high-fidelity orbit propagators and the computational efficiency of low-fidelity orbit propagators, a bi-fidelity filter allows the algorithm to more easily cope with the high non-linearity of orbital equations of motion, and the non-Gaussian distributions of state uncertainties. This paper evaluates the performance of this method with respect to the original linear version, applied to various simulations of optimal orbital manoeuvres.

Author(s): Carlo Pelt, Royal Netherlands Aerospace Centre; Steve Gehly, Delft University of Technology; Pieter Visser, Delft University of Technology; Alexander Haagsma, Royal Netherlands Aerospace Centre (NLR)

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8:15 AM - 8:30 AM

**AAS 25-691**: Optimizing Placement and Reconfiguration of Space-Based Observers for Cislunar Space Domain Awareness Considering Scheduling Constraints

Abstract: This paper proposes the design of an architecture for a constellation of observers in the cislunar domain for space domain awareness capabilities using the Fisher Information Matrix as a metric of observability performance. The optimization of the placement of the observers uses a scenario-based approach, and considers the scheduling constraints of sensor tasking, communication to a receiver satellite, and charging. In addition, the reconfiguration of the set of observers for tracking a high-value target is optimized using a Monte Carlo Tree Search algorithm to determine the best set of orbital maneuvers over a short period of time.

Author(s): Dominic Amato, West Virginia University; Hang Woon Lee, West Virginia University

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8:30 AM - 8:45 AM

**AAS 25-719**: Covariance Based Track Association and Maneuver Detection for Cislunar Orbits

Abstract: This study investigates the applicability and efficacy of the covariance-based track association (CBTA) and maneuver detection for cislunar orbits. Unlike Earth orbits, cislunar CBTA requires nonlinear covariance propagation to capture the nonlinear state error growth. This paper uses Gaussian mixture model and Monte Carlo simulations for covariance propagation. Earth-Moon-barycentric inertial reference frame, CR3BP, and ER3BP normalized synodic reference frames are used to describe state and covariance for Mahalanobis distance computation. Seven tracks obtained from Artemis-1 mission are used for cislunar track association and maneuver detection. Maneuver time and delta-v values will be estimated by minimizing Mahalanobis distance between tracks.

Author(s): Woosang Park, Texas A&M University; Gim Der, DerAstrodynamics; Kyle T. Alfriend, Texas A&M University

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8:45 AM - 9:00 AM

**AAS 25-755**: Cislunar Space Domain Awareness Sensor Tasking Optimization via Mixed Integer Linear Programming

Abstract: Due to the vast distances in cislunar space and spacecraft's reduced field of view (FOV) for better observability characteristics, optimal sensor tasking is essential when designing a constellation capable of detecting and maintaining custody of objects traveling to and from the Moon. This paper introduces a novel mixed-integer linear programming formulation to minimize the revisit time required for observing a set of targets representing a volume of interest in cislunar space. For a given fixed FOV, this approach results in an optimal schedule, where the entire area of interest is consistently observed in minimal time throughout the time horizon.

Author(s): Lois Visonneau, Georgia Institute of Technology; Bradford Robertson, Georgia Tech Aerospace Systems Design Laboratory; Dimitri Mavris, Georgia Institute of Technology

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9:00 AM - 9:15 AM

**AAS 25-838**: Stochastic Polynomial Chaos Expansion: A New Uncertainty Quantification Approach

Abstract: Uncertainty quantification of atmospheric density for modeling of satellite drag perturbations in Low Earth Orbit remains a challenge for the space community. The introduction of probabilistic models provide an important step for quantifying uncertainty; but requires new efficient methods for capturing overall statistics. We present a new mathematical framework, Stochastic Polynomial Chaos Expansion (SPCE), which combines the contributions of driver and model uncertainty for overall statistics. The framework can be generalized to any application and is validated using simple (non-)linear and space weather applications.

Author(s): Gerardo Josue Rivera Santos, West Virginia University; Piyush Mehta, West Virginia University

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9:15 AM - 9:30 AM

**AAS 25-889**: Optimal Visibility-Based Design of Surveillance Trajectories in the Cislunar Region

Abstract: Cislunar Space Domain Awareness (CSDA) is vital for future lunar and interplanetary missions, but traditional near-Earth strategies do not apply due to unique gravitational dynamics. This paper investigates optimal visibility in cislunar space using cost-effective electro-optical sensors. A bi-circular four-body problem (BCR4BP) based model, incorporating visibility constraints and validated against JPL Spice data, parameterizes the region. Daily average visibility is assessed, and particle swarm optimization is used to identify optimal observer locations. These locations guide trajectory design using collocation and nonlinear programming. The approach is demonstrated across multiple cislunar scenarios and validated through high-fidelity simulations under realistic conditions.

Author(s): Surabhi Bhadauria, Purdue University; Carolin Frueh, Purdue University

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9:30 AM - 9:45 AM

**AAS 25-906**: Heuristic-Informed Optimization for Constellation Design: Tracking Trajectories in Cislunar Space

Abstract: The cislunar population of man-made entities is projected to grow exponentially over the next decade to serve civilian and military needs. Awareness of controllable and uncontrollable assets and foreign entities is paramount to establishing safe and sustainable exploration and is an important step towards long-term presence. Tracking such entities involves the complex evaluation of many dynamical models to evaluate performance, feasibility, and stability. The feasibility of tracking requires the complex determination and simulation of multiple models to achieve an accurate guess of real-life

scenarios. This paper hopes to identify several key trends in analyzing parameters of cislunar space domain awareness.

Author(s): Calvin Chan, Rensselaer Polytechnic Institute; Sandeep Singh, Rensselaer Polytechnic Institute

# Trajectory Design and Optimization V

## Wednesday, 08/13/25, 8:00 AM - 10:00 AM

## Session Chair(s): Kenshiro Oguri (Purdue University)

## Room: Duxbury

8:00 AM - 8:15 AM

**AAS 25-862**: Compact Representations of Periodic Orbit Families Using Autoencoder Neural Networks

Abstract: Traditional methods for parameterizing and storing periodic orbit families use discretized representations of the family and require computationally expensive continuations to interpolate between members of the family. In this work, we develop a continuous parameterization of periodic orbit families in the Earth-Moon system using techniques from machine learning. Trained on orbits from the JPL Periodic orbit database, we use autoencoder neural networks to parameterize periodic orbit families in terms of a single, continuous family parameter and a discrete angle. Our approach allows for more efficient computation of periodic orbits and can be applied to mission design and trajectory optimization problems.

Author(s): Thomas Clark, University of Colorado at Boulder; Daniel Scheeres, University of Colorado Boulder

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8:15 AM - 8:30 AM

**AAS 25-865**: Extending the Tisserand Graph Method for Powered Gravity Assist Trajectories

Abstract: The Tisserand graph method can be extended to include impulsive maneuvers performed at the periapsis of planetary flybys. By incorporating velocity changes into the Tisserand graph, the range of accessible transfer arcs is expanded and mission opportunities beyond purely ballistic paths can be found. This approach provides an intuitive tool for visualising v-infinity transitions and designing complex tour sequences involving powered gravity assist trajectories. Time of flight comparisons demonstrate that powered flybys can reduce total mission duration and phasing constraints, through the reduction of repeated flybys of the same planet, offering a practical enhancement to conventional trajectory design techniques.

Author(s): Jack Li, The Pennsylvania State University; Ghanghoon Paik, Northeastern Univeresity; Robert Melton, Pennsylvania State University

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8:30 AM - 8:45 AM

**AAS 25-874**: Nested B-spline Control and Modified (h,e) Elements for Lengthy Low-thrust Cislunar Orbit-raising

Abstract: While mathematically well-posed, many optimal control problem formulations become increasingly numerically ill-conditioned as their size increases. We integrate a few novel ideas within a multiple shooting framework to solve an unusually long orbit raising from a GTO to a NRHO. For example, we propose nested B-splines for low-thrust control parametrization and control compression through singular value decomposition. Furthermore, we introduce a new independent variable for the (h,e) orbital elements to eliminate a singularity encountered for cislunar transfers. The numerical scenario considers launcher performance and a maximum eclipse duration constraint of 90 minutes, treated by forming adjoint equations for an ODE with an implicitly defined endpoint.

Author(s): Adrian Arustei, Wichita State University; Atri Dutta, Wichita State University

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8:45 AM - 9:00 AM

**AAS 25-882**: Polynomial-based solution to the targeting problem for onboard applications

Abstract: This paper solves the targeting problem focusing on accuracy and efficiency. Given the initial spacecraft state, the objective is to compute the optimal maneuver to reach the target state in a fixed time interval. The problem is firstly recast as a polynomial optimization problem (POP) using high-order Taylor expansions of the dynamics and the constraints. Sum-of-squares (SOS) optimization is leveraged to efficiently solve this POP. A convex formulation based on a second-order expansion of the dynamics is also proposed. The POP is more suitable for large maneuvers and long time spans, while the convex formulation is preferred when efficiency is paramount.

Author(s): Alberto Fossà, Vyoma GmbH; Roberto Armellin, Te Punaha Atea - Space Institue, The University of Auckland; Didier Henrion, LAAS-CNRS, University of Toulouse; Renato Zanetti, The University of Texas at Austin

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9:00 AM - 9:15 AM

**AAS 25-898**: Full solution space of Reachable V-Infinity Leveraging Transfers

Abstract: V-infinity leveraging transfers (VILTs) are commonly used as building blocks in trajectory design. Most VILT solvers constrain degrees of freedom with assumptions to reduce the search space. A new VILT formulation is proposed to facilitate the exploration of the whole space, removing assumptions such as tangential boundaries and maneuvers. The extended formulation still anchors the search around ballistic transfers, focusing only on low delta-v solutions. The extra degrees of freedom are particularly helpful for interplanetary tours with smaller search spaces due to the constrained number of revolutions. Examples are provided to validate and showcase the resulting generalized VILT families.

Author(s): Chun-Yi Wu, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin

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9:15 AM - 9:30 AM

**AAS 25-916**: INCORPORATING THE NONLINEARITY INDEX INTO ADAPTIVE-MESH SEQUENTIAL CONVEX OPTIMIZATION FOR MINIMUM-FUEL LOW-THRUST TRAJECTORY DESIGN

Abstract: Indirect and direct methods are the two main approaches for trajectory optimization of space vehicles. Indirect methods solve boundary value problems derived from optimality conditions, whereas direct methods transform the problem into a finite-dimensional nonlinear program (NLP) via transcription. Successive convex programming (SCVX) greatly enhances the robustness and efficiency of direct methods; however, transcription remains a fundamental limitation. Previous work has employed adaptive mesh refinement to mitigate this issue. In this paper, we enhance adaptive mesh refinement stability by integrating it with a nonlinearity-index-based trust-region strategy within the SCVX framework.

Author(s): Saeid Tafazzol, Auburn University; Ehsan Taheri, Auburn University

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9:30 AM - 9:45 AM

**AAS 25-697**: A Bi-Level Optimal Control Framework for Relative Low-Thrust Spacecraft Motion under Missed Thrust Events

Abstract: This paper introduces a bi-level optimal control framework for designing low-thrust trajectories with robustness to missed thrust events. Motivated by long-duration cislunar missions, the framework models missed thrust design through a hierarchical structure in which the upper-level reference solution and the lower-level realization responses are mutually coupled, each influencing the

other through shared constraints. The bi-level problem is reformulated as a single-level nonlinear program using complementarity constraints, enabling efficient solution via standard optimization methods. Demonstrations in two-body relative motion illustrate the ability to synthesize robust solutions, offering an efficient algorithm for incorporating operational anomalies into preliminary mission design.

Author(s): Amlan Sinha, Princeton University; Ryne Beeson, Princeton University

# Cislunar Astrodynamics IV

## Wednesday, 08/13/25, 8:00 AM - 10:00 AM

## Session Chair(s): Anthony Genova (NASA)

## Room: Adrienne Salon

8:00 AM - 8:15 AM

**AAS 25-759**: Biology and Engineering Autonomous Cislunar Optical Navigator (BEACON) Mission Concept

Abstract: With the Artemis program underway and national interest looking ahead towards Mars, it is imperative to understand the effects of deep space radiation on living systems. Utilizing a three-petal Earth-Moon cycler orbit, BEACON will characterize the cislunar radiation environment and study its impact on microbial evolution, in addition to demonstrating autonomous optical navigation capabilities. This report details the process of designing and validating a yearlong mission concept, including trajectory analysis, spacecraft sizing, and associated mission/spacecraft requirements. Consequently, BEACON will advance space biology, and expand the autonomous orbit determination and guidance, navigation, and control capabilities of future deep space missions.

Author(s): Alexander Rodriguez, Georgia Institute of Technology; Molly Riebling, Georgia Institute of Technology; Christopher Carr, Georgia Institute of Technology; E. Glenn Lightsey, Georgia Institute of Technology

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8:15 AM - 8:30 AM

**AAS 25-763**: Quasi-Periodic Orbits Around the 9:2 NRHO in the Inclined Elliptic Hill Restricted 4-Body Problem

Abstract: In this paper, we compute and analyze quasi-periodic orbits (QPOs) in the vicinity of Gateway's planned orbit in the Inclined Elliptic Hill Restricted 4-Body Problem (IE-HR4BP), a quasi-periodically forced dynamical model of cislunar space. Gateway’s orbit is a 3-D QPO in the IE-HR4BP, and 4-D QPOs emanate from it. We compute these invariant tori using a large matrix method referred to as GMOS and explicitly present the extension of GMOS to compute 4-D QPOs. To the best of the authors' knowledge, the 4-D QPOs in this work are the first 4-D invariant tori computed in any model of cislunar space.

Author(s): Gavin Brown, University of Colorado Boulder; Daniel Scheeres, University of Colorado Boulder

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8:30 AM - 8:45 AM

**AAS 25-775**: Inferring Orbital Structure from Scalar Observables via Delay-Embedded Time Series and Persistent Homology

Abstract: The application of homology constructs, especially from topological data analysis (TDA) promises to capture topological details and signatures, such as shape information and shape-related invariants, in cislunar dynamical structures that existing methods may overlook. In this work, we present TDA-derived descriptors of univariate time series data that are associated with periodic orbits in cislunar space to infer orbital structure properties. Such time series may be associated with data streams from earth- or space-based sensors for domain awareness.

Author(s): Luke Scharck, Auburn University; Firas Khasawneh, Michigan State University; Davide Guzzetti, Auburn University

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8:45 AM - 9:00 AM

**AAS 25-783**: Long-Term Spacecraft Trajectory Prediction Using Behavioral Motion Primitives

Abstract: This paper leverages behavioral motion primitives for spacecraft trajectory prediction in cislunar space. A behavioral motion primitive summarizes trajectories with a similar geometry and is labeled by the associated behaviors (e.g., maneuvering objective and intent) and spacecraft parameters. The volume spanned by these geometrically similar trajectories is labeled as the region of existence of each primitive and approximated using voxels. Uncertain state estimates are projected onto these regions of existence for short-term predictions. Sequences of composable primitives, with overlapping regions of existence in the configuration space, are then used to generate digestible long-term trajectory predictions.

Author(s): Austin Bodin, CU Boulder; Natasha Bosanac, University of Colorado, Boulder; Cole Gillespie, University of Colorado Boulder

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9:15 AM - 9:30 AM

**AAS 25-794**: ANALYSIS OF GRAVITY GRADIENT TORQUE DISTURBANCES IN THE NRHO REGIME

Abstract: This work will investigate the attitude motion and its coupling with the orbital dynamics in the CR3BP. Specifically, an analysis of the effect of the gravity gradient torques is of interest, as it is often the most significant. The range of attitude motion of a spacecraft with mass properties similar to the Lunar Gateway station along the 9:2 NRHO is investigated and characterized.

Author(s): Nestor Hernandez, Texas A&M University; Ian Down, Texas A&M University; James McElreath, Land, Air and Space Robotics Laboratory; Texas A&M University; Manoranjan Majji, Texas A&M University, College Station

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9:30 AM - 9:45 AM

**AAS 25-855**: The Modified Generalized Equinoctial Orbital Elements for High-Fidelity Cislunar Propagation

Abstract: The complex cislunar dynamical environment poses challenges for spacecraft navigation and Space Domain Awareness operations, where the knowledge of current and future spacecraft states is essential. To accurately model the underlying dynamics, this work explores the Modified Generalized Equinoctial Orbital Elements to enable high-fidelity propagation for cislunar applications. The accuracy of the solutions is demonstrated via comparisons against Cartesian n-body solutions across various cislunar orbits. The characterization of uncertainty in generalized coordinates under high-fidelity propagation is compared against Cartesian methods.

Author(s): Maaninee Gupta, Texas A&M University; Kyle DeMars, Texas A&M University

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9:45 AM - 10:00 AM

**AAS 25-858**: Analytic Continuation Method for Accurate and Efficient Cis-Lunar Orbit Propagation

Abstract: This work presents the application of the Analytic Continuation method, a highly precise semi-analytic integrator, for simulating cis-lunar trajectories by solving the Circular Restricted Three-Body Problem (CR3BP). Initially developed for perturbed two-body dynamics, this method is extended to propagate cis-lunar trajectories with exceptional accuracy and efficiency. Simulations of four representative trajectories demonstrate that this approach significantly outperforms traditional Runge-Kutta methods in both conserving the Jacobi constant and reducing computational time.

Author(s): Tahsinul Haque Tasif, University of Central Florida; Tarek Elgohary, University of Central Florida; Riccardo Bevilacqua, Embry-Riddle Aeronautical University

# In-Space Assembly, Manufacturing, and Space Robotics

Wednesday, 08/13/25, 10:30 AM - 12:30 PM

Session Chair(s): William Fife (Texas A&M University)

Room: Plymouth

10:30 AM - 10:45 AM

**AAS 25-705**: Understanding and Utilizing Dynamic Coupling in Free-Floating Space Manipulators for On-Orbit Servicing

Abstract: This study investigates the dynamic coupling behavior in free-floating space manipulator systems under varying joint actuation conditions. Unlike existing studies that focus on static system parameters, this study analyzes how varying joint torques influence base disturbances in real time. The dynamic coupling matrices are evaluated across different motion scenarios, and their key components are identified using singular value or eigenvalue decomposition. The extracted coupling information can then be leveraged to support the development of intelligent control strategies for safe, efficient, and actuator-free base operation in close-proximity missions.

Author(s): Gargi Das, University of Cincinnati; Daegyun Choi, University of Cincinnati; Donghoon Kim, University of Cincinnati

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10:45 AM - 11:00 AM

**AAS 25-727**: Fuzzy-Based Control Method for Autonomous Spacecraft Inspection with Minimal Fuel Consumption

Abstract: This study explores an energy-efficient control strategy for spacecraft inspection using a fuzzy inference system combined with a bio-inspired optimization technique to incorporate learning capability into the control process. The optimized fuzzy controller produces a minimal fuel-consumed force while maintaining reliable inspection within constraints, such as illumination, restricted field of view, thrust limits, and safe regions. The performance of the proposed control strategy is validated through Monte Carlo simulations.

Author(s): Daegyun Choi, University of Cincinnati; Donghoon Kim, University of Cincinnati; Hyunjae Lee, Chosun Univ.

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11:00 AM - 11:15 AM

**AAS 25-762**: Passive Gravity Gradient Capture for In-Space Assembly and Manufacturing

Abstract: In-space assembly and manufacturing (ISAM) offers an opportunity to overcome the volume limitations of the rocket fairing and construct large structures optimized for loads in space. A key challenge for the design of ISAM spacecraft is the design of the attitude control system, which is complicated by the varying mass properties and environmental disturbances over long timescales of construction. In addition, it is unclear how disturbances such as gravity gradients can be advantageously used to minimize attitude control requirements. In this paper, we explore the strategy of gravity gradient capture, which refers to planning a passive attitude trajectory that results in a stable orientation after construction.

Author(s): Harsh Bhundiya, Massachusetts Institute of Technology; Michael Marshall, The Johns Hopkins University Applied Physics Laboratory; Zachary Cordero, Massachusetts Institute of Technology

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11:30 AM - 11:45 AM

**AAS 25-801**: A Model-Based Astrodynamics Simulation Paradigm for Multi-Body Spacecraft Systems

Abstract: This paper presents a model-based, message-passing simulation framework for spacecraft systems with generally articulated structures. Traditional astrodynamics simulations often assume rigid, single-body spacecraft, limiting their applicability to modern systems with robotic arms, deployable arrays, and other moving parts. The proposed framework decomposes kinematics, forces, and dynamics into compartmentalized models that exchange information via messages. This enables intuitive and rapid simulation setup without requiring expertise in complex dynamics algorithms. The resulting implementation integrates the Basilisk simulation architecture with the MuJoCo dynamics engine, combining accurate orbital propagation with advanced multi-body dynamics. An example scenario with code excerpts and numerical results is presented.

Author(s): Juan Garcia Bonilla, CU Boulder; Hanspeter Schaub, University of Colorado

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11:45 AM - 12:00 PM

**AAS 25-891**: Adapting Biological Reflexes for Dynamic Reorientation in Space Manipulator Systems

Abstract: Controlling space manipulator systems (SMSs) remains a significant challenge due to the dynamic coupling between the manipulator and its base. This study explores the potential of using biological inspiration to address this issue, focusing on animals that exhibit mid-air righting reflexes. By examining behavioral and morphological similarities between SMSs and these animals, motion trajectories are extracted from videos through computer vision. These trajectories are analyzed using a multi-objective optimization framework to identify the behavioral goals and their relative importance. The resulting motion is then applied as reference trajectories for SMS control, with baseline controllers used to track them.

Author(s): Daegyun Choi, University of Cincinnati; Alhim Adonai Vera Gonzalez, University of Cincinnati; Donghoon Kim, University of Cincinnati

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12:00 PM - 12:15 PM

**AAS 25-553**: MODELING AND CONTROL FRAMEWORK FOR AUTONOMOUS SPACE MANIPULATOR HANDOVER OPERATIONS

Abstract: Autonomous space robotics is poised to play a vital role in future space missions, particularly for In-space Servicing, Assembly, and Manufacturing (ISAM). A key capability in such missions is the Robot-to-Robot (R2R) handover of mission-critical objects. This work presents a dynamic model of a dual-arm space manipu- lator system and compares various tracking control laws. The key contributions of this work are the development of a cooperative manipulator dynamic model and the comparative analysis of control laws to support autonomous R2R handovers in ISAM scenarios.

Author(s): Diego Quevedo, University of Cincinnati; Sarah Hudson, University of Cincinnati; Donghoon Kim, University of Cincinnati

# Orbital Debris and Space Environment

## Wednesday, 08/13/25, 10:30 AM - 12:30 PM

## Session Chair(s): Tahsinul Haque Tasif (University of Central Florida)

## Room: Adrienne Salon

10:30 AM - 10:45 AM

**AAS 25-511**: Programmable Dust for Active Debris Remediation: Comparative Analysis for Deployed Dust Fields

Abstract: The orbital and sub-orbital deployment of micron-sized dust fields creates an artificial drag environment for small debris (1mm – 1 cm). Essentially amounting to “programmable dust”, programmable metamaterial particle ensembles (PMPEs) can be engineered to harness solar radiation pressure to passively self-regulate orbital decay rates. Orbitally deployed fields of this programmable dust gain enable engineers to tailor mission design and concepts of operations to remediate more and larger debris than fields made of inert particles. In this paper, we present our mission analysis framework and results that show the performance advantages of PMPE-based deployed fields compared to inert-particle fields.

Author(s): Joseph Ivarson, Auburn University; Luke Scharck, Auburn University; Ana Barona-Mejia, Auburn University; Luis Manuel Postigo, Auburn University; Laith Bader, Auburn University; Kate Handel, Auburn University; Allan David, Auburn University; Davide Guzzetti, Auburn University

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10:45 AM - 11:00 AM

**AAS 25-663**: Environment versus Operation Impact on Collision Avoidance Maneuvers: Use of a New Mission Planning Method

Abstract: The operational cost of Collision Avoidance Maneuvers (CAMs) relies on the following aspects: i) surrounding environment of the mission, ii) risk assessment and choices for mitigation actions. The paper presents the impact of both aspects on mission operations using a new method for mission planning. The proposed method intends to fit the operational specificities of the French Collision Avoidance Service CAESAR in order to help missions to evaluate the impact of risk assessment on their operations.

Author(s): Christophe Taillan, Centre National d'Études Spatiales (CNES); Emmanuel Delande, Centre National d'Études Spatiales; François Vinet, CNES

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11:00 AM - 11:15 AM

**AAS 25-684**: Reinforcement Learning-Based Task Planning of Space-Based Lasers for Orbital Debris Remediation

Abstract: Orbital debris poses a significant threat of collision to space missions and satellites and needs to be remediated. Space-based lasers are proposed to address this. Because the space environment has highly dynamic characteristics that make real-time, human-controlled methods undesirable, task planning methods are preferred. We present a proof of concept for a system of space-based lasers capable of safely lowering the periapsis radius of debris in low Earth orbit through reinforcement learning methods. From our results, we can see that the agent successfully outperforms a baseline algorithm in lowering the total periapsis of a debris field in most instances studied.

Author(s): Gavin Baker, West Virginia University; Hang Woon Lee, West Virginia University

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11:15 AM - 11:30 AM

**AAS 25-769**: Performance assessment of VLEO sensors for space surveillance and tracking

Abstract: Over the past decade, smaller and more affordable spacecraft have driven a sharp increase in satellite launches, particularly for communications and Earth observation. This growth has crowded higher Low Earth Orbit, raising concerns about space traffic and debris. As a result, Very Low Earth Orbit, below 450 kilometers, is gaining interest for its natural debris mitigation. Its geometry also offers unique advantages for tracking space objects, with fewer Earth obstructions and faster revisit times. This study explores the feasibility of space tracking missions in this region through geometric analysis and sensor modeling, aiming to inform future mission designs and strategies.

Author(s): Michele Maestrini, Politecnico di Milano

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11:30 AM - 11:45 AM

**AAS 25-770**: Statistical Evaluation of Dust-Based Just-in-time Collision Avoidance Systems and Policies

Abstract: Under the just-in-time collision avoidance (JCA) paradigm, we prevent imminently forecast high-risk collisions by perturbing the orbit of one of the objects involved; this work supports the design and optimization of on-orbit deployer constellations that carry out these JCA perturbations via intercept with high-velocity fine-dust clouds. Specifically, we provide a method based on ergodicity for simultaneously evaluating statistical performance metrics (e.g. quantiles of interception lead time) for many such constellations in realistically-distributed test conjunction scenarios. We use this method to generate Pareto fronts of optimal dust JCA systems and explore the implication of policy variables on the optimized costs and designs.

Author(s): Riley Fitzgerald, Virginia Tech; Truman DeWalch, Virginia Tech; Isaac Payne, Virginia Tech; Evan Lutchmidat, Virginia Polytechnic Institute

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11:45 AM - 12:00 PM

**AAS 25-835**: Concurrent Optimization of Space-Based Laser Sizing, Location, and Scheduling for Orbital Debris Remediation

Abstract: This paper tackles the problem of remediating orbital debris using a constellation of space-based lasers. We propose a bilevel optimization problem of space-based laser platform sizing and mission design. The optimization determines the dry and fuel mass of the platform as well as the location of the platforms and the scheduling of the laser-to-debris engagements. A random search algorithm is proposed to solve the optimization problem. A case study with a randomly generated debris field enables us to show the value of the optimization problem presented.

Author(s): David Williams Rogers, West Virginia University; Hang Woon Lee, West Virginia University

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12:00 PM - 12:15 PM

**AAS 25-880**: Derivation of the planetary Lorentz perturbation within Gauss's variational equations and applications to charged space debris

Abstract: Sub-centimeter debris particles are generated during space operations in Low Earth Orbit and pose a threat to future missions but are currently undetectable by radar ground stations.  Objects moving through ionospheric plasma become charged and experience a Lorentz force from Earth's natural electromagnetic field. This study presents closed-form analytical solutions to the electric and magnetic perturbing forces as functions of the osculating orbital elements. Using Gauss's variational equations, the resulting mathematical formulations predict the dynamics of space debris in response to the Lorentz perturbation. Specific conditions are identified that have implications on debris lifespans

and orbit evolution.

Author(s): Jonathan Wrieden, University of Maryland; Christine Hartzell, University of Maryland

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12:15 PM - 12:30 PM

**AAS 25-702**: Large-Scale Numerical Simulation of Dust Particle Fields for Orbital Debris Removal

Abstract: Dust fields have been proposed as a non-traditional remediation for smaller debris. However, accurately and efficiently simulating the interaction of small dust particles in low Earth orbit with small debris remains a challenge. This effort will focus on using an advanced direct numerical integration framework to simulate each individual particle in the field with user-defined equations of motion. The framework is utilized to analyze two mechanisms that are important for debris remediation: dust particle collisions with debris and dust field dispersion over long time periods.

Author(s): Luke Scharck, Auburn University; Davide Guzzetti, Auburn University; Joseph Ivarson, Auburn University

# Spacecraft Guidance, Navigation and Control (GNC) II

## Wednesday, 08/13/25, 10:30 AM - 12:30 PM

## Session Chair(s): Christopher D'Souza (NASA/JSC)

## Room: Dedham

10:30 AM - 10:45 AM

**AAS 25-674**: Integrated Navigation and Guidance for Autonomous Landing on Small Planetary Bodies

Abstract:
Landing on small planetary bodies remains a significant challenge that limits the scientific return of spacecraft missions. This work presents an integrated guidance and navigation architecture to further enable autonomous spacecraft operation in uncertain environments. The proposed approach uses an extended Kalman filter simultaneous localization and mapping algorithm with optical landmark measurements to improve state estimation. Solving a convex programming problem steers the spacecraft toward a landing region while improving filter observability. This unified framework advances autonomous guidance and navigation capabilities essential for future small body missions.

Author(s): Zachary Donovan, University of Colorado Boulder; Jay McMahon, University of Colorado Boulder, CCAR

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10:45 AM - 11:00 AM

**AAS 25-720**: State and Parameter Estimation of a Target Spacecraft without Onboard Sensing via a TSE(3)-based UKF

Abstract: The growing threat of space debris demands advanced techniques to estimate internal parameters of non-cooperative objects. This paper presents joint estimation of a target's relative states and parameters using only relative pose measurements from onboard vision-based sensors. Formulated on the Lie group SE(3) and its tangent bundle TSE(3), the estimation framework naturally captures coupled translational and rotational dynamics. The TSE(3)-based square-root unscented Kalman filter ensures numerical robustness and covariance consistency. Internal disturbances within the target from microgravity propellant slosh are modeled via the moving pulsating ball model. A case study on a Delta II second-stage rocket validates the method's effectiveness.

Author(s): Marco Fagetti, Embry-Riddle Aeronautical University; Herman Gunter, Embry-Riddle Aeronautical University; Morad Nazari, Embry-Riddle Aeronautical University; Matthew Wittal, National Aeronautics and Space Administration; Michael Elmore, a.i. solutions; Jeffrey Smith, Gateway Logistics Element, NASA Kennedy Space Center

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11:00 AM - 11:15 AM

**AAS 25-764**: Counter-Adversarial Estimation for Space Navigation: The Fusion Reproducing Kernel Hilbert Space Extended Kalman Filter

Abstract: Estimating spacecraft states in space is uniquely challenging due to nonlinear and uncertain dynamics, limited or unreliable observations, and the presence of external disturbances, such as signal interference and spoofing. This paper introduces the fusion (inverse) reproducing kernel Hilbert space extended Kalman filter (REKF) as a novel approach for robust and adaptive state estimation in this regime. By leveraging an online expectation-maximization algorithm, the REKF learns unknown system parameters and approximates nonlinear dynamics and measurements, through kernel-based function representations. This framework enables accurate threat detection and active sensing, offering a promising approach for resilient spacecraft navigation in uncertain conditions.

Author(s): Alberto Zamora, Texas A&M University; Kyle DeMars, Texas A&M University

11:15 AM - 11:30 AM

**AAS 25-776**: Taylor Propagation for Ensemble Based Filtering

Abstract: The propagation step in navigation can be computationally expensive when dealing with particles, making the implementation of nonlinear filters difficult for onboard applications. Studying fast propagation schemes is crucial to enable the use of nonlinear filters onboard. In this work, propagation based on the Taylor method is compared with RK integrators in the context of the Earth-Moon system. The Taylor integrator is shown to be faster than the numerical propagators, without accuracy loss. The Taylor integrator is also used in a relative navigation scenario using the EnGMF, where a chaser is in a QPO relative to Gateway in the NRHO.

Author(s): Felipe Giraldo-Grueso, The University of Texas at Austin; Alberto Fossà, Vyoma GmbH; Ryan Menges, University of Colorado Boulder; Daniel Scheeres, University of Colorado Boulder; Renato Zanetti, The University of Texas at Austin

11:30 AM - 11:45 AM

**AAS 25-780**: Estimation-Based Morse-Lyapunov Tracking Control for Rigid-Body Spacecraft in the Cislunar Region

Abstract: This paper presents an estimation-based tracking controller for rigid-body spacecraft operating in the cislunar region. These dynamics are formulated on the special Euclidean group SE(3) to naturally account for the inherent coupling of rotational and translational motion. An estimation-enhanced backstepping control law is developed using a Morse-Lyapunov approach, with state estimation provided by a square-root unscented Kalman filter defined on TSE(3). The disturbances from the Earth–Moon system are modeled via the circular restricted full three-body problem, which extends the classical CR3BP by incorporating rigid-body dynamics. The performance of the controller is demonstrated through numerical simulations of an orbit tracking scenario.

Author(s): Herman Gunter, Embry-Riddle Aeronautical University; Morad Nazari, Embry-Riddle Aeronautical University; Marco Fagetti, Embry-Riddle Aeronautical University

11:45 AM - 12:00 PM

**AAS 25-820**: An AI-assisted Vision-based Navigation Approach for Pinpoint Lunar Landing: Development, Validation and Testing

Abstract: Optical terrain relative navigation is emerging as a key enabling technology to support pinpoint landing operations for the lunar exploration missions. This paper presents a tightly-coupled vision-based navigation pipeline that leverages image-to-database crater matches to estimate the spacecraft trajectory. A fine-tuned deep learning crater detection model is integrated into the navigation framework to achieve robust detection performance, and its accuracies are preliminarily evaluated in a controlled Blender-based simulation environment. Pseudo hardware-in-the-loop experiments are then conducted through a NVIDIA Jetson Orin Nano, providing a preliminary assessment for advancing commercial off-the-shelf hardware for accurate AI-enabled landing navigation operations.

Author(s): Simone Andolfo, Sapienza University of Rome; Mohamed El Awag, Sapienza University of Rome; Fabio Valerio Buonomo, Sapienza University of Rome; Anna Maria Gargiulo, Sapienza University of Rome; Ludovica Cavalieri, Sapienza University of Rome; Antonio Genova, Sapienza University of Rome

12:00 PM - 12:15 PM

**AAS 25-844**: Enhancements to Space Shuttle Powered Explicit Guidance for Planetary Ascent and Descent

Abstract: In the present paper, a number of enhancements to Space Shuttle Powered Explicit Guidance (PEG) algorithm are developed that increases its validity and accuracy for various planetary ascent and descent trajectory guidance applications. These specific PEG enhancements studied in this work include precise targeting of the line-of-apsides for ascent burns, range and burn ignition time control for precision landing, and compensation for atmospheric drag during ascent burns. Two different simulations for lunar and Mars vehicles are implemented to compare the performance of these enhancements with that of the conventional PEG algorithm.

Author(s): Bharat Mahajan, Odyssey Space Research LLC; Gerald Condon, NASA

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12:15 PM - 12:30 PM

**AAS 25-731**: MAGNETOMETER-BASED SELF-LIFE-SHORTENING SCHEME, DYNAMICS AND THE DEVICE

Abstract: The debris management system has been awaiting the development of devices that can be attached to spacecraft in an auxiliary manner for shortening the orbital life. This paper presents an innovative scheme for simultaneous orbit and attitude determination based solely on magnetometer, without the use of filters. The system autonomously activates when the bus system malfunctions. Additionally, the paper discusses attitude control and the stability associated with propulsive maneuvers. The results demonstrate the effectiveness and utility of the scheme through its astrodynamics properties with numerical examples.

Author(s): Junichiro Kawaguchi, School of Engineering, College of Engineering and Computer Cybernetics, Australian National University; Aditya Gopalakrishnan, Australian National University (ANU); Shingo Nishimoto, Australian National University (anu); Kawsihen Elankumaran, The Australian National University

# Trajectory Design and Optimization VI

## Wednesday, 08/13/25, 10:30 AM - 12:30 PM

## Session Chair(s): Robyn Woollands (University of Illinois at Urbana-Champaign)

## Room: Duxbury

10:30 AM - 10:45 AM

**AAS 25-518**: Optimal Satellite Orbit Control via Aerodynamic Forces in Very Low Earth Orbits

Abstract: This work investigates decay-optimized aerodynamic control strategies for satellites in Very Low Earth Orbit (VLEO). An analytical lift profile is derived to minimize orbital decay while achieving inclination changes, providing insight into the underlying dynamics. Building on this, the manoeuvre is formulated as a constrained optimal control problem and solved using direct collocation. The approach is demonstrated through Sun-synchronous orbit maintenance, where lift is used to maintain Sun-synchronicity during orbital decay. Parametric studies explore sensitivity to aerodynamic performance and environmental conditions. The results contribute to aerodynamic orbit control and support extended satellite operations in the challenging VLEO environment.

Author(s): Fabrizio Turco, Institute of Space Systems, University of Stuttgart; Constantin Traub, Institute of Space Systems, University of Stuttgart; Stefanos Fasoulas, Institute of Space Systems, University of Stuttgart

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10:45 AM - 11:00 AM

**AAS 25-552**: Xe99: A DV99 Equivalent for Low-Thrust Trajectories

Abstract: Low-thrust trajectories are susceptible to navigation and maneuver execution errors due to the long-duration thrust periods. Statistical modeling is a critical step to characterize a margined propellant budget and prove the mission operations plan is robust to these errors. This paper details the approach and functionality of a new low-thrust statistical analysis tool developed at the Johns Hopkins University Applied Physics Laboratory.

Author(s): Jackson Shannon, Johns Hopkins Applied Physics Laboratory; Jacob Englander, Johns Hopkins Applied Physics Laboratory

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11:00 AM - 11:15 AM

**AAS 25-593**: A Scheduler Methodology for the Telescope/Starshade Formation Flying Problem

Abstract: A top-down scheduler methodology, called Pathfinder, for the telescope/starshade formation flying problem is developed. In particular, it is a multi-objective, constrained optimization that maximizes science yield and minimizes fuel expenditures while adhering to imaging and thruster contraints. Its novelty lies in exploiting the naturally occurring dynamics around Sun-Earth L2 to determine a fuel-optimal path that observes the most amount of objects of interest. Additionally, approximate analytical solutions are used for the relevant dynamics, which enables Pathfinder’s computational efficiency, permitting users to execute it using different parameters and heuristics.

Author(s): Hailee Hettrick, The Charles Stark Draper Laboratory; Begum Cannataro, Draper; David Miller, Massachusetts Institute of Technology

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11:15 AM - 11:30 AM

**AAS 25-603**: A general analytical mission-based approach to reconfigurable satellite constellation design for astronomical bodies

Abstract: This paper provides an analytical solution whereby a small reconfigurable satellite constellation can be used to calculate the zonal harmonics up to the sixth order of astronomical body for which these values may not be precisely known. For both Earth and Jupiter the J2, J4 and J6 values calculated using this method were found to differ from the values used in the propagator taken from literature by only a maximum of 0.00185%. This paper then outlines a procedure to find repeating ground track and sun-synchronous orbits about any astronomical body that can be modelled as an ellipsoid in hydrostatic equilibrium.

Author(s): Shalom Treblow, University of Manchester; Ciara McGrath, University of Manchester; Sung Wook Paek, MIT

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11:30 AM - 11:45 AM

**AAS 25-610**: Information-based Guidance for Angles-only Relative Navigation in Nonlinear Dynamics

Abstract: The increasing presence of small spacecraft in nonlinear dynamics environments demands autonomous navigation strategies capable of dealing with limited sensing capabilities. This work presents a guidance policy that improves angles-only relative navigation performance through impulsive maneuvers that maximize information gain. The maneuver is optimized using nonlinear programming under constraints on proximity to a reference trajectory and fuel consumption. A test case involving two spacecraft on bounded lunar orbits demonstrates improved state observability. Applications include formation flying, satellite inspection, and asteroid exploration missions, where enhanced navigation performance is essential for mission success in complex dynamical environments.

Author(s): Sergio Bonaccorsi, Politecnico di Milano; Alberto Fossà, Vyoma GmbH; Roberto Armellin, Te Punaha Atea - Space Institue, The University of Auckland; Pierluigi Di Lizia, Politecnico di Milano; Renato Zanetti, The University of Texas at Austin

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12:00 PM - 12:15 PM

**AAS 25-634**: Self-supervised diffusion model fine-tuning for costate initialization using Markov Chain Monte Carlo

Abstract: Global optimization of long-duration, low-thrust spacecraft trajectories with the indirect method is challenging due to a complex solution space and the difficulty of generating good initial guesses for the costate variables. To address this, we propose a novel framework combining self-supervised fine-tuning of diffusion models with Markov Chain Monte Carlo (MCMC) sampling. Starting from a baseline diffusion model trained on related problems, our approach fine-tunes the model using reward-weighted training based on direct evaluations of constraint violations and objective value. This eliminates extensive upfront data generation and enhances adaptability across transfer scenarios. The proposed method is designed for global and local exploration of the solution space.

Author(s): Jannik Graebner, Princeton University; Ryne Beeson, Princeton University

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12:15 PM - 12:30 PM

**AAS 25-671**: End-to-End Optimization of Low-Thrust Trajectories in Cislunar Space

Abstract: Complex low-thrust trajectories in Cislunar space are commonly designed in segments, with different tools being used for each segment. For example, a low-thrust trajectory from GTO to LLO might be designed with an orbital averaging tool for the GTO to cislunar spiral, a direct or indirect shooting method to transfer to the Moon, and finally back to the averaging tool for the descent spiral to LLO. In this work, we present an approach for simultaneously solving all of these phases in a

single tool. We then present a worked example, including a transition to high fidelity for all mission phases.

Author(s): Jacob Englander, Johns Hopkins Applied Physics Laboratory; Jackson Shannon, Johns Hopkins Applied Physics Laboratory

# Poster Session

## Wednesday, 08/13/25, 2:00 PM - 5:00 PM

## Session Chair(s): Brian Gunter (Georgia Institute of Technology), Tarek Elgohary (University of Central Florida)

## Room: Grand Ballroom

2:00 PM - 5:00 PM

**AAS 25-701**: Hybrid Methods for Efficient Interplanetary Trajectory Design

Abstract: This paper presents a perturbation-aware framework for early interplanetary trajectory design, offering a lightweight alternative to traditional two-body methods. By propagating Lambert arcs under solar radiation pressure (SRP), the method reveals how persistent forces reshape feasibility—eliminating over 34% of classically valid Earth–Mars transfers. A new SRP ΔV rate metric highlights sensitivity trends across the design space. Unlike optimisation, which can miss broader patterns, this approach could enable structured, global inspection and early identification of interplanetary paths. It also models re-targeting under perturbation, informing mid-course strategy. As a pre-optimisation filter, it enhances design-space visibility while remaining computationally efficient and operationally relevant.

Author(s): Belen Lopez Pardo, University of Manchester; Ciara McGrath, University of Manchester; Katharine Smith, University of Manchester

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2:00 PM - 5:00 PM

**AAS 25-554**: Solar Sail Orbits in Cislunar Space for Lunar Surface Surveillance

Abstract: Repeatedly observing the lunar surface at close ranges possesses significant chal-lenges. In this paper, we present results from an ongoing study that explores the feasibility of conducting comprehensive surveying of the entire lunar surface from an altitude of 10 km, within a 30-day response window. To address the high cost of traditional propulsion methods, we propose leveraging solar sail technology. Our preliminary findings indicate it is feasible to scan approximately one-eighth of the lunar surface within the specified altitude and time constrains by maintain-ing the spacecraft in the vicinity of the Earth-Moon Lagrange points and perform-ing occasional low altitude excursions.

Author(s): Megan Estrada, NASA Marshall Space Flight Center

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2:00 PM - 5:00 PM

**AAS 25-678**: Non-Spherical Secondary Augmented Circular Restricted 3-Body Problem

Abstract: The CR3BP is a simplistic system that describes the dynamics of three bodies orbiting each other. Periodic orbits in this system have been used for several missions, and transfer trajectories may leverage unique dynamic structures to reduce their fuel cost. However, spacecraft in the vicinity of the primaries are likely to experience significant non-spherical effects, rendering traditionally optimal control designs sub-optimal. This work studies an augmentation to the CR3BP which considers non-spherical effects of the secondary body. For an assumed fidelity, equations of motion are derived and propagated to compare periodic orbits and low-thrust optimal trajectories with the traditional model.

Author(s): Alex Diehl, Rensselaer Polytechnic Institute; Sandeep Singh, Rensselaer Polytechnic Institute

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2:00 PM - 5:00 PM

**AAS 25-799**: Using Multiple Model Adaptive Estimation of Unscented Kalman Filter Parameters for

Cislunar Navigation

Abstract: The increasing number of missions in cislunar space demands robust state estimation in nonlinear gravitational environments. Traditional filters often lack accuracy in these complex regions. This project develops an adaptive method for spacecraft state estimation using a Multiple Model Adaptive Estimation (MMAE) approach within an Unscented Kalman Filter (UKF). The MMAE framework runs multiple UKFs with varied tuning parameters, selecting the optimal one in real time based on performance. This adaptive strategy enhances filter robustness and reliability across dynamic regimes. Through simulation, the method aims to demonstrate improved accuracy and stability for spacecraft navigation in the challenging cislunar domain.

Author(s): Meredith Wilmer, XAnalytix Systems, LLC and SUNY University at Buffalo; John Crassidis, University at Buffalo, State University of New York; Chris Nebelecky, University at Buffalo/CUBRC

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2:00 PM - 5:00 PM

**AAS 25-588**: ISS Control-Structure Interaction Mitigation Study

Abstract: An analysis is performed on three control-structure interaction (CSI) mitigation strategies as applied to the International Space Station: a PID controller, flex filter, and phase plane controller. A platform is designed to model both the rigid-body dynamics and flex body dynamics of a generic spacecraft. For the purpose of this paper, the platform models the International Space Station in a 400km circular orbit subject to gravity gradient disturbance torque only. A PID controller, flex filter, and phase plane controller are designed and implemented on the platform. The results of the techniques are summarized in a trade study.

Author(s): Amanda Macha, Texas A&M University; Kyle DeMars, Texas A&M University; Jiann-Woei Jang, Draper

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2:00 PM - 5:00 PM

**AAS 25-902**: Probability of Collision Between Two Rigid Bodies

Abstract: The problem of quantifying the probability of collision between two rigid bodies that exhibit general relative motion is considered. Traditional approaches to evaluate the collision probabilities between spheres in three degrees of freedom are discussed with special consideration on long-term encounters between the particles of interest. Engineering approximations are presented that enable the evaluation of the collision probabilities between rigid bodies as a sum of the particle collision probabilities. Applications to spacecraft servicing demonstrate the utility of the proposed work.

Author(s): Manoranjan Majji, Texas A&M University, College Station; Luke Murphy, Texas A&M University

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2:00 PM - 5:00 PM

**AAS 25-926**: Comparison of Techniques to Estimate Thrust from Launch Vehicle IMU Measurements

Abstract: Launch vehicles rely on Inertial Measurement Units (IMUs) for precise localization. These sensors provide linear acceleration and angular velocity. From these readings, position, velocity, and Euler angles of the rocket are commonly recovered. This paper will explore different optimization methods to also recover the thrust of the rocket from IMU readings with measurement noise. For a simplified approach, constant thrust of a launch vehicle from a sample of IMU readings of a vertical takeoff was estimated. The nonlinear least squares method, particle swarm optimization, and genetic algorithm were then compared to estimate thrust.

Author(s): Samuel Horine, Embry-Riddle Aeronautical University; Troy Henderson, Embry-Riddle Aeronautical University; Daniel Lopez, Embry-Riddle Aeronautical University

2:00 PM - 5:00 PM

**AAS 25-810**: Calibration Maneuver Plan For GRACE-Continuity

Abstract: The Gravity Recovery and Climate Experiment - Continuity (GRACE-C) mission will extend the mass change records establish by the former GRACE and GRACE Follow-On (GRACE-FO) missions. Build on the heritage on those mission, the project Science Data System developped a Maneuver Calibration plan for in-orbit calibrations aiming at veryfing and satisfying project requirements for instruments positions and alignements, as well as instrument response, that have direct impact on the instruments observations accuracy and indirect impact on the quality of the monthly gravity solutions estimated from them.

Author(s): Nadege Pie, Center for Space Research, The University of Texas at Austin; Furun Wang, Center for Space Research, The University of Texas at Austin; Himanshu Save, Center of Space Research, The University of Texas at Austin; Christopher McCullough, Jet Propulsion Laboratory; David Wiese, Jet Propulsion Laboratory

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2:00 PM - 5:00 PM

**AAS 25-864**: End-To-End Measurement Validation For The Quantum Gravity Gradiometer Pathfinder Mission

Abstract: Quantum gravity sensors, based on cold atom interferometry, represent a new paradigm shift in gravity sensing. The Quantum Gravity Gradiometer pathfinder (QGGpf) is to be the first step toward the deployment of a science grade instrument (SGI) into low Earth orbit (LEO) capable of delivering a spatial-temporal resolution of Earth gravity field. The QGGpf Science Adisory Group (SAG) is developing end-to-end measurement validation (E2EMV) concepts through forward modelling appraoches to verify the key benefits of quantum sensing technologies and with the ultimate goal of delivering the first ever Earth gravity model derived from quantum sensors.

Author(s): Nadege Pie, Center for Space Research, The University of Texas at Austin; Srinivas Bettadpur, The University of Texas at Austin; Furun Wang, Center for Space Research, The University of Texas at Austin; David Wiese, Jet Propulsion Laboratory; Bryant Loomis, NASA GSFC; Benjamin Krichman, UT Austin Center for Space Research; geethu Jacob, University of Texas at Austin

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2:00 PM - 5:00 PM

**AAS 25-790**: Backsubstitution Method for Prescribed Motion Actuators with Attached Dynamic Sub-Components

Abstract: Advancements in actuated spacecraft components such as robotic manipulator arms, articulating solar arrays, and other gimballed attachments have prompted a need for the simulation software development of complex actuated spacecraft components. Previous work using the Backsubstitution Method formulated the dynamics for N prescribed motion components and N chained translational or rotational components attached to a central rigid hub. Seeking to expand the current simulation capability under the assumptions of the Backsubstitution Method, this work develops the new ability to simulate select prescribed motion-relative branching of spacecraft components

Author(s): Leah Kiner, University of Colorado Boulder; Hanspeter Schaub, University of Colorado

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2:00 PM - 5:00 PM

**AAS 25-791**: Modeling and Control for Distributed Measurements of the Earth's Energy Imbalance

Abstract: The scientific objective of this work is to obtain high accuracy estimates of the Earth's Energy Imbalance (EEI). This robust metric quantifies the difference between the absorbed solar radiation, and the emitted infrared radiation. This paper proposes to monitor and map the EEl in-orbit,

using high-accuracy accelerometry on spherical spacecraft. We focus on the dynamics and an optimal control framework of a formation of spacecraft to enable high-precision measurements of the EEl. The controller also maintains the desired spin, minimizes the deviation from the orbital normal to a maximum of one degree,  while minimizing the relative attitude error between the spacecraft.

Author(s): Rayan Mazouz, NASA Jet Propulsion Laboratory; Marco Quadrelli, Jet Propulsion Laboratory; Rashied Amini, Jet Propulsion Laboratory; Maria Hakuba, Jet Propulsion Laboratory, California Institute of Technology4800 Oak Grove Dr; Charles Reynerson, Jet Propulsion Laboratory; David Wiese, Jet Propulsion Laboratory

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2:00 PM - 5:00 PM

**AAS 25-560**: Enhancing Deep Space Optical Navigation: Deep Learning Models for Mars and Asteroids Flyby Image Processing

Abstract: Autonomous navigation is essential for deep space missions due to the delay in signals. The more remote the spacecraft is, the more valuable autonomous modes become. Camera images are common and intuitive measurements used for OpNav.  The challenge lies in robustly extracting valuable information via image processing for on-board state filtering. This work shows that integrating deep learning models for image processing within an OpNav pipeline can improve spacecraft autonomy. CNN, ResNet, and CNN-LSTM architectures were developed to track the center of brightness and mass of celestial bodies. Models were trained and tested using Basilisk simulation data.

Author(s): Bushra Aldhanhani, Technology Innovation Institute; Thibaud Teil, Laboratory of Atmospheric Space Physics, CU Boulder

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2:00 PM - 5:00 PM

**AAS 25-768**: A Hierarchical Decision-Making Framework for Autonomous and Adaptive Planetary Robotics

Abstract: We propose a hierarchical decision-making framework for autonomous planetary robotics, centered around a modular Large Language Module (LLM)-based orchestrator that integrates high-level planning with low-level control. The system coordinates heterogeneous robotic platforms through a dual-loop architecture, where guidance and control are, depending on the target platform and mission specification, driven by either Deep Reinforcement Learning (DRL) policies or classical robust schemes. A key capability of the proposed architecture relies on the possible integration of continual learning mechanisms. By enabling real-time policy refinement and mission adaptation in resource-constrained, stochastic environments, this framework ensures robust and scalable autonomy for future space exploration.

Author(s): Miguel Leiva, Universidad Politecnica de Madrid; Victor Rodriguez-Fernandez, Universidad Politécnica de Madrid (UPM); Hodei Urrutxua, Universidad Rey Juan Carlos; Nicolás Gastón, Indra Sistemas S.A.

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2:00 PM - 5:00 PM

**AAS 25-815**: Diffusion Model-Based Solver for Two-Point Boundary Value Problems Between the Moons

Abstract: Recent initiatives such as NASA's Commercial Lunar Payload Services program have dramatically expanded opportunities for lunar transportation, driving a growing need for advanced trajectory designs that exploit lunar gravity assists. Such techniques can effectively increase or decrease the hyperbolic excess velocity, enabling mission planners to achieve greater trajectory flexibility and accommodate diverse mission objectives under stringent $\Delta V$ constraints. The CR3BP lacks the  analytic expressions and exhibits significantly greater multimodality. We propose a diffusion model-based framework for solving two-point boundary value problems in the CR3BP and demonstrate its application to Moon-to-Moon transfers with demonstrating the diversity of feasible trajectories.

Author(s): Hirotaka Okada, The University of Tokyo; Yosuke Kawabata, The University of Tokyo; Naoya Ozaki, ISAS, JAXA; Hiraiwa Naoki, ISAS, JAXA; Satoshi Ikari, The University of Tokyo; Ryu Funase, The University of Tokyo; Shinichi Nakasuka, The University of Tokyo

2:00 PM - 5:00 PM

**AAS 25-827**: Sequence and Operator-Based Learning Frameworks for Orbit Prediction Using Resident Space Object Historical Data

Abstract: This work introduces SCOPE, a modular orbit prediction framework for Resident Space Objects (RSOs) based on learning from historical orbital data. The study addresses limitations in generalization and adaptability of current machine learning approaches, especially under realistic operational constraints. SCOPE integrates both transformer and neural operator architectures, with data-driven and physics-informed variants, to predict short and extended-horizon trajectories using equinoctial elements and drag parameters from TLEs. A roll-over inference strategy and hybrid loss formulation are evaluated to improve long-term accuracy and physical consistency. Preliminary results suggest SCOPE offers a scalable alternative to traditional propagators for catalog prediction and autonomous operations.

Author(s): Brandon Escamilla, Universidad Politécnica de Madrid; Victor Rodriguez-Fernandez, Universidad Politécnica de Madrid; Hodei Urrutxua, Universidad Rey Juan Carlos

2:00 PM - 5:00 PM

**AAS 25-565**: Pseudo-Arclength Continuation and Variational Autoencoders for Invariant Manifolds of Periodic Orbits around Asteroids

Abstract: A comprehensive understanding of the dynamical environment surrounding asteroids is essential for exploration missions, planetary defense and so on. Invariant manifolds play a significant role in the dynamic analysis. However, the existence of high-dimensional invariant manifolds for periodic orbits around asteroids presents challenges for their investigation. This article proposes a method for the computation of local manifolds with the corresponding skeleton orbits and the generation of manifold surfaces. The former employs the pseudo-arclength continuation algorithm to reduce computational complexity, while the latter utilizes Variational Autoencoders to enhance generation efficiency. Their geometric characteristics are qualitatively analyzed, providing insights for subsequent dynamic analysis of asteroid environments.

Author(s): Zihan Liu, Tsinghua University; Fanghua Jiang; Li Junfeng,

2:00 PM - 5:00 PM

**AAS 25-742**: Optimal transfer and rendez-vous into constellations of near-circular orbit

Abstract: This work addresses the problem of inserting a satellite into a near-circular constellation, with the correct phasing. A relative elements based model is built synoptically for Geostationary and inclined orbits, accounting for finite thrust and perturbations, and used to get minimum DV solutions with a NLP solver. Not modeled effects are managed including the optimizer in a differential corrector with a propagator in the loop. We present several tests, including transfer between Sun-Synchronous orbits, insertion into Galileo and Geostationary box. The optimization results to be quite efficient, quickly providing solutions for mission analysis or precise solutions for flight

Author(s): luigi imperi, Thales Alenia Space Italia; Simone Proietti, Thales Alenia Space Italia

2:00 PM - 5:00 PM

**AAS 25-771**: Linear Visual Odometry for Autonomous Spacecraft Proximity Operations

Abstract: This paper introduces a linear visual odometry method for stereo cameras by re-formulating egomotion estimation within the Optimal Linear Attitude Estimator framework. By treating inter-frame 3D point correspondences as vector observations in the body frame between two time instances, the method estimates relative rotation via a closed-form least-squares solution. Translation is simultaneously recovered through linear constraints on the same correspondences, enabling full 6-DOF egomotion estimation. The approach avoids nonlinear optimization, resulting in a computationally efficient and noise-robust solution. Experimental results demonstrate competitive accuracy while offering significant gains in runtime performance.

Author(s): Graeme Sutterlin, Pennsylvania State University; Roshan Eapen, ; Puneet Singla, The Pennsylvania State University

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2:00 PM - 5:00 PM

**AAS 25-782**: Fuel – Time Trade Space analysis for the Rendezvous problem: How to establish a common ground for the different RPO procedures.

Abstract: We propose a methodology to compare different RPOs. We identify a trade space that focuses on Fuel consumption and Time to perform the RPO. By using the theoretical minimum-fuel problem solution as a reference to define the trade space, we can compare the performance of our RPO problem: any deviation from the reference solution will imply a decrease in performance from the fuel consumption viewpoint, and a change in the operation time. This trade space can be used to evaluate the performance of different RPO methodologies. Moreover, we can translate any simulation, test, or demonstration into this trade space.

Author(s): Cristobal Garrido, University of Southern California; David Barnhart, University of Southern California

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2:00 PM - 5:00 PM

**AAS 25-657**: Motion Planning for Grasping Uncooperative Target using Space Robotic Arm

Abstract: Motion planning in joint space is essential for feasible trajectory generation of space robotic arms, as it directly handles joint variables without relying on inverse kinematics. A motion planning in the joint space is proposed for a space robotic arm to track a dynamic target. The target is mapped into the joint space, and an initial path is generated using Jump Point Search. When the target moves, the relative position is rapidly computed using the Jacobian. The search space is confined using current joint angles and previous path information to efficiently update the trajectory. The proposed algorithm was validated in a simulation environment.

Author(s): Sara Woo, Korea Aerospace University; Heokjune You, Korea Aerospace University; Kenwoo Kim, Korea Aerospace University; Hyunju Lee, Korea Aerospace University; Dongwon Jung, Korea Aerospace University

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2:00 PM - 5:00 PM

**AAS 25-796**: LASER ABLATION FOR EFFICIENT SPACE DEBRIS REMOVAL

Abstract: This research explores laser ablation for space debris removal, using laser-induced plasma to adjust debris trajectories for safe re-entry or transfer to graveyard orbits. Nanosecond pulsed laser ablation (100 kJ/m2 fluence, 6 ns pulse) will be used to quantify mass loss and refine momentum-transfer models affecting orbital paths. Additionally, femtosecond pulsed laser ablation (100 fs pulse) will be examined for its directional plasma plume, offering enhanced control for tasks like reducing debris rotation. The study also addresses challenges such as real-time tracking and targeting, highlighting the potential of ground-based laser systems for effective and precise space debris mitigation.

Author(s): Prasoon Diwakar, South Dakota School of Mines and Technology; Jaden Dougal, South

Dakota School of Mines and Technology

2:00 PM - 5:00 PM

**AAS 25-591**: Symplectic Collocation for Optimal Control Indirect Methods

Abstract: This paper investigates symplectic collocation methods for solving optimal control problems using indirect methods. By preserving the Hamiltonian structure, symplectic integrators are well-suited for long-term dynamical systems, which naturally arise in the necessary conditions for optimality in optimal control problems. Three schemes—Gauss, Radau, and Lobatto IIIA-IIIB—are tested on a low-thrust orbital rendezvous problem. While Gauss and Lobatto are symplectic, Radau is not, enabling performance comparison. Results show symplectic methods conserve the Hamiltonian effectively, even with coarse discretization, and achieve higher objective accuracy than non-symplectic approaches. The study highlights symplectic collocation's advantages for indirect optimal control.

Author(s): Yilin Zou, Tsinghua University; Fanghua Jiang; Junfeng Li,

2:00 PM - 5:00 PM

**AAS 25-630**: Leveraging Low-Thrust Optimization for Tori Intersection Transfers in the Earth-Moon System

Abstract: With the advent of advanced space exploration, novel approaches are essential to navigate the Earth-Moon system. The Lunar Gateway project is pivotal for lunar and interplanetary missions, necessitates new rendezvous strategies and transfer routes. Several methods, including Lunar Flybys, multi-impulse maneuvers and solutions using periodic orbits, have been proposed to address these challenges. This investigation aims to use Quasi-Periodic Orbit (QPO) intersections combined with low thrust to reduce costs and improve transfer flexibility. By leveraging Pontryagin's Maximum Principle (PMP), we facilitate efficient transfers between QPOs, enhancing mission success and flexibility.

Author(s): Nathaniel Sailor, Purdue University; Matteo Santacesaria, Politecnico di Milano; Andrea Capannolo, Purdue University

2:00 PM - 5:00 PM

**AAS 25-739**: A low thrust trajectory optimizer for autonomous orbit raising in Earth applications

Abstract: Performing an orbit raising into the operational orbit with electric propulsion is a strategy to increase P/L mass in orbit. Enabling the autonomous execution of the raising requires a reliable and efficient algorithm to compute the optimal solution in real time. With this purpose, we analyze and discuss a refinement of the Directional Adaptive Guidance algorithm, testing its applicability in different scenarios, covering transfers into Geostationary and inclined orbits, and comparing against a benchmark global optimum. The results show how a suited a priori tuning of the algorithm can provide near-global optimal solutions with an inefficiency lower than 1%

Author(s): luigi imperi, Thales Alenia Space Italia; Simone Proietti, Thales Alenia Space Italia; Leonardo Mazzini, Thales Alenia Space Italia; Glauco Di Genova, Telespazio Italia

2:00 PM - 5:00 PM

**AAS 25-740**: Conflict-Aware Scheduling of Stellar and Lunar Observations on LEO Satellites

Abstract: Low Earth Orbit (LEO) Earth observation satellites, primarily designed for terrestrial imaging, offer opportunities for secondary lunar and stellar observations to support sensor calibration. We present an integrated scheduling framework that uses orbital propagation and celestial ephemerides to identify observation windows considering geometric conditions such as solar illumination, Earth occultation, and lunar phase. Our method uniquely incorporates star-tracker visibility constraints—ensuring attitude maneuvers for celestial imaging do not compromise the satellite's primary Earth-pointing orientation. This approach enables optimal celestial observation periods, improving sensor calibration accuracy and enhancing overall scientific mission return.

Author(s): Kyunsang Park, Korea Aerospace Research Institute; Jeonghoon Hyun, Korea Aerospace Research Institute; Hwayeong Kim, Korea Aerospace Research Institute; Seok Teak Yun, Gyeongsang National University

2:00 PM - 5:00 PM

**AAS 25-747**: Design and Evaluation of Minimum-Configuration Spinning Planetary Lander Using Solid Rocket Motors

Abstract:

This paper proposes a minimum-configuration spinning planetary lander using solid rocket motors with thrust vector control. While SRMs are rarely used for soft landing due to their fixed-thrust nature, the proposed design significantly reduces complexity and launch mass. This enables high-frequency missions and access to small, remote, or dynamically uncertain bodies. Scalability is demonstrated through motor sizing, and a design methodology is derived from spin dynamics and attitude tilt analysis. A Monte Carlo simulation targeting Ceres shows that well-structured guidance can reduce landing dispersion even with limited control authority, revealing the potential of minimalistic architectures under strict constraints.

Author(s): Kaho Nakagawa, The University of Tokyo; Haruhito Ohki, The University of Tokyo; Tetsuya Kusumoto, Graduate School of Engineering, The University of Tokyo; Yuichi Tsuda, Japan Aerospace Exploration Agency

2:00 PM - 5:00 PM

**AAS 25-748**: Exact Analytical Solution for Nodal Precession Rate Change in Circular Orbits and Its Applications

Abstract: This paper presents an exact analytical solution for the secular RAAN drift change induced by a single arbitrary impulse in a circular orbit under Earth's J2 perturbation. The impulse is defined in the local VNB frame, and the post-impulse orbit is derived using geometric vector relations and spherical trigonometry. The result captures all $\Delta v$ components without linearization or iteration. As the precession rate change is expressed in terms of impulse magnitude and direction, the formulation may support optimizing impulse orientation under fixed $\Delta v$. A practical mission application will be presented in the full paper.

Author(s): Han-gyeol Kim, KAIST; Jinsung Lee, Satellite Technology Research Center / Korea Advanced Institute of Science and Technology; Youngbum Song, Korea Astronomy and Space Science Institute; Jaemyung Ahn, Korea Advanced Institute of Science and Technology

2:00 PM - 5:00 PM

**AAS 25-766**: Spacecraft Navigation using Angles Only Measurements in Cislunar Space

Abstract: With the burgeoning number of cislunar missions, space-based navigation is becoming increasingly important. This research examines angles-only navigation in cislunar space, with a target (Lunar Gateway) and a chaser satellite orbiting in a close-by QPO. The second-order EKF (SOEKF) will be studied along with the standard EKF and UKF, as a major contribution to existing literature. Preliminary results show that the SOEKF performs similarly to the EKF, with a slight advantage in close proximity chaser orbits. The expected result is a detailed characterization of the performance of the SOEKF, under various constraints, against the EKF and UKF.

Author(s): Amogha Sarang, Purdue University; Andrea Capannolo, Purdue University

2:00 PM - 5:00 PM

**AAS 25-809**: A Geometric Algebra Framework for Spacecraft Pose Estimation Using Points and Lines

Abstract: Pose estimation from images is a critical capability for spacecraft optical navigation, enabling key activities such as relative navigation and mapping of planetary bodies. This paper proposes a pose estimation algorithm to solve the perspective-n-point (PnP) problem using geometric algebra (GA). The GA formulation yields a series of quadratic constraints that are defined by the geometry of point and line projections onto the image plane. The problem is then cast into linear algebra for more efficient computation. This formulation offers a unified algorithm to handle point and line correspondences and provides geometric intuition that is less obvious in conventional methods.

Author(s): Jennifer Nolan, Georgia Institute of Technology; John Christian, Georgia Institute of Technology

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2:00 PM - 5:00 PM

**AAS 25-830**: Multi-Probe Exploration of Trans-Neptunian Objects Using a Single Launch

Abstract: This concept study outlines a dual-probe mission to Ixion and Huya, along with other targets, using a combined Delta-V Earth Gravity Assist and Powered Jupiter Gravity Assist trajectory. The architecture lowers launch energy and cuts down transfer time, all while staying within Falcon Heavy's recoverable limits. We modeled the mission using MAnE software and showed that around 1000 kilograms of payload can be delivered over 14.8 to 15.6 years. The approach is modular, scalable to other TNOs, and keeps solid performance margins. It's a practical way to get strong scientific returns without needing multiple launches or overly complex mission profiles.

Author(s): Jacob Ralston, University of Tennessee, Knoxville; Jonathan Bailey, University of Tennessee, Knoxville; Jaeden Kenworthy, University of Tennessee Knoxville; Canaan Anderson, University of Tennessee, Knoxville; James Lyne, The University of Tennessee

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2:00 PM - 5:00 PM

**AAS 25-839**: Approximation of Extremal Field Maps for Mission Planning

Abstract: For indirect methods for solving optimal control problems (OCPs), the necessary information to describe the optimal solution is contained within the optimal initial costates and the differential equations. For any OCP, a range of optimal solutions can be pre-computed at discrete sets of parameters and and efficiently stored as an Extremal Field Map (EFM). Using interpolation, the EFM provides optimal solutions for any set of parameters within a finite range. Orthogonal polynomial approximation is used to smoothly approximate EFM data over a parameter space around a nominal trajectory, to be used as a quasi-closed loop guidance system.

Author(s): Austin Widmer, Texas A&M; John L. Junkins, Texas A&M University

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2:00 PM - 5:00 PM

**AAS 25-842**: Solar Sail Reachability Analysis via Optimal Control in the Earth-Moon System

Abstract: Solar sail spacecraft use photon momentum transfer as their primary mode of propulsion. The synergy between a sail's continuously-available thrust and the dynamical sensitivity of motion in the cislunar environment warrant an investigation of the reachability of such systems, which have the potential to be useful in cislunar applications benefiting from mobility. Optimal control theory is used to analyze the solution space for flow throughout the environment which minimize transfer time and maximize dynamical reach. A sampling of this solution space parametrizes a 'time-to-go' map for a sailcraft with arbitrary characteristics and initial placement within the system.

Author(s): Zachary Funke, University of Colorado Boulder; Marcus Holzinger, University of Colorado Boulder

2:00 PM - 5:00 PM

**AAS 25-883**: A Differential Geometric Approach to Measuring Nonlinearity for Cislunar Navigation

Abstract: The highly nonlinear dynamics of cislunar space can degrade the performance of onboard GNC algorithms that rely on linear approximations of the system dynamics. This paper develops measures of nonlinearity from the perspective of differential geometry by connecting the concept of nonlinearity with the curvature of an embedded surface. This approach enables us to derive several measures that are analytic. They are evaluated along sample cislunar orbits and compared to nonlinearity indices, an established method of measuring nonlinearity. Finally, it is demonstrated that these measures can improve the performance of a cislunar EKF by using them to inform propagation frequency.

Author(s): Liam Smego, Georgia Institute of Technology; John Christian, Georgia Institute of Technology

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2:00 PM - 5:00 PM

**AAS 25-907**: Toward Early Classification of Station-Keeping Behavior in GEO via Unsupervised Time Series Clustering

Abstract: This work presents an unsupervised method for learning meaningful taxonomies for diverse station-keeping (SK) behaviors exhibited by GEO satellites. By applying HDBSCAN with DTW to mean-centered longitude segments, we identify interpretable behavior classes without relying on priors. Preliminary results show that cluster groupings correlate with propulsion type and support further deconstruction of SK patterns into distinct sub-classes indicative of underlying factors such as lifecycle phase or operator-specific control strategies. By preserving time-series dynamics, this approach enables generalized behavior classification for large satellite populations on the one-week timescale and detailed behavioral insights in support of tactical awareness in the GEO regime.

Author(s): Haley E. Solera, Massachusetts Institute of Technology; Thomas G. Roberts, Georgia Institute of Technology; Richard Linares, Massachusetts Institute of Technology

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2:00 PM - 5:00 PM

**AAS 25-913**: Adaptive Mesh Refinement for Optimal Control Using Superconvergent Patch Recovery

Abstract: This paper presents a one-step adaptive mesh refinement method for optimal control problems using a recovery-based mesh density framework. The approach employs Superconvergent Patch Recovery (SPR) on a coarse solution to derive an optimal density by fitting accurate gradients at superconvergent points. These points, more accurate than nodal values, enable improved error estimation via local least-squares fitting. The resulting density guides non-uniform mesh redistribution, enhancing accuracy without increasing degrees of freedom. Validated on a benchmark problem, the SPR-based framework is efficient, accurate, and extendable to multi-dimensional optimal control applications.

Author(s): Aniket Bire, Texas A&M University; John L. Junkins, Texas A&M University; Theofanis Strouboulis, Texas A&M University

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2:00 PM - 5:00 PM

**AAS 25-538**: Spacecraft State and Covariance Interpolation via Unscented Transforms

Abstract: The growing number of artificial satellites in near-Earth space demands accurate prediction of states and uncertainties for collision avoidance. However, covariances are often unavailable or tied to undisclosed dynamical models, complicating interpolation. We propose a novel method using the Unscented Transform (UT) to interpolate satellite states and covariances without requiring knowledge of underlying dynamics. Sigma points are generated at discrete times, and overlapping intervals are used to ensure numerical stability and reduce endpoint errors. We present the mathematical

formulation, validate the method through numerical experiments, and demonstrate its relevance for orbital estimation and space situational awareness.

Author(s): Nayan Jangid, University of Illinois Urbana-Champaign; Siegfried Eggl, University of Illinois at Urbana-Champaign

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2:00 PM - 5:00 PM

**AAS 25-683**: Evolving Attack-Resistant Satellite Constellation Designs

Abstract: For decades, the space environment was a sanctuary where spacecraft faced only natural threats. Today, cyberattacks on satellite constellations have become a concerning threat. Constellations must be designed for resilience against such attacks; not possible with traditional design methods. This paper introduces a constellation design framework which accounts for the presence of a reactive adversary. This framework combines a dynamical model of a constellation with a game-theoretic model of the constellation's operators and attackers, which is solved via an evolutionary algorithm. The outcome of the game is used as a fitness function for an evolutionary algorithm that optimizes the design.

Author(s): Raymond Patrick, Auburn University; Sean Harris, Auburn University; Daniel Tauritz, Auburn University; Samuel Mulder, Auburn University; Davide Guzzetti, Auburn University

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2:00 PM - 5:00 PM

**AAS 25-737**: Observer-based Stochastic Optimal Control for Spacecraft Formation Flying with Mode Switching

Abstract: This paper proposes an optimal control framework for observer-based stochastic hybrid systems, focusing on satellite formation flying. The method integrates belief space planning under the Maximum Likelihood Observation assumption with mode scheduling using the mode insertion gradient. This allows to account for observation uncertainty and discrete transitions, such as sensor switching or thruster actuation. The effectiveness of the method is demonstrated through numerical simulations, showing high-precision formation control is achievable by sequentially switching between multiple sensors based on their availability and accuracy. While motivated by formation flying, the framework is applicable to a broad class of hybrid systems under uncertainty.

Author(s): Michinari Kake, The University of Tokyo; Satoshi Ikari, The University of Tokyo; Ryu Funase, The University of Tokyo; Shinichi Nakasuka, The University of Tokyo

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2:00 PM - 5:00 PM

**AAS 25-636**: Progress on the radar-based mass estimation of space objects

Abstract: Many tracked space objects in orbit lack size or mass data, critical for assessing collision risks. The NASA Conjunction Assessment Risk Analysis (CARA) team has developed processes to estimate the unknown properties using radar cross-section data. However, previous processes were observed to be impacted by anomalies and inaccuracies in reported ballistic and solar radiation pressure coefficients. This paper presents key improvements, including outlier filtration and the introduction of perigee altitude dependency, to the CARA mass estimation procedure and illustrates the performance of the new process and how these changes reduce mass estimation uncertainties and improve accuracy.

Author(s): Sina Es haghi, Omitron Inc.; Luis Baars, Omitron, Inc.; Doyle Hall, Omitron, Inc.

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2:00 PM - 5:00 PM

**AAS 25-804**: Showcase and Comparison of Three Methods for Visualizing Near-Earth Satellite Conjunction Events

Abstract: The field of satellite conjunction assessment, dating back to the early NASA Space Shuttle Program, is a cornerstone of modern space environment aware-ness and safety, with the goal of keeping spacecraft in orbit safe from poten-tially catastrophic collisions. This paper explores three different methods for visualizing near-Earth satellite conjunction events (ellipsoid, bananoid, and point cloud), including derivations, analyses of use cases, and comparisons to currently-employed methods. Parallels are highlighted between these visualiza-tion methods and the corresponding probability of collision calculation meth-ods developed by NASA CARA. A discussion is included of future visualiza-tion considerations and visualizations for non-near-Earth (e.g., cislunar) con-junctions.

Author(s): Erick White, Omitron; Luis Baars, Omitron, Inc.

2:00 PM - 5:00 PM

**AAS 25-526**: Multi-axis Gyroscope Calibration Utility

Abstract: This paper presents the algorithm and test results for a spacecraft gyroscope calibration method (called simply GCAL). GCAL compares rates measured on each gyro channel with computed reference rates projected onto gyro sensitive axes. GCAL solves for calibration parameters using an iterated Gauss-Newton least-squares method to minimize differences between observed and expected rates on each axis. The constraint that sensitive axes be unit vectors is imposed using a Lagrange multiplier. Reference rates are determined using a Kalman filter/smoother, processing data from gyro and attitude sensors. The paper compares GCAL results with other methods using both simulated and flight data.

Author(s): Joseph E. Sedlak, a.i. solutions, Inc.

# Machine Learning and Artificial Intelligence Applied to Spaceflight IV

Thursday, 08/14/25, 8:00 AM - 10:00 AM

Session Chair(s): Jason Leonard (KinetX)

Room: Dedham

8:00 AM - 8:15 AM

**AAS 25-888**: Reinforcement Learning for Autonomous Low-Thrust Trajectory Design and Tracking to Asteroid Apophis

Abstract: This work uses reinforcement learning (RL) to help a spacecraft reach asteroid Apophis using low-thrust propulsion. The goal is to reduce the need for constant communication with Earth by allowing the spacecraft to make decisions on its own. Two RL strategies are tested: one where the agent learns a full trajectory to the asteroid, and another where it learns to follow a pre-planned path, even when unexpected forces are present. By enabling onboard autonomy and real-time adaptation, RL offers a promising solution for managing complex space missions with less reliance on ground-based support.

Author(s): Roberto Cuéllar, Embry-Riddle Aeronautical University; Reza Karimi, NASA-JPL; Troy Henderson, Embry-Riddle Aeronautical University

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8:15 AM - 8:30 AM

**AAS 25-901**: MW-NeRF: Multi-Wavelength NeRF Models for Spacecraft Modeling in Shadowed Environments

Abstract: Spacecraft operators are often unaware of the shape and size of catalogued spacecraft and debris in their vicinity, resulting in assumptions that can impact mission resources and safety. Neural Radiance Fields (NeRFs) provide a new and powerful method for creating accurate continuous 3D models of scenes, but can struggle with the complex lighting that characterizes orbital environments. We propose MW-NeRF, a novel framework that leverages multi-wavelength imagery to improve visual-band NeRF performance in adverse conditions. This representation captures fine details in illuminated areas while constraining the shape in shadowed regions---delivering robust, high-fidelity 3D reconstructions for enhanced Space Situational Awareness.

Author(s): Logan Selph, University of Maryland - College Park; John Martin, University of Maryland

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8:30 AM - 8:45 AM

**AAS 25-909**: Adaptive Relative Pose Estimation Framework with Dual Noise Tuning for Safe Approaching Maneuvers

Abstract: This work presents an adaptive vision-based estimation framework for Active Debris Removal (ADR) missions targeting uncooperative targets like ESA's ENVISAT. A CNN detects satellite corners from chaser imagery, and 2D detections are converted into 3D measurements using a calibrated camera model. These are fused within an Unscented Kalman Filter (UKF) with a dual adaptive strategy: measurement noise covariance R is tuned via innovation analysis, and process noise covariance Q is adapted using state divergence metrics. High-fidelity simulations demonstrate robust 12-state relative pose estimation under varying visibility conditions, significantly improving performance over non-adaptive filters during eclipse and uncertainty phases.

Author(s): Batu Candan, Iowa State University; Simone Servadio, Iowa State University

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8:45 AM - 9:00 AM

**AAS 25-914**: Online Reinforcement Learning Method For Automatic Satellite Reorientation Under Failures

Abstract: Autonomous recovery under attitude control failures is critical for satellites in safe mode. We propose an online reinforcement learning (RL) framework that trains a controller per failure scenario to reorient the antenna toward Earth. Using Basilisk-based simulations of a CubeSat CAPSTONE model under ADCS failures, we pre-train agents offline with Deep Deterministic Policy Gradient (DDPG) and fine-tune them onboard in a single non-resettable episode with enforced dynamical constraints. We also examine Proximal Policy Optimization (PPO) for online adaptation under power and actuation limits. Preliminary results show successful antenna reorientation without failure priors, supporting enhanced autonomy for deep space missions.

Author(s): Saeed Ahmadi, Embry-Riddle Aeronautical University; Matthew Willoughby, Embry-Riddle Aeronautical University; Hao Peng, Embry-Riddle Aeronautical University

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9:00 AM - 9:15 AM

**AAS 25-524**: Uncertainty-Aware Guidance for Continuous Thrust Transfers Using Gradient Boosting and Temporal Convolutional Networks

Abstract: Long-duration space travel with low control authority demands intelligent in-situ decision-making. Amplified state uncertainty requires careful handling when generating control laws. This work presents a method for generating an uncertainty-aware dataset and training a learning model for autonomous low-thrust guidance. It addresses limitations of onboard replanning by constructing trajectory bundles incorporating state covariance via the Unscented Transform. A Random Forest Regression model is trained to predict control profiles from state and covariance inputs. Results show promising accuracy in prediction, validated by error metrics and trajectory comparisons. This framework reduces dependence on ground-based replanning for deep space missions.

Author(s): Scott Blender, Rensselaer Polytechnic Institute; Sandeep Singh, Rensselaer Polytechnic Institute

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9:15 AM - 9:30 AM

**AAS 25-543**: Structured State Space Sequence Models Transfer Learning Between Circular Restricted Three-Body Problem Orbit Families

Abstract: Machine learning has long been plagued with the reliance on large datasets and computational centers. The deployment of machine learning algorithms in cislunar space remains difficult because of these constraints. This work explores a structured state space sequence model, Mamba, and its ability to perform transfer learning between circular restricted three-body problem orbit families. The results show that Mamba learns and performs time series forecasting at a much higher accuracy compared to LSTMs. Learning the same datasets, Mamba can approximate the time series with less learnable parameters for a marginal increase in computational complexity at forward evaluation time.

Author(s): Hunter Quebedeaux, University of Central Florida; Tarek Elgohary, University of Central Florida

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9:30 AM - 9:45 AM

**AAS 25-845**: A Markov Decision Process Framework for Early Maneuver Decisions in Satellite Collision Avoidance

Abstract: This work introduces a Markov decision process (MDP) framework and a policy gradient algorithm to enable autonomous satellite maneuver decision-making in Low Earth Orbit (LEO), aiming

to minimize fuel while maintaining acceptable collision risks. The decision process for the collision avoidance maneuver (CAM) is modeled as a MDP, where the critical decision is determining when to initiate the maneuver. Analytical models for conjunction risk, fuel expenditure, and transit orbit geometry are incorporated in the model. Compared to a conventional cut-off policy, the trained policy has over 7% higher maneuver frequency while lowering the fuel usage by 50%.

Author(s): Francesca Ferrara, ETH Zurich; Lander Schillinger Arana, Georgia Institute of Technology; Florian Dorfler, ETH Zurich; Sarah Li, Georgia Tech

# Trajectory Design and Optimization VII

Thursday, 08/14/25, 8:00 AM - 10:00 AM

Session Chair(s): Damien Gueho (Geminus.AI)

Room: Duxbury

8:00 AM - 8:15 AM

**AAS 25-672**: Differential Dynamic Programming with Homotopy Continuation for Spacecraft Trajectory Optimization

Abstract: This study presents a homotopy-enhanced differential dynamic programming (DDP) method for solving challenging optimal control problems with high sensitivity or complexity. By introducing a homotopy parameter, the algorithm traces a pseudo-arclength path using quadratic approximations during the backward sweep. Step sizes are adaptively regulated based on the accuracy of expected cost reduction. The proposed approach successfully handles trajectory optimization scenarios where standard DDP fails to converge, particularly in problems with strong nonlinearities or extended durations. The method is broadly applicable and may be extended to various space mission design problems requiring robust optimization strategies.

Author(s): Masahiro Fujiwara, Japan Aerospace Exploration Agency

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8:15 AM - 8:30 AM

**AAS 25-716**: Heteroclinic Transfer Between L1 and L3 in Earth-Moon System

Abstract: In this study, we explore the existence of heteroclinic transfers between Lyapunov orbits around the L1 and L3 Lagrange points in the Earth-Moon system using the Planar Circular Restricted Three-Body Problem (PCR3BP) model. While transfers involving L1 and L2 have been extensively studied, transfers to L3 remain underutilized despite their potential benefits for long-term observation and low stationkeeping requirements. By computing Lyapunov orbits and their associated invariant manifolds, Poincare maps are constructed to identify potential heteroclinic connections. Using this method, two transfer trajectories were found in each energy level. Those trajectories differ in their travel time between L1 and L3.

Author(s): Abdullah Braik, Virginia Tech; Shane Ross, Virginia Tech

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8:30 AM - 8:45 AM

**AAS 25-718**: An Optimization Method for Low-energy Cislunar Trajectories

Abstract: Spacecraft operating in cislunar space are subject to highly nonlinear dynamics and the operational challenges of intermittent communication and navigation uncertainty. Guidance methods that are robust to these challenges and computationally efficient are paramount. Building off recent developments in the application of State Transition Tensors (STTs), this work will develop an optimization framework to achieve probabilistic constraints on low-energy trajectories in cislunar space. We utilize sequential quadratic programming (SQP) to achieve multiple chance constraints with an interior-point method. These constraints are designed to improve the capture into stable manifolds about reference trajectories of interest.

Author(s): Dillon Waxman, University of Colorado, Boulder; Jay McMahon, University of Colorado Boulder, CCAR

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8:45 AM - 9:00 AM

**AAS 25-736**: Aditya-L1 Launch Window Analysis

Abstract: The paper discusses about the launch window analysis for ISRO's first lagrangian mission Sun-earth L1. In this paper, the Differential Evolution Scheme has been developed as an independent tool for backward trajectory design to generate initial bounds for AOP, RAAN, and DeltaV for the full force model. Discrete trajectory solutions were obtained for discretized AOPs using first-order gradients with respect to HOI initial conditions. This was followed by employing polynomial interpolation to evaluate minimum HOI DeltaV. Successively, launch window was generated considering launcher AOP constraints and the penalty limits. Finally, the mission profile was planned meticulously to ensure backup opportunities.

Author(s): Gaurav Vaibhav, INDIAN SPACE REASEARCH ORGANIZATION; Kuldeep Negi, ISRO Satellite Centre (ISAC),ISRO, India

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9:00 AM - 9:15 AM

**AAS 25-745**: Search for L1 optimal Earth-Moon transfer orbits using stable and unstable manifolds

Abstract: We propose a method to search for minimum-fuel Earth-Moon transfer orbits, which become the nonlinear L1 optimal control problems for the CRTBP. The new method uses stable and unstable manifolds for the system where an L1 optimal control input is applied. The Hamiltonian canonical equation is numerically integrated to approximate the manifolds, and they are used to design transfer orbits. It enables us to search for non-low-thrust orbits with a free time interval, considering the maximum admissible acceleration. The proposed method is verified through numerical simulations to search for the $L^1$ optimal Earth-Moon transition orbit efficiently.

Author(s): Yutatsu Nakao, Kyoto University; Ichiro Maruta, Kyoto University; Kenji Fujimoto, Kyoto University

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9:30 AM - 9:45 AM

**AAS 25-798**: Constrained 6DOF Optimal Powered Descent Trajectory Optimization With the Indirect Method

Abstract: Optimal powered descent guidance (PDG) enables the landings of increasingly larger payloads of modern space missions. Indirect methods are an invaluable approach for their accuracy, guaranteed (local) extremality, and theoretical insight gleaned from the necessary conditions (NCs) of optimality. In this study, we derive the NCs for the state-path-constrained fuel- and time-optimal 6DOF PDG pin-point landing problem. Closed-form extremal control expressions are derived subject to all the control constraints, and state-path inequality constraints are enforced with exact penalty functions. Results which satisfy the NCs are presented for the time-optimal problem and compared against DIDO for further validation.

Author(s): Nicholas Nurre, Auburn University; Ehsan Taheri, Auburn University

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9:45 AM - 10:00 AM

**AAS 25-852**: From Impulsive to Finite- and Low-Thrust Maneuvers: A Cislunar Application

Abstract: Impulsive trajectories are notably simpler to generate and optimize compared to their finite- and low-thrust counterparts. A fundamental astrodynamics problem is to convert impulsive trajectories into low-thrust trajectories. This study applies a thrust-continuation based mapping between extremal minimum-$\Delta v$ impulsive and the finite-thrust fuel-optimal trajectories. Two notable features of the proposed method are: 1) guessing the non-intuitive costates is completely circumvented, and 2) multiple-impulse trajectories can be converted into multiple-revolution low-thrust trajectories. The method is used successfully for solving cislunar maneuvers between Halo orbits under circular

restricted three-body dynamics.

Author(s): Keziban Saloglu, Auburn University; Ehsan Taheri, Auburn University

# Cislunar Astrodynamics V

## Thursday, 08/14/25, 8:00 AM - 10:00 AM

## Session Chair(s): Pugazhenthi Sivasankar (University of Central Florida)

## Room: Adrienne Salon

8:00 AM - 8:15 AM

**AAS 25-861**: Cislunar Constellation Reconfiguration via Time-Expanded Assignment Problem

Abstract: This work addresses the reconfiguration problem for cislunar constellations comprising satellites on libration point orbits (LPOs).

The configurations of such constellations can vary significantly based on parameters such as the number of satellites or operational requirements, for example, monitoring a region of interest for space situational awareness applications.

To enable adaptability as these parameters change, we propose a time-expanded assignment problem with a disruption constraint to perform constellation reconfiguration. The problem minimizes total propellant consumption using precomputed low-thrust porkchop plots between the initial and targeted constellation configurations, while limiting the number of satellites transferring at any given time.

Author(s): Yuri Shimane, Georgia Institute of Technology; Gregory Badura, Georgia Tech Research Institute; Koki Ho, Georgia Institute of Technology

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8:15 AM - 8:30 AM

**AAS 25-863**: Set-Based Reachability for Low-Thrust Spacecraft in Two-Body and Cislunar Dynamical Systems

Abstract: This paper investigates zonotope-based reachability analysis for low-thrust spacecraft within two-body and cislunar dynamics. Reachable sets are generated under two-body (Earth-Mars transfer) and circular restricted three-body problem dynamics (L1/L2 Halo orbits, NRHOs) using set-based methods employing Taylor expansions. A state-dependent coefficient (SDC) parameterization is also explored, representing nonlinear dynamics pseudo-linearly for efficient matrix-based set propagation. Resulting reachable sets enable safe trajectory generation and tracking. The study compares model predictive control (MPC) and LQR-based station-keeping techniques using these sets. This approach provides a scalable framework for analyzing spacecraft behavior under complex dynamics and control constraints.

Author(s): Jinaykumar Patel, The University of Texas at Arlington; Kamesh Subbarao, University of Texas at Arlington

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8:30 AM - 8:45 AM

**AAS 25-869**: BEYOND NRHOS: A UNIFIED FRAMEWORK FOR MULTI-SHOOTING CORRECTIONS IN CISLUNAR PERIODIC AND QUASI-PERIODIC ORBITS

Abstract: This paper presents a versatile and computationally efficient approach for deriving Near Rectilinear Halo Orbits and other periodic trajectories in the Earth-Moon Circular Restricted Three-Body Problem. A multi-shooting differential corrector is implemented to enforce periodicity and compute stable NRHO solutions near L2. This framework extends to other orbit families, including Distant Retrograde Orbits, butterfly orbits, and highly stable quasi-periodic orbits around the L5 Lagrange point. Additionally, a single-shooting differential corrector is employed to compute 2D planar periodic orbits around the Moon and 3D periodic orbits around the Earth, essential for long-term lunar exploration, gateway operations, and station-keeping strategies.

Author(s): Pedro J. Llanos, Embry-Riddle Aeronautical University

8:45 AM - 9:00 AM

**AAS 25-870**: Near-Optimal Transfers from Varying Orbit Families to Low-Lunar Orbits via Analytical Lower-Bound Delta-V Comparison

Abstract: With growing interest in recent lunar exploration, efficient transfers from the cislunar orbit families to low-lunar orbits (LLOs) are becoming increasingly critical. Previous studies compute multiple feasible transfer scenarios and find that, while transfer time varies, the total required $\Delta v$ remains nearly constant. This work studies an analytical lower bound for the transfer $\Delta v$ and investigates how LLO orbital elements affect the transfer optimality. Using the global optimization tool pydylan, the study identifies transfer solutions that closely approach the theoretical minimum, providing insight into near-optimal cislunar transfers and validating their efficiency through analytical comparison.

Author(s): Mauro Palomo, Embry-Riddle Aeronautical University; David Canales Garcia, Embry-Riddle Aeronautical University; Seur Gi Jo, Embry-Riddle Aeronautical University; Ryne Beeson, Princeton University; Amlan Sinha, Princeton University; Jannik Graebner, Princeton University

9:00 AM - 9:15 AM

**AAS 25-903**: The Finite-Horizon Time-Varying Vinnicombe Gap Metric for Robust Cislunar Station-Keeping

Abstract: This paper utilizes the Vinnicombe gap (v-gap) metric to analyze controller performance in the context of cislunar orbit station-keeping. This metric quantifies the difference between dynamical systems in terms of their closed-loop behaviors. A new method is derived for computing the v-gap between finite-horizon linear time-varying (LTV) systems. The approach is demonstrated by analyzing a parametrically excited pendulum as a proof of concept, before extending to several cislunar case studies. First, the v-gap is computed between successive orbits in L2 orbit families. Secondly, it is used to compare a periodic halo orbit to trajectories on an associated quasi-periodic torus.

Author(s): Quintin Nelson, Texas A&M University; Manoranjan Majji, Texas A&M University, College Station

9:15 AM - 9:30 AM

**AAS 25-908**: Utilizing a Homotopy Method for Abort Trajectory Generation for the Artemis Missions

Abstract: The circular restricted three body problem (CR3BP) is a powerful tool for constructing abort trajectories guesses for the Artemis missions. Although many trajectories created in the CR3BP converge well when directly transitioned to an ephemeris force model, challenges can arise with regard to computational efficiency and convergence properties of some trajectories. Utilizing a homotopy method as an additional step between the lower-fidelity CR3BP model and the higher-fidelity ephemeris model will decrease time to converge as well as aid in converging previously failed trajectories. This work demonstrates the homotopy approach when designing aborts for the Artemis III mission.

Author(s): Daniel Owen, Advanced Space; Galen Savidge, Advanced Space; Aurelie Heritier, OneWeb; Brian McCarthy, a.i. solutions, Inc

# Attitude Dynamics, Determination and Control II

Thursday, 08/14/25, 10:30 AM - 12:30 PM

Session Chair(s): James Thorne (Institute for Defense Analyses (IDA))

Room: Duxbury

10:30 AM - 10:45 AM

**AAS 25-778**: Real-Time Testing of Satellite Attitude Control with A Reaction Wheel Hardware-In-the-Loop Platform

Abstract: This work is the next stage step toward a comprehensive testing framework for validation of spacecraft attitude control algorithms. The proposed HIL platform includes brushless DC motors and drivers that communicate using a CAN bus, an embedded computer that executes attitude determination and control algorithms, and a satellite simulator that produces simulated sensor data and responds to actions of the external actuators. The HIL platform is utilized to test an adaptive controller that estimates the health of reaction wheels concurrent to achieving the attitude tracking objective.

Author(s): Camilo Riano-Rios, Florida Institute of Technology; Morokot Sakal, Florida Institute of Technology; George Nehma, Florida Institute of Technology; Madhur Tiwari, Florida Tech

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10:45 AM - 11:00 AM

**AAS 25-786**: Planar Spacecraft Control Through One Degree of Freedom Time-Varying Thruster Configurations

Abstract: This paper investigates the use of thrusters mounted on robotic manipulators for planar control of the position and orientation of a spacecraft. The proposed solution addresses the fuel consumption and mass concerns of fixed thruster configurations. The coupling of spacecraft and manipulator dynamics is addressed through the incorporation of momentum exchange devices. A dynamical analysis of the system is performed and control laws are developed that minimize reaction torques on the spacecraft. Numerical simulations are used to validate the control design and evaluate the viability of various momentum exchange devices in mitigating the effects of reaction torques.

Author(s): William Schwend, University of Colorado Boulder; Hanspeter Schaub, University of Colorado

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11:00 AM - 11:15 AM

**AAS 25-814**: Predictive Attitude Control Based on Dynamic Equilibrium Tracking for Solar Sail Spacecraft

Abstract:
This study proposes a predictive attitude control method for solar sail spacecraft based on dynamic equilibrium tracking. By adjusting the phase angle around the spin axis, the equilibrium direction is steered to guide the spacecraft toward sustained solar pointing. The control algorithm selects the phase angle that minimizes the predicted pointing error at each step. This approach enables precise attitude control using super-slow spin, where the spin rate is comparable to the timescale of solar radiation pressure effects. Analytical formulation and numerical simulations demonstrate the effectiveness and stability of the proposed method.

Author(s): Koki Kimura, Japan Aerospace Exploration Agency

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11:15 AM - 11:30 AM

**AAS 25-819**: Fast Star Identification for Uncalibrated Cameras with Bucket Algorithms

Abstract: Star identification (ID) is a key capability for optical navigation and image-based attitude determination systems. An especially challenging type of star ID occurs when good a priori estimates of the camera calibration parameters are not known. The current work presented here draws on previous implementations of uncalibrated star ID while incorporating estimation of camera distortion for a more integrated camera calibration and star ID functionality. While this baseline implementation addresses the practical concerns of catalog generation, querying, and camera calibration, it will also it will also provide the backbone for further development towards a principled, generic star ID.

Author(s): Joseph Clary, Georgia Institute of Technology; Albert Zheng, Georgia Institute of Technology; Ava Thrasher, Georgia Institute of Technology; John Christian, Georgia Institute of Technology; Kaia Reenock, Haverford College; Rebecca Inman, NASA Johnson Space Center

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11:30 AM - 11:45 AM

**AAS 25-900**: a study on constructing rotation representations that establish a one-to-one correspondence between SO(3) and a quaternion reflecting quaternion characteristics

Abstract: Quaternion-based representations are widely used for expressing three-dimensional rotations. However, due to the double covering in which SO(3) and quaternions correspond a one-to-two, an unwinding phenomenon occurs, which is a significant issue in spacecraft control.

Therefore, this study aims to fundamentally resolve the unwinding phenomenon. To this end, a new rotational action is proposed that extends SO(3) by incorporating the rotational direction characteristic of quaternions, with the goal of achieving a one-to-one correspondence between the rotational action using a quaternion and the rotational action using SO(3).

Author(s): Yuki Ishihara, Teikyo University; Masaki Nakamiya, Teikyo University

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11:45 AM - 12:00 PM

**AAS 25-505**: Near-Optimal Camera Calibration using Star Fields

Abstract: Camera calibration is essential for the use of precise vision navigation algorithms in space. While preflight calibration of optical instruments occurs, calibration parameters change on orbit. In-flight geometric camera calibration is a foundational capability. Nearly every contemporary space mission accomplishes this by opportunistically capturing star field images. This practice neglects the quality of images collected, which is experimentally confirmed to yield less informative measurements. This paper formulates an optimal experimental design approach for capturing image sequences while considering operational mission constraints. Optimally designed image sequences were used to calibrate night sky images, resulting in pointing errors > 100 arcsec lower

Author(s): Kevin Zhang, Georgia Institute of Technology; John Christian, Georgia Institute of Technology; Courtney Mario, Draper

# Rendezvous, Relative Motion, and Proximity Operations III

Thursday, 08/14/25, 10:30 AM - 12:30 PM

Session Chair(s): Pradipto Ghosh (Johns Hopkins University Applied Physics Lab)

Room: Dedham

10:30 AM - 10:45 AM

**AAS 25-760**: Analysis of Spacecraft Safe Abort Corridors in the Presence of Uncertainty

Abstract: Safe abort corridors define the acceptable relative state between two spacecraft performing rendezvous. During safety-critical operations, it is essential for the approaching vehicle to be able to abort its rendezvous without further endangering the target vehicle. This paper describes the linear reachability analysis and nonlinear propagation techniques that verify the defined corridors meet all safety requirements in the event of an abort. These missions require safety in the presence of variation in each vehicle's operational commanded states, state knowledge error, thruster performance error, and monitoring abilities. An analysis process that accounts for all of these uncertainties is described.

Author(s): Christopher Jewison, Draper; Louis Breger, Draper

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10:45 AM - 11:00 AM

**AAS 25-779**: Thruster Pointing Constrained Optimal 6-DOF Proximity Operations using Indirect Optimization

Abstract: On-orbit servicing missions require trajectories that avoid thruster-induced contamination and plume impingement on sensitive components of the client spacecraft. We introduce a novel thruster pointing constraint, which limits the angular range over which the chaser spacecraft's thrusters may operate, into the six degrees-of-freedom (6DOF) optimal rendezvous problem and solve it using indirect optimization techniques. By embedding the constraint directly into the dynamics, our method does not rely on prior knowledge of the burn sequence or the precise times at which the constraint transitions to active/inactive. We assume the chaser is actuated by fixed translational thrusters and an attitude control torque.

Author(s): Himmat Panag, University of Illinois Urbana-Champaign; Ruthvik Bommena, University of Illinois Urbana-Champaign; Robyn Woollands, University of Illinois at Urbana-Champaign

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11:00 AM - 11:15 AM

**AAS 25-886**: Summarizing Relative Motion near Periodic Orbits with Motion Primitives

Abstract: This paper focuses on using motion primitives to summarize relative motion in the neighborhood of a target vehicle that is located along a periodic orbit in the Earth-Moon circular restricted three-body problem. These relative trajectories will be generated near various libration points and Moon-centered orbits. Then, each trajectory will be transformed into a suitable reference frame and discretized. The sampled states will be used to form finite-dimensional feature vectors that are clustered to generate groups of geometrically similar relative trajectories. A motion primitive is extracted from each cluster to explore fundamental types of relative motion in cislunar space.

Author(s): Maxwell Joyner, University of Colorado Boulder; Natasha Bosanac, University of Colorado, Boulder

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11:15 AM - 11:30 AM

**AAS 25-893**: Ellipsoidal thruster pointing constrained optimal trajectories for satellite servicing at SEL2

Abstract: In-space assembly and servicing missions are attracting increasing interest and avoiding thruster plume contamination of the client spacecraft during close-proximity operations is critical. This study proposes a novel mathematical formulation to implement multiple ellipsoidal control pointing constraints into the 6 degree of freedom fuel-optimal rendezvous problem applied to a spacecraft orbiting Sun-Earth L2. We solve this problem using indirect optimization and make use of the nonlinear relative dynamics under the Circular-Restricted-Three-Body-Problem model. We anticipate that our novel constraint formulation will allow for reduced plume contamination and safety hazard for RPOD missions targeted on spacecraft orbiting Sun-Earth L2.

Author(s): Marin Hubert, University of Illinois Urbana-Champaign, COSMOS Research Group; Himmat Panag, University of Illinois Urbana-Champaign; Robyn Woollands, University of Illinois at Urbana-Champaign

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11:45 AM - 12:00 PM

**AAS 25-600**: Linear Programming For a Fixed-Time V-Bar Glideslope under LOS constraints

Abstract: This study presents a linear programming (LP) framework for fuel-optimal impulsive rendezvous trajectory design under line-of-sight (LOS) constraints. The trajectory consists of V-bar-aligned impulsive hops, with LOS constraints enforced by analytically bounding the peak altitude of each hump-shaped segment. All dynamics and constraints are formulated linearly, ensuring efficient real-time implementation. The problem is further simplified into a parameter optimization structure to reduce computational cost and improve onboard applicability.

Author(s): Jeongwoo Lim, Korea Advanced Institute of Science and Technology; Donghun Lee, KAIST

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12:00 PM - 12:15 PM

**AAS 25-730**: OPTICAL GUIDANCE AND ASSOCIATED RANGE ESTIMATION, ALIGNED INTERCEPT IN ACTIVE DEBRIS REMOVAL

Abstract: This study presents a camera-only, image-based guidance strategy designed for active debris removal that does not rely on range information regarding non-cooperative targets. It extracts range information as the spacecraft maneuvers. Additionally, the study aims to direct the spacecraft's approach from a specified direction based solely on camera input. The paper first outlines the limitations associated with the guidance for relative motion in low Earth orbit, followed by a discussion of previously developed properties, including simultaneous range estimation and aligned intercept.

Author(s): Junichiro Kawaguchi, School of Engineering, College of Engineering and Computer Cybernetics, Australian National University; Kawsihen Elankumaran, The Australian National University; Shingo Nishimoto, Australian National University (anu); Saki Komachi, Tohoku University

# Spacecraft Guidance, Navigation and Control (GNC) III

Thursday, 08/14/25, 10:30 AM - 12:30 PM

Session Chair(s): Riley Fitzgerald (Virginia Tech)

Room: Adrienne Salon

10:30 AM - 10:45 AM

**AAS 25-868**: Optimal Thruster Configuration for 6-DOF Control of a Small Satellite

Abstract: With the growing deployment of small satellites in Low Earth Orbit (LEO) for targeted applications like imaging, communication, and data storage, there is increasing attention on orbit maintenance and attitude control. A common approach for active orbit control involves the use of multiple thrusters, which, when properly arranged, can also generate the required torque for attitude control. This paper presents a set of thruster configurations that use the minimum number of thrusters while still enabling full 6-DOF control. Viable configurations are further evaluated for their attitude control performances, demonstrating that sufficient maneuverability can be achieved even with a reduced thruster count.

Author(s): Suguru Sato, The University of Texas at Arlington; Jinaykumar Patel, The University of Texas at Arlington; Kamesh Subbarao, University of Texas at Arlington

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10:45 AM - 11:00 AM

**AAS 25-894**: Crater Identification Using Projective Invariants for Crater Triads

Abstract: Terrain-relative optical navigation enables spacecraft to autonomously localize using surface features like craters. This paper investigates projective invariants derived from coplanar crater conic triads for reliable crater identification. While these invariants are theoretically constant across viewing geometries, real-world factors like non-coplanarity and measurement noise introduce variability. Even under ideal conditions, few studies explore how sensitivity to triad geometry affects robustness to such variability. We analyze this sensitivity across crater geometries under realistic conditions, evaluating the invariants' ability to distinguish triads within large crater databases. Results inform conditions under which these invariants remain descriptive enough to support autonomous crater-based navigation.

Author(s): Basil Russell-McCorkle, Georgia Institute of Technology; Tara Mina, Georgia Institute of Technology; John Christian, Georgia Institute of Technology

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11:00 AM - 11:15 AM

**AAS 25-895**: Star Tracker Misalignment Compensation in Deep Space Navigation Through Model-Based Estimation.

Abstract: This work introduces a novel robust estimation framework for CubeSats operating in deep space without GPS. A 9-state Multiplicative Extended Kalman Filter (MEKF) is employed to estimate attitude, angular velocity, and gyroscope bias using TRIAD-based vector measurements. To address star tracker misalignment, a Bayesian Multiple-Model Adaptive Estimation (MMAE) framework is integrated using an $N \times N \times N$ 3D hypothesis grid. The architecture fuses quaternion outputs via Markley's averaging method. Preliminary results show accurate estimation of both attitude and misalignment, demonstrating the method's suitability for low-cost, autonomous platforms. Fine-tuning the algorithm and full Monte Carlo validation will be presented in the final manuscript.

Author(s): Ridma Ganganath., Iowa State University; Simone Servadio, Iowa State University; David Lee, Iowa State University

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11:15 AM - 11:30 AM

**AAS 25-896**: Tracking Maneuvering Spacecraft with a Laplacian Random Process

Abstract: This work presents a novel method of uncertainty propagation to improve maneuvering spacecraft tracking. The maneuver model is a correlated random process that better emulates real thrust profiles. The random process is combined with sensitivity measures to ensure accurate uncertainty propagation is tractable through large observation gaps. A motivation to improve uncertainty propagation is to provide more reliable probabilistic data association. The performance of the random process model is compared to a zero-order hold model. It is demonstrated that modeling the maneuver as a random process improves the ability to track spacecraft operating with unknown maneuvers.

Author(s): Bora Unalmis, The University of Texas at Austin; Brandon Jones, The University of Texas at Austin

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11:30 AM - 11:45 AM

**AAS 25-850**: Observability-Enhanced MPC Algorithm For Cislunar Spacecraft Relying on Angles-Only Navigation

Abstract: This paper explores the challenges of controlled rendezvous maneuvers from a GNC standpoint for cislunar spacecraft relying on angles-only navigation. Several algorithms are examined with the goal of minimizing fuel usage while maximizing observability. Effectively balancing these objectives presents unique challenges, including handling nonlinear measurement models, achieving accurate state estimation, and maintaining computational efficiency. A new algorithm is proposed and evaluated against the state-of-the-art using various performance metrics, including total Delta v, relative range error, the determinant of the Fisher information matrix, robustness under an EKF, and computational runtime.

Author(s): Matthew Stephens, Purdue University; Andrea Capannolo, Purdue University

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11:45 AM - 12:00 PM

**AAS 25-596**: Optimal Launch to Rendezvous Leveraging Controllable Sets

Abstract: This work presents an autonomous launch guidance framework for rendezvous missions that incorporates reachability theory into a neighboring optimal control formulation. Terminal state deviations are weighted using ellipsoidal approximations of the controllable set, shaping the post-launch distribution along directions of higher controllability. This improves robustness to thrust magnitude and launch angle perturbations while ensuring feasibility of a subsequent low-thrust transfer. The resulting distributions are analyzed to bound required low-thrust capability and minimum time-to-rendezvous. Applied to a planar Lunar launch, the method reduces worst-case fuel use and improves targeting directionality, demonstrating the utility of reachability-informed guidance for launch-to-rendezvous scenarios.

Author(s): Kristen Ahner, University of Colorado Boulder; Robyn Natherson, University of Colorado, Boulder; Daniel Scheeres, University of Colorado Boulder; Jay McMahon, University of Colorado Boulder, CCAR

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12:00 PM - 12:15 PM

**AAS 25-723**: Atmospheric density estimation using satellite constellation navigation data

Abstract: This paper demonstrates using navigation data from satellite constellations to estimate atmospheric density and satellite drag coefficients. The atmosphere is discretized into spatial tiles defined by altitude, latitude, and longitude boundaries. In each tile, the atmosphere is modeled using an exponential profile with two estimable parameters. Leveraging constellation global coverage, the parameters are estimated using a linearized Kalman filter and Rauch–Tung–Striebel smoother. Results

show the filter-smoother system's ability to decouple parameter and Cd biases, demonstrating the algorithm's potential for local, spatially varying, density characterization in low Earth orbit with uncertain drag coefficients and an arbitrary atmospheric density distribution.

Author(s): Victor Haxholdt, North Carolina State University; Nolan Canegallo, North Carolina State University; Mark Moretto, North Carolina State University