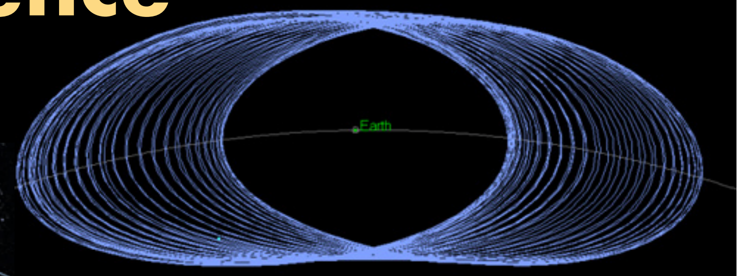
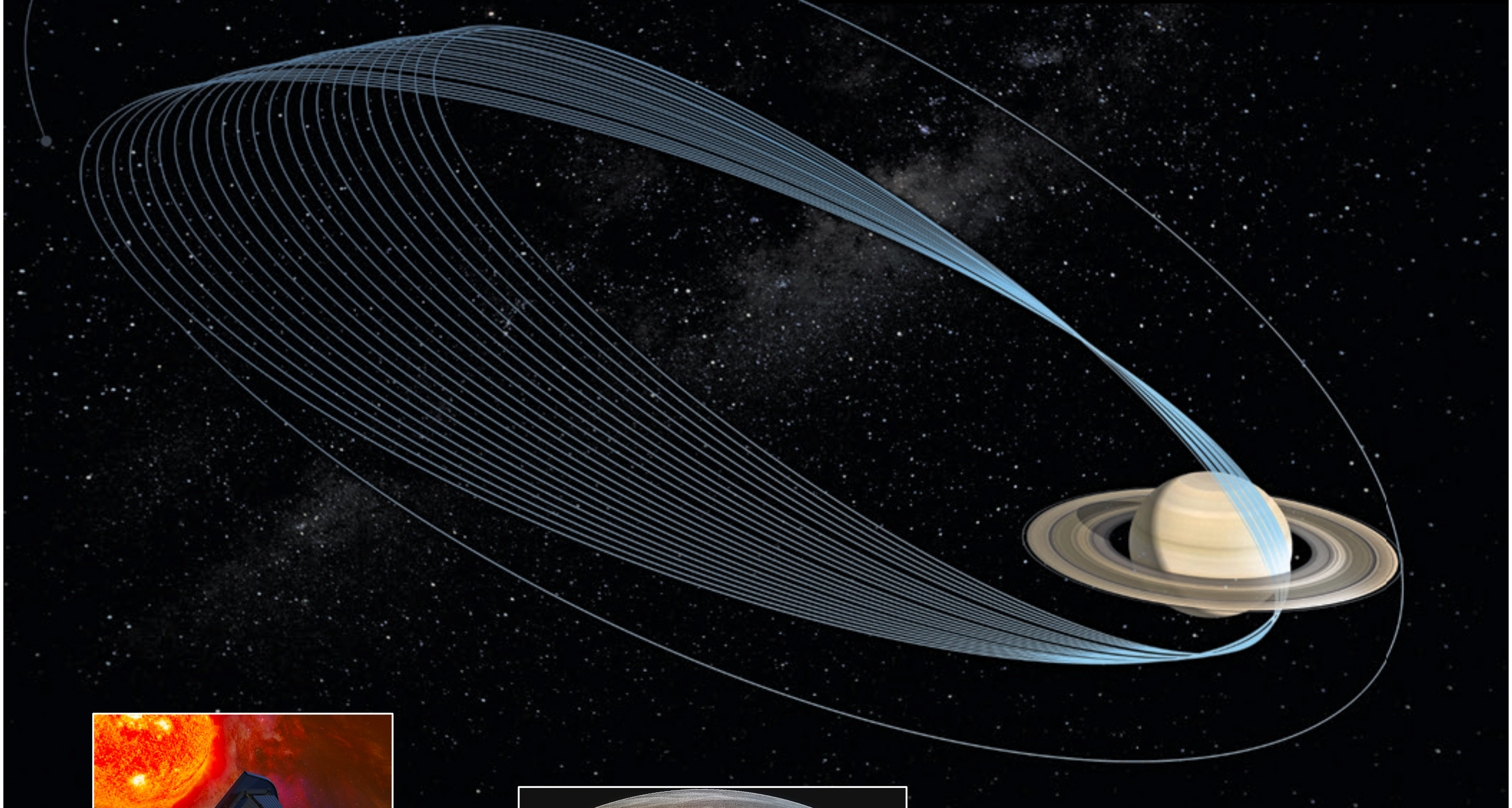
2017 AAS/AIAA Astrodynamics Specialist Conference

Columbia River Gorge, Stevenson, WA
August 20-24, 2017





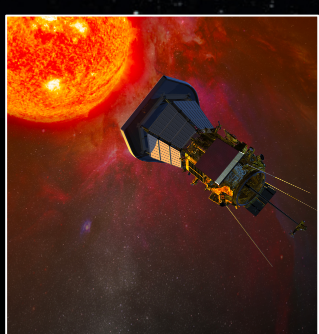


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TABLE OF CONTENTS

TABLE OF CONTENTS **1**

GENERAL INFORMATION **4**

REGISTRATION **4**

DAILY SCHEDULE OF EVENTS **6**

SPECIAL EVENTS **8**

EARLY BIRD RECEPTION 8
THE GREAT AMERICAN ECLIPSE 8
POSTERS ON DISPLAY 9
STUDENT COMPETITION 9
PLENARY SESSION: DR. LOUIS FREIDMAN, "POLITICAL ADVOCACY FOR THE PLANETS" 10

CONFERENCE LOCATION **11**

CONFERENCE VENUE LAYOUT **12**

ADDITIONAL INFORMATION **13**

SPEAKER ORIENTATION 13
VOLUNTEERS 13
PRESENTATIONS 13
"NO-PAPER, NO-PODIUM" POLICY 13
PRE-PRINTED MANUSCRIPTS 14
CONFERENCE PROCEEDINGS 14
COMMITTEE MEETINGS 15

CONFERENCE SCHEDULE **16**

SESSION 1: POSTERS 16
SESSION 2: STUDENT DESIGN COMPETITION 23
SESSION 3: ATTITUDE CONTROL I 27
SESSION 4: LOW-THRUST TRAJECTORY DESIGN 30
SESSION 5: SPACE SITUATIONAL AWARENESS 34
SESSION 6: TRAJECTORY DESIGN 38
SESSION 7: ADVANCES IN SPACECRAFT DESIGN 42
SESSION 8: ATTITUDE CONTROL II 46
SESSION 9: COLLISION AVOIDANCE 48
SESSION 10: PLANETARY EXPLORATION 52
SESSION 11: ATTITUDE ESTIMATION 56
SESSION 12: ORBITAL DYNAMICS 59
SESSION 13: SMALL BODY EXPLORATION 62
SESSION 14: SPECIAL SESSION: OUTER PLANET EXPLORATION 65
SESSION 15: EARTH ORBITERS 67
SESSION 16: ORBIT DETERMINATION 71
SESSION 17: SMALL BODY MODELING 74
SESSION 18: SPECIAL SESSION: CONSTRAINED GLOBAL TRAJECTORY OPTIMIZATION 78
SESSION 19: CONSTELLATIONS AND FORMATIONS 82
SESSION 20: LOW-ENERGY MISSION DESIGN 85
SESSION 21: RELATIVE MOTION 89

SESSION 22: SPACECRAFT GNC I 92
SESSION 23: PROXIMITY OPERATIONS 95
SESSION 24: SPACECRAFT GNC II 99
SESSION 25: SPACEFLIGHT MECHANICS 104
SESSION 26: SPECIAL SESSION: HUMAN MISSIONS BEYOND EARTH ORBIT 107

CONFERENCE ATTENDEE PLANNING TOOL: MONDAY **110**

CONFERENCE ATTENDEE PLANNING TOOL: TUESDAY **112**

CONFERENCE ATTENDEE PLANNING TOOL: WEDNESDAY **118**

CONFERENCE ATTENDEE PLANNING TOOL: THURSDAY **124**

AUTHOR INDEX **131**

CHAIR INDEX **138**

Front Cover Images

Top-right:	The orbit of Asteroid 2016 HO3. Credit: NASA/JPL-Caltech
Center:	An illustration of Cassini's grand finale. Credit: NASA/JPL-Caltech
Lower-left:	Parker Solar Probe, illustrated with heat shield on Sunward side. Credit: JHU/APL
Lower-center:	Jupiter's great red spot, captured by the Juno spacecraft. Credit: NASA/JPL-Caltech/SwRI/MSSS/Jason Major
Lower-right:	ULA's CubeSat Launch Program.
Bottom:	The March 7th 1970 total solar eclipse. Credit: NSO/AURA/NSF

Cover design by Jeff Parker

2017 AAS/AIAA Astrodynamics Specialist Conference
Stevenson, Washington
20-24 August 2017

GENERAL INFORMATION

Welcome to the 2017 Astrodynamics Specialist Conference, hosted by the American Astronautical Society (AAS) and co-hosted by the American Institute of Aeronautics and Astronautics (AIAA), August 20 – 24, 2017. This meeting is organized by the AAS Space Flight Mechanics Committee and the AIAA Astrodynamics Technical Committee, and is held at the Skamania Lodge in Stevenson, Washington along the Columbia Gorge.

Information about the conference, including registration, online program, manuscript submissions, etc., may be found here: http://www.space-flight.org/docs/2017_summer/2017_summer.html

REGISTRATION

Attendees to the conference are encouraged to utilize the online registration system at the conference website. Registering online will provide several benefits. You will avoid the lines at the registration table and you will have free access to preprints. Free access to preprints will only be available to people registering through the online system.

	Early (On or before June 30, 2017)	Normal (On or before July 27, 2017)	Walkup (After July 27, 2017)
Full Registration - Member (AAS or AIAA)	$550	$620	$720
Full Registration - Non-Member (AAS or AIAA)	$650	$720	$820
Registration Retiree - Member (AAS or AIAA)	$200	$270	$370
Registration Retiree - Non-Member (AAS or AIAA)	$250	$320	$420
Registration - Student (incl. 1 yr AAS membership)	$200	$270	$370

The registration fee for AAS or AIAA members is $550 (early), $620 (normal), $720 (walkup). The registration fee for AAS or AIAA member students/retiree is $200 (early), $270 (normal), $370 (walkup). Student registration includes a free one year membership to AAS. Non-members have an additional fee of $100 (full-registration) or $50 (retiree). The online registration system is programmed to accept Visa, Mastercard, Discover and American Express credit cards.

Attendees may still register via the online system during the conference or in person at the registration table.

A conference registration and check-in table will be located in the Conference Lobby of the Skamania Lodge and will be staffed according to the following schedule:

- Sunday Aug. 20 3:00 PM – 6:00 PM
- Monday Aug. 21 3:00 PM – 7:00 PM
- Tuesday Aug. 22 7:30 AM – 12:00 PM
- Wednesday Aug. 23 7:30 AM – 12:00 PM
- Thursday Aug. 24 7:30 AM – 12:00 PM

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

DAILY SCHEDULE OF EVENTS

Day	Time	Function	Room
Sunday, 8/20	3:00pm	*poster area open for hanging posters*	Conference Lobby
	3:00pm – 6:00pm	Registration	Conference Lobby
	6:00pm – 9:00pm	Early Bird Reception	Cascade Lawn

Day	Time	Function	Room
Monday, 8/21	Before 6:00am	Carpools depart for eclipse	Hotel Lobby
	9:00am – Noon	Eclipse Viewing (Madras, OR)	***Madras, Oregon***
	8:00am – 7:00pm	*posters on display for browsing*	Conference Lobby
	3:00pm – 7:00pm	Registration	Conference Lobby
	3:00pm – 7:00pm	01 Poster Session & Reception	Stevenson Ballroom
	3:00pm – 7:00pm	02 Student Competition	Stevenson Ballroom
	6:30pm	Plenary Speaker, Lou Friedman	Stevenson Ballroom

Day	Time	Function	Room
Tuesday, 8/22	7:30am – Noon	Registration	Conference Lobby
	8:00am – 5:00pm	*posters on display for browsing*	Conference Lobby
	8:00am – 12:10pm	03 Attitude Control I	Cascade A
	8:00am – 12:10pm	04 Low-Thrust Trajectory Design	Stevenson C/D
	8:00am – 12:10pm	05 Space Situational Awareness	Stevenson B
	8:00am – 12:10pm	06 Trajectory Design	Stevenson A
	9:40am – 10:10am	Morning Break	
	12:10pm – 1:40pm	Joint Astrodynamics TC Meeting	Hood
	1:40pm – 5:50pm	07 Advances in Spacecraft Design	Stevenson B
	1:40pm – 5:50pm	08 Attitude Control II	Cascade A
	1:40pm – 5:50pm	09 Collision Avoidance	Stevenson C/D
	1:40pm – 5:50pm	10 Planetary Exploration	Stevenson A
	3:20pm – 3:50pm	Afternoon Break	
	6:00pm – 8:00pm	Evening Reception	Cascade Lawn
	7:00pm – 8:00pm	Sub-Committee Meetings	Stevenson

Day	Time	Function	Room
Wednesday, 8/23	7:30am – Noon	Registration	Conference Lobby
	8:00am – 5:00pm	*posters on display for browsing*	Conference Lobby
	8:00am – 12:10pm	11 Attitude Estimation	Cascade A
	8:00am – 12:10pm	12 Orbital Dynamics	Stevenson A
	8:00am – 12:10pm	13 Small Body Exploration	Stevenson C/D
	8:00am – 12:10pm	14 Special Session: Outer Planets Exploration	Stevenson B
	9:40am – 10:10am	Morning Break	
	12:10pm – 1:40pm	AIAA Astrodynamics TC Meeting	Rainier
	1:40pm – 5:50pm	15 Earth Orbiters	Stevenson A
	1:40pm – 5:50pm	16 Orbit Determination	Cascade A
	1:40pm – 5:50pm	17 Small Body Modeling	Stevenson C/D
	1:40pm – 5:50pm	18 Special Session: Constrained Global Trajectory Optimization	Stevenson B
	3:20pm – 3:50pm	Afternoon Break	
	6:00pm – 8:00pm	Evening Reception (Student Competition Winners Announced)	Cascade Lawn

Day	Time	Function	Room
Thursday, 8/24	7:30am – Noon	Registration	Conference Lobby
	8:00am – 5:00pm	*posters on display for browsing*	Conference Lobby
	8:00am – 12:10pm	19 Constellations and Formations	Stevenson C/D
	8:00am – 12:10pm	20 Low-Energy Mission Design	Stevenson B
	8:00am – 12:10pm	21 Relative Motion	Stevenson A
	8:00am – 12:10pm	22 Spacecraft GNC I	Cascade A
	9:40am – 10:10am	Morning Break	
	12:10pm – 1:40pm	AAS Astrodynamics TC Meeting	Rainier
	1:40pm – 5:50pm	23 Proximity Operations	Stevenson A
	1:40pm – 5:50pm	24 Spacecraft GNC II	Cascade A
	1:40pm – 5:50pm	25 Spaceflight Mechanics	Stevenson C/D
	1:40pm – 5:50pm	26 Special Session: Human Missions Beyond Earth Orbit	Stevenson B
	3:20pm – 3:50pm	Afternoon Break	

The conference will adjourn Thursday at 6:00 pm.

Authors: please upload your final manuscripts to the conference website by:
September 8, 2017 11:59:00 pm Eastern Time.

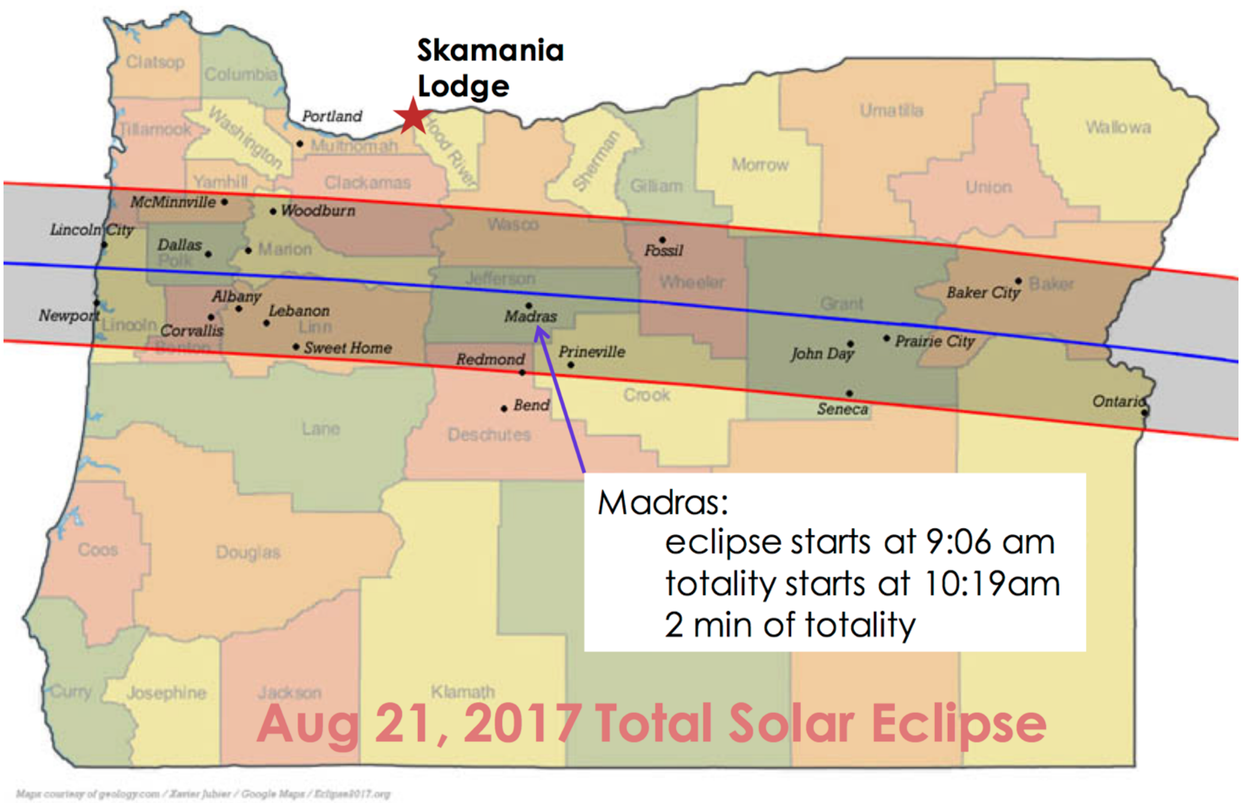
Special Events

Early Bird Reception

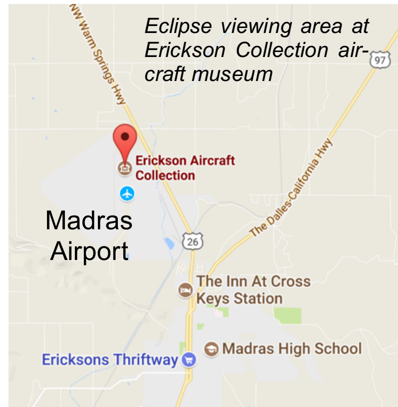
Sunday, August 20, 6:00 pm – 9:00 pm in the Cascade Lawn.

The Great American Eclipse

The path of totality for the August 21 “Great American Eclipse” will pass just south of the conference location. An eclipse watching event for conference attendees will be held at the **Erickson Collection museum** in Madras, OR on the morning of August 21. Conference events (student competition, poster session, and keynote speaker) will resume at 4:00pm at the Skamania Lodge.



The eclipse starts at approximately 9:00 am local time and Madras is 2.5 hours from the Skamania Lodge *without* traffic. Traffic the morning of the eclipse will be extremely unpredictable, so leaving several hours prior to 6:00 am, or on Sunday, is recommended.



The Erickson Collection museum is located at the Madras airport: 2408 NW Berg Dr, Madras, OR. You will be directed to the parking as you approach the airport. The eclipse viewing area for conference attendees and their guests is adjacent to the museum. **Additional information on the eclipse event is on the website including a link to traffic conditions and traffic cameras.**

It is advisable to have a full tank of gas, food, water and whatever supplies you need for these adventures.

POSTERS ON DISPLAY

Posters will be featured throughout the conference; poster authors will be attending their posters during the Monday afternoon session in the Stevenson Ballroom for questions and discussions. Posters will be rotated in and out of display throughout the conference, though the authors may not be present except Monday afternoon. Posters will be taken down by Thursday morning.

STUDENT COMPETITION

Mission and Spacecraft Design to Asteroid (469219) 2016 H03: The first ever Astrodynamics Specialist Conference Student Competition will be held on Monday, August 21. Details on the competition are on the conference website. Student teams will make brief presentations of their concepts starting at 4PM on Monday, followed by poster board presentations of their concepts. Their submitted designs are available for download from the online paper website.

The competition is being sponsored and judged by Planetary Resources, Inc., with a 1st place prize of $3000, 2nd place prize of $2000 and 3rd place prize of $1000, checks to be payable to the student's home universities for support of their travel. Winners will be announced on Wednesday evening.

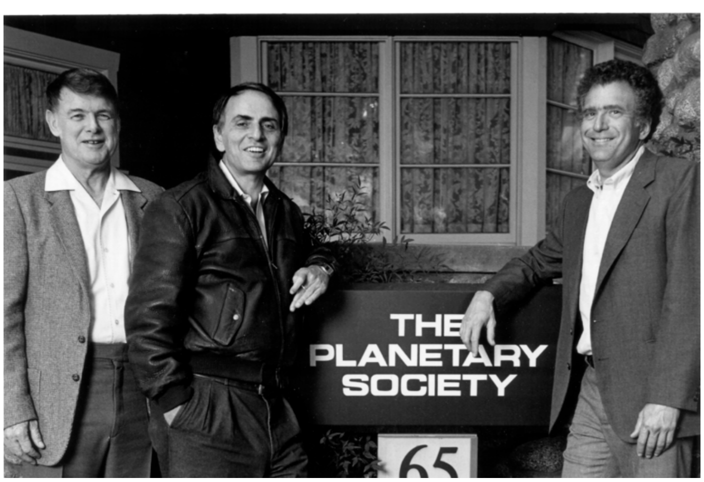
PLENARY SESSION: DR. LOUIS FREIDMAN, "POLITICAL ADVOCACY FOR THE PLANETS"

Monday Aug, 21, 6:30 pm in the Stevenson Ballroom

Dr. Freidman will speak on the founding of The Planetary Society, with Carl Sagan and Bruce Murray, and the political conditions at that time representing an existential threat to U.S. planetary exploration. He will recount the initiation of Society projects such as Mars Balloon and Rover development, international cooperation on missions to Halley's Comet, the attempt to fly the first solar sail and the Living Interplanetary Flight Experiment. He will also describe international cooperation advocacy by the Society including joint projects with the Soviet Union, and then Russia.

Dr. Friedman is Executive Director Emeritus of the Planetary Society and co-founded The Planetary Society with Carl Sagan and Bruce Murray in 1980. He was Executive Director of the Society for 30 years and remained on the Board of Directors until Oct 2014. The Society is a non-profit, popular society seeking to inspire the people of Earth to explore new worlds and seek other life, through research, education and public participation. It is the largest space interest organization in the world. While at the Society he worked on the Mars Balloon development, international Mars rover testing, a Mars microphone, and the joint educational project with LEGO – Red Rover Goes to Mars. He led Cosmos 1, the attempt to fly the first solar sail and was the Co-Inventor and Principal Investigator of the Living Interplanetary Flight Experiment (LIFE) on the Russian Phobos Sample Return mission was lost in orbit following launch in Nov. 2011. This experiment was to have been the first instance of purposely sending life from Earth to interplanetary space. Friedman led the design and development of the LightSail™ spacecraft scheduled for flights 2015 and 2016.

Dr. Friedman worked at the AVCO Space Systems Division from 1963-1968, on both civilian and military space programs. From 1970 to 1980 he worked on deep space missions at the Jet Propulsion Laboratory (JPL) in Pasadena, California. He performed mission analysis and navigation system studies for pre-project definition of Mariner Venus-Mercury, Voyager and Galileo and was the program development leader for Venus Orbital Imaging Radar, which later became Magellan. He led the development and design for the Halley Comet Rendezvous-Solar Sail proposal and was the leader of the post-Viking Mars Program in the late 1970s. In 1979-80 he originated and led the International Halley Watch. He was manager of Advanced Planetary Studies at JPL. Dr. Friedman is the author of more than 20 technical papers on Celestial

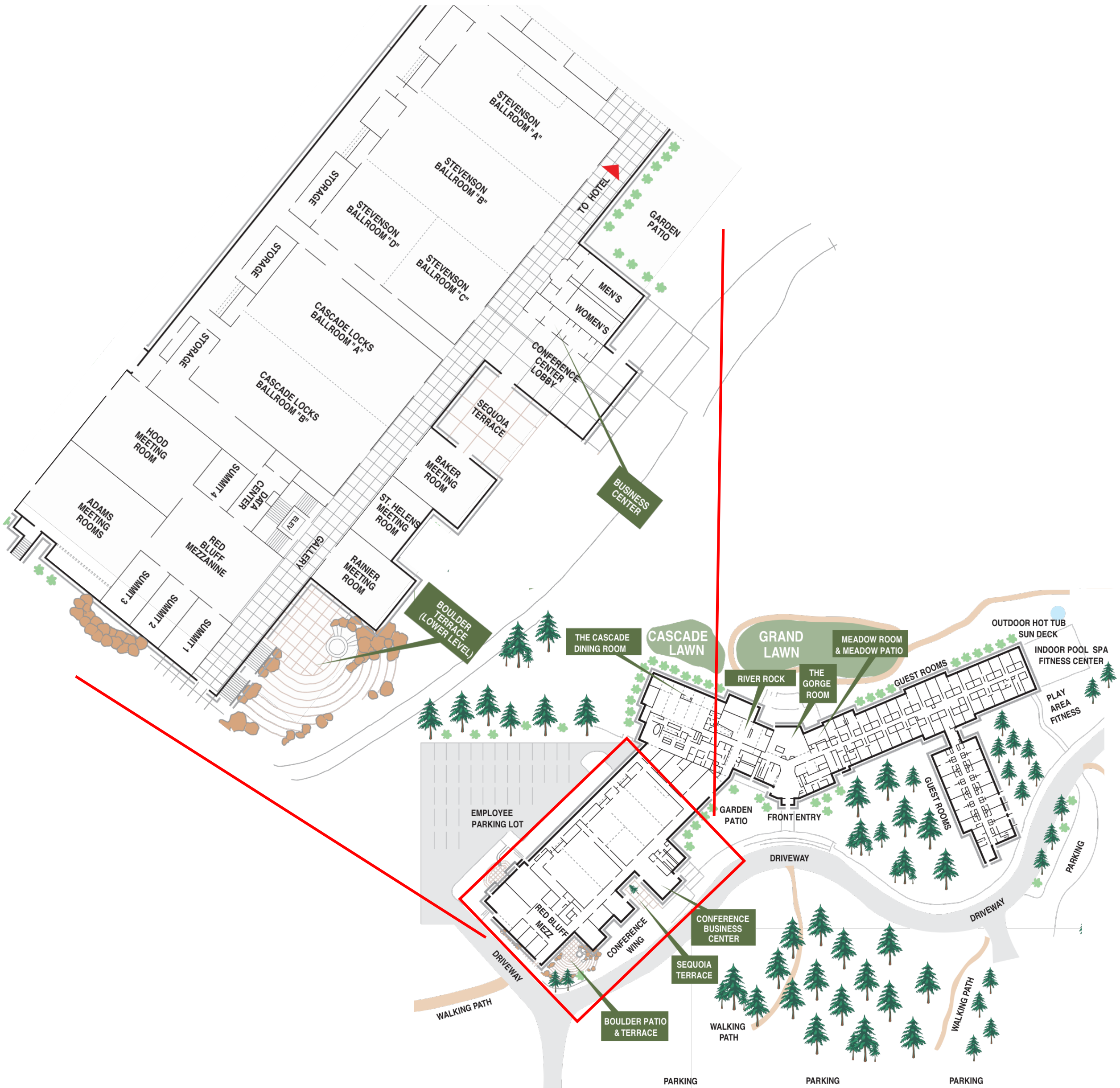


Navigation, Astrodynamics, Mission Analysis and Design, and Mission Planning. He is the author of the books: *Starsailing: Solar Sails and Interstellar Travel* and *From Mars to the Stars: The Future of Human Space Flight.*

CONFERENCE LOCATION

The conference will be held at the Skamania Lodge in Stevenson, WA. (1131 SW Skamania Lodge Way). Please review the lodge's extensive information online for more information about amenities, local activities, maps, and the like. It may be found here:
https://www.destinationhotels.com/skamania/resort

CONFERENCE VENUE LAYOUT



ADDITIONAL INFORMATION

SPEAKER ORIENTATION

Coordinate with your session chair prior to your session to become oriented with the session, including the presenting computer, microphone, and laser pointer; to ensure that the presentation file is formatted properly, and to ensure that the chair has the proper speaker bio for the introduction. Each speaking slot is 20 minutes long, including:

- 1 minute for the session chair to introduce the speaker
- 16 minutes for the presentation
- 2 minutes for questions and answers
- 1 minute for transition to the next speaker

The session chair will maintain this schedule in order to keep the four parallel sessions properly coordinated.

VOLUNTEERS

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

PRESENTATIONS

Each presentation is limited to 16 minutes, as indicated above. Session chairs shall maintain the posted schedule to allow attendees the option of joining a parallel session. Each room is equipped with a laser pointer, an electrical outlet, and a video projector that can be driven by a computer. Presenters shall coordinate with their Session Chairs regarding the computing equipment, software, and media requirements for the session; however, each presenter is ultimately responsible for having the necessary computer and software available to drive the presentation. Microsoft PowerPoint and PDF are the most common formats.

"*NO-PAPER, NO-PODIUM*" *POLICY*

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

PRE-PRINTED 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 for registrants who use the online registration system. The hotel provides conference guests with complimentary wireless internet access in guest rooms and the conference meeting space. Registrants without an internet-capable portable computer, or those desiring traditional paper copies should download and print preprint manuscripts before arriving at the conference.

CONFERENCE PROCEEDINGS

All full registrants will have access to the online proceedings of the conference. Univelt will reach out to all registrants via their profile email contacts to determine who would like to receive a physical CD of the proceedings after the conference (extra copies are available for $60 during the conference). Please be sure to update your conference profile contact information if your contact information has changed.

The hardbound volume of Advances in the Astronautical Sciences covering this conference will be available to attendees at a reduced pre-publication cost, if ordered at the registration desk. After the conference, the hardbound proceedings will more than double in price, although authors will still receive a special 50% discount off the post-conference rate even if they delay their order until after the conference. Cost of Proceedings:

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

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

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

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

Journal of Spacecraft and Rockets
Editor-in-Chief: Dr. Hanspeter Schaub, University of Colorado Boulder
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 Schedule

Session 1: Posters

Aug 21, 2017 | **01 Poster Session** | Stevenson Ballroom

Co Chair: Manoranjan Majji

AAS 17-560 Error suppression data processing method on Inter-satellite link measurement

Dongxia Wang, Beijing Satellite Navigation Center

Aiming at the inter-satellite observation pretreatment, this article describes the error suppression and epoch normalization. We adopt gross identification and robustness estimation to remove the gross error, and use mathematical model prediction and compensation method to correct the transmission errors. Moreover, we adopt Lagrange interpolation, continued fraction interpolation and Aitken interpolation to calculate and analyze the epoch. The experiment results illustrate the feasibility of error suppression, and point out that the interpolation order and sampling interval are the main factors which influence the normalization precision of inter-satellite links.

AAS 17-562 Research on fault diagnosis and fault-tolerant technology for GNSS navigation satellites

Dongxia Wang, Beijing Satellite Navigation Center

According to the large structure, complex running environment, and long-time in-orbit running of satellite navigation system, it is hard to avoid fault problem. In order to improve the fault tolerance capability of navigation system, this article not only describes the status of fault diagnosis based on analytic model, signal processor and artificial intelligence in detail, but also summarizes the critical research issues related to active fault-tolerant and passive fault-tolerant. Moreover, this paper amplifies the unfathomed problems, which provides a reference for navigation study of our country.

AAS 17-578 Navigation Automation for the Soil Moisture Active Passive Observatory

Robert Haw, NASA / Caltech JPL; Min-Kun Chung, Jet Propulsion Laboratory; Ramachandra Bhat; Jessica Williams, Lockheed Martin Space Systems; Maximilian Schadegg, NASA JPL; Julim Lee, NASA JPL

Soil Moisture Active Passive (SMAP) is a NASA Earth science mission designed to measure soil moisture content and freeze/thaw cycles over a three-year period. This paper presents a 2-year summary of navigation performance, shows navigation compliance (and non-compliance) with Science Orbit Requirements, and describes how automated processes appreciably reduced the size of the navigation team.

AAS 17-594 **A Volumetric Integral Based Method of Calculating Satellites Collision Probability for Long-term Encounters**

Changxuan Wen, Chinese Academy of Sciences

A parametric method is developed to compute collision probability for long-term encounters. To describe a random event meaningfully, a common random variable (RV) space is defined as the transformed state space at the fixed initial time, such that the 1-sigma error ellipsoid of the initial state is mapped into a unit sphere. Meanwhile, the motion of the combined hardbody sphere is transformed to an effective volume in the RV space. Finally, the probability of collision for the long-term encounter can be computed by integrating the isotropic probability density function over this effective volume.

AAS 17-632 **LUCY: NAVIGATING A JUPITER TROJAN TOUR**

Dale Stanbridge, KinetX Aerospace, Inc.; Bobby Williams, KinetX SNAFD; Coralie Jackman, KinetX Aerospace; Kenneth Williams, KinetX Aerospace, Inc.

In January 2017, NASA selected the Lucy mission to explore six Jupiter Trojan asteroids. These six bodies, remnants of the primordial material that formed the outer planets, were captured in the Sun-Jupiter L4 and L5 Lagrangian regions early in the solar system formation. These particular bodies were chosen because of their diverse spectral properties and the chance to observe for the first time, up close, two orbiting approximately equal mass binaries Patroclus and Menoetius. KinetX, Inc. is the primary navigation supplier for the Lucy mission. This paper describes preliminary navigation analyses of the approach phase for each Trojan encounter.

AAS 17-671 **Features and Characteristics of Earth-Mars Bacon Plots**

Robert Potter, Purdue University; Ryan Woolley, NASA / Caltech JPL; Austin Nicholas, Jet Propulsion Laboratory/Caltech; James Longuski, Purdue University

Solar electric propulsion (SEP) uses low-thrust trajectories to deliver larger payloads compared to conventional ballistic trajectories. However, current techniques to evaluate low-thrust trajectories require the use of optimization software that can require several hours to days of analysis. The goal of this research is to describe the creation and use an early mission design tool, analogous to ballistic porkchop plots, also known as a bacon plot. Such a tool would allow for the fast and easy estimation of a SEP spacecraft's optimal power, thrust, trajectory, and required propellant, through the use of a generalized bacon plot.

AAS 17-680 USING TETHERS TO BUILD A "CAPTURE PORTAL" FOR THE PLANETS

Alessandra Ferreira, National Institute of Space Research - INPE; Antonio Fernando Bertachini Prado, INPE; Anna Guerman, University of Beira Interior, Porrtugal; Othon Winter, Universidade Estadual Paulista - UNESP; Denilson Paulo Souza dos Santos, Universidade Estadual Paulista - UNESP

The literature shows several applications of space tethers to maneuver spacecrafts. Some of them are combinations with the slingshot effect. In one type of this family of applications, tethers are used to make the capture of spacecraft by a planet of the Solar System. The present paper explores in more details this effect. The main idea is to build a permanent structure fixed in one of the moons of a given planet, such that it can be used an unlimited number of maneuvers. With this goal, this research searches for equilibrium points that can be used to place those structures.

AAS 17-702 ANALYSIS OF GEOSTATIONARY SATELLITE CONJUNCTION MONITORING

Yoola Hwang; Byoung-Sun Lee, ETRI

As geostationary satellites are increasing, the numbers of operating satellites placed at the same longitude are increasing. Two Line Elements (TLE) can be easily used to monitor and analyze the satellites located at same or similar longitude for collision avoidance. However, TLE in accuracy is not enough to perform maneuver for collision avoidance. In this paper, we analyze the collision risk by calculating distances between two satellites at each epoch using TLE and studying covariance analysis for neighboring satellites. We also discuss the conjunction monitoring differences using NORAD TLE and JSPoC CSM though our experience.

AAS 17-719 Binocular Vision Observation Based Accuracy Position and Pose Calculation for Space Station Accompanying Satellite

hengwang zhao, Xidian University; Decai Shen, Xidian University; Xiao Chen, xidian university; Hang Yu

With the development of human space exploration, Space Station Accompanying Satellite (SSAS) has been playing more important role for its effective on-orbit services. A target precise recognition and location algorithm based on binocular stereo vision technology is proposed in this paper. In order to solve the key problem of stereo matching the algorithm learns a similarity measure on small image patches using a convolutional neural network, which exploit the proir information and the multiple heterogeneous features to improve the matching accuracy. Experiments on synthetic and real images show that the method can greatly improve the accuracy of the disparity map.

AAS 17-735 **DETERMINING LOCATIONS AND TRANSFERS OF ARTIFICIAL EQUILIBRIUM POINTS IN A DOUBLE ASTEROID SYSTEM**

Geraldo Magela Couto Oliveira, National Institute for Space Research - INPE; Allan Junior, National Institute for Space Research - INPE; Antonio Fernando Bertachini Prado, INPE

The goal of the present paper is to obtain the locations of artificial equilibrium points in a double asteroid system where the spacecraft has a solar sail. Several families of solutions are found for the points L_1 and L_2 in Sun-Ida system. After that bi-impulsive transfers are calculated to link those points. The solar radiation pressure are taken into account in those transfers, and it may help to decrease that magnitude of the impulses required for the transfers. The parameter area/mass used is fixed at 0.3 m^2/kg and the asteroid Ida is placed at the origin of the reference system.

AAS 17-751 **Dynamics of Space Tether on Binary Asteroids**

Antonio Fernando Bertachini Prado, INPE; Alessandra Ferreira, National Institute of Space Research - INPE; Anna Guerman, University of Beira Interior, Porrtugal; Othon Winter, Universidade Estadual Paulista -UNESP; Denilson Paulo Souza dos Santos, Universidade Estadual Paulista -UNESP

The present paper studies the dynamics of space elevators to be constructed in double asteroids, assuming an irregular shape for the bodies. To make this task, a tether is attached to the surface of one of the asteroids, with a spacecraft attached in the other end. The analysis of the equilibrium situations to place the tether and the stability of those situations are made. The irregularities of the bodies, assumed to be ellipsoids, are described by the coefficients of a spherical harmonics expansion. The method was applied to the double asteroid systems (3169) Ostro and (90) Antiope, which are synchronous.

AAS 17-752 **IMPULSIVE AERO-GRAVITY ASSISTED MANEUVERS IN VENUS AND MARS TO CHANGE THE INCLINATION OF A SPACECRAFT**

Antonio Fernando Bertachini Prado, INPE; Jhonathan Murcia, INPE

The powered aero-gravity-assisted is a maneuver that combines three basic components: gravity-assisted, a passage by the atmosphere of the planet during the close approach and the application of an impulse during this passage. The present paper uses this type of maneuver considering Drag and lateral Lift, so it is possible to make a plane change in the trajectory of the spacecraft, which are very expensive maneuvers. The lift to drag ratio goes up to 9.0, because there are vehicles that can be designed to have these values. The planets Venus and Mars are used for the numerical simulations.

AAS 17-764 **ON THE USE OF SOLAR RADIATION PRESSURE TO EJECT A SPACECRAFT ORBITING THE ASTEROID 65803 DIDYMOS (1996 GT)**

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

Asteroids and comets have become the target of space missions. A major goal of future missions is to find solutions that minimize costs. Our study presents the use of solar radiation pressure, by varying the area-to-mass ratio and/or the reflectivity coefficient of the spacecraft, with the goal to assist in the ejection of the spacecraft from an orbit around an asteroid, for a possible return phase to the Earth. The asteroid Didymos, which has a small natural moon (Didymoon), is chosen as the focus of the present study, because it is a possible target for the next missions.

AAS 17-805 **Minimum-Time Low Thrust Orbit Transfers using the Method of Particular Solutions and Integral Collocation**

Robyn Woollands, Texas A&M University ; Julie Read, Texas A&M University; Nathan Budd , Texas A&M University ; John Junkins, Texas A&M University

We have developed a method for solving optimal control minimum time transfers using the method of particular solutions and an integral collocation. The method first computes a sub-optimal solution by iteratively solving for the coefficients of the Chebyshev polynomials that parameterize each of two steering angles of the control vector. This unique implementation of minimum norm direct optimization is attractive in that it does not require partial derivatives, yet we have shown that we can accommodate a relatively high dimensional parameterization of the control variables. Once the sub-optimal solution has been obtained it is used as a warm start to solve the minimum-time optimal control problem.

AAS 17-620 **Engagement Heuristics for Optimizing the Effect of Ground Based Lasers on Orbital Debris in LEO**

Liam Smith, Lockheed Martin; Andrew Zizzi, Lockheed Martin

Lockheed Martin's Advanced Technology Center (ATC) has developed modeling capabilities to study how ground-based lasers can be used to manipulate the orbits of debris in Low-Earth Orbit. The models account for atmospheric attenuation, target attitude, and material properties. Analysis shows that a 10kW laser can induce an orbital perturbation with a magnitude nearly equivalent to Solar Radiation Pressure. Our study indicates this force is not powerful enough to induce a large change in the orbit when the target is engaged at every opportunity. However, applying intelligent engagement heuristics that take advantage of the target's astrodynamics lead to dramatically different results.

AAS 17-674 **Improvements to a Hierarchical Mixture of Experts System Used for Characterization of Resident Space Objects**

Elfego Pinon, Emergent Space Technologies, Inc.; Jessica Anderson, Emergent Space Technologies, Inc.; Angelica Ceniceros, Emergent Space Technologies, Inc.

Part of the Space Situational Awareness (SSA) problem involves detecting, tracking, identifying and characterizing resident space objects (RSOs). Emergent Space Technologies, Inc. has conducted SSA research, sponsored by the Air Force Research Laboratory (AFRL), focused on the use of Hierarchical Mixtures of Experts (HMEs) to process simulated electro-optical measurements to determine RSO characteristics such as attitude profile, size, and shape. This paper discusses recent efforts to improve the performance of the HME by integrating it with advanced bidirectional reflectance distribution function (BRDF) models, a finite set statistics (FISST) based algorithm for detecting and tracking RSOs, and with advanced propagators.

AAS 17-700 **Analytical and statistical characterizations of the long term behavior of a cloud of debris generated by a break-up in orbit.**

Florent Deleflie, IMCCE; Delphine Thomasson, IMCCE / Observatoire de Lille; Walid Hassan, Cairo University; Alexis Petit, University of Namur; Michel Capderou, LMD

This paper provides an analytical formulation of the time required to form a cloud that can be considered as a randomly distributed one around the Earth after a break-up of a satellite. Starting with a break-up model, we characterize, thanks to a statistical approach, typical values of mean changes of velocity within the cloud that enable to describe the changes induced on the inital orbital elements of motion. The effects of zonal parameters, especially J2, and third body attraction is accounted for. The sensitivity of the approach is investigated, and a comparison with Fengyun-1C TLE data sets is provided.

AAS 17-717 **The space debris revolution chaos analysis and the low-cost disposal strategy design**

Chong Sun; Jianping Yuan

The modern life is strongly dependent on the on-orbit service spacecraft, such as the internet, the global climate observer, the satellite positioning system service, or the worldwide communication. However, as the progress of the modern space activities, the number of the space debris experience explosive growth, which results a great threat for the active spacecraft in space. In this paper, the problem of the space debris revolution and the active removal are studied. First, the dynamics model of the large scale space debris (whose radius is larger than 10cm) is developed, considering the earth oblateness, the atmosphere drag, the solar

AAS 17-769 **COMPARISON OF OPTIMIZERS FOR GROUND BASED AND SPACE BASED SURVEY SENSORS**

Bryan Little, Purdue University; Carolin Frueh, Purdue University

Sensor surveys are an important aspect of the construction and maintenance of a catalog of resident space objects (RSO). Due to the high number of known RSOs and the expected number of unknown RSOs, efficient survey strategies are required to continue to improve the knowledge of the overall population and to maintain custody of the known population. This paper presents a comparison of some optimizers for determining efficient survey strategies for both ground based and space based sensors.

AAS 17-772 **Orbit Prediction Uncertainty of Space Debris due to Drag Model Errors**

Christoph Bamann, Technical University of Munich, Chair of Satellite Geodesy

Orbit prediction uncertainties are crucial products for many debris-related activities like conjunction analyses and collision avoidance planning. Aerodynamic drag models commonly represent the largest source of uncertainty in low-Earth orbit. Not only errors in atmospheric density and composition, but also in object shape, attitude, and mass enter the orbit prediction uncertainty through the drag model. The present work provides detailed uncertainty analyses of these components using high-fidelity thermosphere and CAD object models. Its results shall support modeling drag-induced process noise both in terms of the functional form and the level of detail for typical orbit prediction scenarios of space debris.

AAS 17-583 **Low Thrust Cis-Lunar Transfers using a 40 kW-Class Solar Electric Propulsion (SEP) Spacecraft**

Melissa McGuire, NASA GRC; Laura Burke, NASA Glenn Research Center; Steven McCarty, NASA Glenn Research Center; Ryan Whitley, NASA; Diane Davis, a.i. solutions, Inc.; cesar ocampo, Odyssey Space Research; Kurt Hack, NASA Glenn Research Center

To further human exploration beyond low earth orbit (LEO), NASA has conducted multiple studies into the evaluation of orbits which could be useful in conducting the next steps of human missions in cislunar space. One such orbit in particular, the Near Rectilinear Halo Orbit (NRHO), has found much focus in these staging orbit studies. This paper captures analysis of using a representative low thrust high power Solar Electric Propulsion (SEP) vehicle, in the 20-40 kW power to the EP system range, to move a mass around cislunar space.

AAS 17-585 **Overview of the Mission Design Reference Trajectory for NASA's Asteroid Redirect Robotic Mission (ARRM)**

Melissa McGuire, NASA GRC; Laura Burke, NASA Glenn Research Center; Steven McCarty, NASA Glenn Research Center; Nathan Strange, Jet Propulsion Laboratory / California Institute of Technology; Gregory Lantoine, NASA / Caltech JPL; Min Qu, AMA; Haijun Shen, Analytical Mechanics Associates, Inc.; Matthew Vavrina, a.i. solutions; David Smith, Vantage Partners, LLC

National Aeronautics and Space Administration's (NASA's) recently cancelled Asteroid Redirect Mission (ARM) was proposed to rendezvous with and characterize a 100+ m class near- Earth asteroid and provide the capability to capture and retrieve a boulder off of the surface of the asteroid and bring the asteroidal material back to cis-lunar space. The purpose of this paper is to document the final reference trajectory of this asteroid boulder mass capture portion of ARM and its ground rules and assumptions as it stood at the cancellation of the mission as well as the challenges and unique methods employed in trajectory modeling.

Session 2: Student Design Competition

Aug 21, 2017 — Stevenson Ballroom

02 Student Design Competition

Co Chair: Daniel Scheeres

AAS 17-621 **The Astrodynamics Research Group of Penn State (ARGoPS) Solution to the 2017 Astrodynamics Specialist Conference Student Competition**

Pennsylvania State University

Jason Reiter, Davide Conte, Andrew Goodyear, Ghanghoon Paik, Guanwei He, Mollik Nayyar, Matthew Shaw

We present the methods and results of the Astrodynamics Research Group of Penn State (ARGoPS) team in the 2017 Astrodynamics Specialist Conference Student Competition. A mission was designed to investigate Asteroid (469219) 2016 HO3 in order to determine its mass and volume and to map and characterize its surface. This data would prove useful in determining the necessity and usefulness of future missions to the asteroid. The mission was designed such that a balance between cost and maximizing objectives was found.

AAS 17-744 **The Near-Earth Asteroid Characterization and Observation (NEACO) Mission**

University of Colorado Boulder & Sao Paulo State University (UNESP)

Chandrakanth Venigalla, Nicola Baresi, Jonathan Aziz, Benjamin Bercovici, Gabriel Borderes Motta, Daniel Brack, Luke Bury, Josue Cardoso dos Santos, Andrew Dahir, Alex Davis, Stijn De Smet, JoAnna Fulton, Nathan Parrish, Marielle Pellegrino, Stefaan Van wal

The Near-Earth Asteroid Characterization and Observation (NEACO) mission pro- poses to explore the fast-rotating asteroid (469219) 2016 HO3 with a SmallSat spacecraft and perform an early scientific investigation to enable future, more in- depth missions. The NEACO spacecraft is equipped with a low-thrust, solar elec- tric propulsion system to reach its target within two years, making use of an Earth gravity assist. Its instrument suite consists of two optical cameras, a spectrometer, an altimeter, and an explosive impactor assembly. Upon arrival at HO3, NEACO uses pulsed plasma thrusters to hover, first at a high altitude of 50 km to perform lit surface mapping and shape modeling, and later at a lower altitude of 10 km to refine these models and perform surface spectroscopy. Following the hovering phases, the spacecraft performs several flybys with decreasing periapses in order to estimate the asteroid's mass. Finally, NEACO uses an additional flyby to release an explosive impactor that craters the asteroid surface. After spending a few weeks at a safe hovering distance, the spacecraft returns and images the crater and freshly exposed sub-surface material. This provides information on the strength of the asteroid surface. The science operations are completed within eight months, with the total mission lasting less than three years. The objectives met by the NEACO mission satisfy all science goals for the student competition of the 2017 AAS Astrodynamics Specialist Conference.

AAS 17-754 **The Frontier Mission Design Document**

University of Illinois at Urbana-Champaign

Jigisha Sampat, Yufeng Luo, Jasmine Thawesee, Isabel Anderson

The recently discovered small asteroid by the name 2016 HO3 is known to be a companion to Earth while it orbits around the sun. The asteroid has a very similar orbit to Earth's and has been a stable quasi-satellite of the Earth for over a century and will continue to follow this pattern for centuries to come. Although it has been around for so long, it only came to our notice very recently and hence, very little is known to us about this satellite.

The Frontier satellite mission aims to study 2016 HO3's spectral properties, map its surface, and create a global shape model. The satellite uses Lambert's equations of orbital relative motion to travel along the asteroid in it's orbit around the sun while mapping it from different directions. While staying outside the field of influence of the asteroid, the satellite will be able to map its surface at 10 m2 resolution. It will also be able to provide input on the morphology of the planet, its surface composition, overall size, and shape and spin characteristics.

AAS 17-770 **NEO: Mission Proposal for Asteroid (469216) 2016 HO3**
The Johns Hopkins University & Iowa State University

Matthew Heacock, Katherin Larsson, Matthew Brandes, Nathan McIntosh

The satellite mission concept was developed in response to the AAS/AIAA Student Competition request for the 2017 Astrodynamics Specialist Conference. The competition asked for a small satellite mission to Asteroid (469219) 2016 HO3, henceforth referred to as Asteroid HO3, that could be a secondary payload with the intention to observe and collect data about the asteroid, that lies in a quasi-orbit about the Earth. The satellite mission was developed to satisfy Goals 3, 4, 5 and 7 from the problem statement. In addition to the above given goals, NEO will be primarily composed of off the shelf parts to demonstrate the ability to design science missions with a low barrier to entry and reduce risk. NEO must also be less than 140 kg wet mass and shall fit on an ESPA ring.

AAS 17-817 **FORTUNE: A Multi-Cubesat, Near-Earth Asteroid Prospecting Mission**
Purdue University

J.R. Elliott, E. Shibata, P.A. Witsberger, J.L.L. Pouplin, R.J. Rolley, P. Podesta

Asteroids present a unique resource gathering opportunity, since materials gathered from the asteroid do not need to be launched from the Earth's surface. Potential resources include metals for construction purposes and water for fuel. Recently discovered asteroid 2016 HO3 resides in a quasi-orbit about Earth, making it an attractive target for asteroid mining purposes. In this paper we present a multi-CubeSat mission for prospecting and assessing 2016 HO3's potential for resource mining. The mission consists of a 12U CubeSat orbiter that will image the asteroid in the visible wavelengths. X-ray and near-infrared spectra will be obtained. In addition to the orbiter, a 12U impactor system will deliver a 1.35U copper impactor approximately 37 days after the orbiter's arrival. The orbiter will observe the impact, study the resulting crater, and take spectra of sub- surface material excavated during the impact. An analogy-based cost model was developed, and mission cost was found to be $38 million in FY17$.

AAS 17-843 **HO3 Asteroid Rendezvous Explorer – H.A.R.E.**

Florida Institute of Technology

Matthew Austin, Larissa Balestrero, Anthony Genova, Fernando Aguirre, Muzammil Arshad, Max Skuhersky, Mathieu Plaisir, Filippo Mazzanti, Nashaita Patrawalla, Joshua Newman, Stephen Sullivan, Tanner Johnson, Connor Nelson, Evan Smith

HO3 Asteroid Rendezvous Explorer (HARE) serves as a prototype for analyzing the characteristics of asteroid 2016 HO3 using a low-mass spacecraft. Primary objectives of this mission include imaging the asteroid, determining its mass and volume over a specific area, measuring the spectral properties of its surface, and measuring surface hardness. HARE outlines how each of these objectives will be met and the spacecraft meets the mass requirement of less than 140 kg. In addition to the spacecraft structure, the trajectory being utilized is thoroughly outlined.

AAS 17-846 **Block-like Explorer of a near-Earth Body by achieving Orbital Proximity (BEEBOP)**

University of Arizona & Politecnico di Milano

Kristofer Drozd, Ethan Burnett, Eric Sahr, and Drew McNeely, Vittorio Franzese, Natividad Ramos Moron

BEEBOP is a remote sensing space mission designed to investigate 2016 HO3, an asteroid recently discovered that lies in a quasi-orbit about the Earth. This mission is designed as a precursor operation such that enough information about 2016 HO3 can be collected so future endeavors to the asteroid, if necessary, will have a higher probability of success. To drive down cost, a 6 U CubeSat with was selected as BEEBOP's spacecraft. Optimal trajectories from Earth to 2016 HO3 were constructed by means of the Calculus of Variations and Indirect Method. Proximity operation trajectories were found by propagating the spacecraft forward in time within a developed model representing the environment around 2016 HO3. The Zero-Effort-Miss/Zero-Effort-Velocity Guidance Algorithm was utilized to maneuver between these trajectories. Lastly, the spacecraft subsystems were formed through multiple iterations until volumetric, mass, power, thermal, and science requirements were met.

SESSION 3: ATTITUDE CONTROL I

Aug 22, 2017 Cascade A

03 Attitude Control I

Co Chair: Juan Arrieta

8:00 **AAS 17-571** **POINTING JITTER CHARACTERIZATION FOR VARIOUS SSL 1300 SPACECRAFTS WITH SIMULATIONS AND ON-ORBIT MEASUREMEN**

Byoungsam (Andy) Woo, Space Systems Loral; Erik Hogan, SSL

Jitter - line of sight instability or high frequency platform oscillation - is one of the critical performance measures in various pointing sensitive missions, especially high resolution imaging or optical communication missions. If the jitter characteristic of the platform, Earth orbiting satellites in this research, is available at early phase of the development of such missions, the imaging or optical communication payload design can be largely optimized and simpli ed. This paper describes jitter characterization for SSL 1300 series satellites by modeling/simulations and on-orbit measurements in various operational modes.

8:20 **AAS 17-622** **Decentralized finite-time attitude control for multi-body system with terminal sliding mode**

Li Jinyue, Beijing Institute of Technology; Jingrui Zhang

Terminal sliding mode (TSM) is a finite-time control related design method. TSM controller ensures system's trajectories converge to equilibrium in finite time. It also offers system better performance. Decentralized control is originated from large-scale system`s control problem. By separating one system into several subsystems, and control the subsystems with several independent controllers, a decentralized control is presented. Decentralized control gives system greater efficiency and higher robustness. By combing the concept of decentralized control and TSM control, a decentralized TSM controller is proposed. The designed control law is applied to a multibody system. Numerical simulation is presented to show the controller`s superiority.

8:40 **AAS 17-646** **LOCAL ITERATIVE LEARNING CONTROL DESIGN**

Jianzhong Zhu; Richard Longman, Columbia University

Iterative Learning Control (ILC) is a method to converge to zero tracking error in feedback control systems that repeatedly perform a tracking problem. Spacecraft applications include high precision pointing maneuvers with a sensor. It often occurs that one only need high precision during a small segment of the trajectory. This paper develops methods that allow one to do local refinement in output of a feedback control system performing a trajectory. The local learning approaches developed significantly improve both convergence rate in the region of interest compared to the previous approach. And local learning substantially reduces the computation burden of ILC.

9:00 AAS 17-656 ON THE RANGE OF DIFFICULTIES PRODUCED BY SAMPLING ZEROS IN DESIGNING REPETITIVE CONTROL COMPENSTORS

Tianyi Zhang, Columbia University, MC4703 ; Richard Longman, Columbia University

Repetitive control (RC) aims to eliminate the influence of periodic disturbances to a control system. Spacecraft applications include jitter cancellation from CMGs or reaction wheels. RC needs a compensator to cancel the influence of zeros introduced outside the unit circle during the conversion of a continuous to discrete time. This paper examines the zeros locations produced by different feedback configurations, then studies how frequency response based and Taylor series based designs handle the range of possibilities. Compensator design for these configurations is examined. In particular, difficulties produced by the presence of fast phase changes approaching Nyquist frequency are studied.

9:20 AAS 17-657 DYNAMIC CHARACTERISTICS AND PERFORMANCES ANALYSIS OF THE MAGNETIC SUSPENSION VIBRATION ISOLATION SYSTEM

Chao Sheng

The vibration isolation platform is widely used to isolate the micro vibration that is harm to the sensitive load on satellites. The traditional passive vibration isolation platform has difficulty in isolating vibration with low frequency. In this work, a new kind of vibration isolation platform whose actuators are based on the magnetic suspension techniques is presented. The dynamic characteristics and the performances of this platform are analyzed.

9:40 BREAK

10:10 AAS 17-681 Proof of a New Stable Inverse of Discrete Time Systems

Xiaoqiang Ji, Columbia University MC4703 ; Richard Longman, Columbia University; Te Li, Columbia University

Digital control needs discrete time models, but conversion from continuous to discrete introduces sampling zeros often outside the unit circle producing an unstable inverse system. This prevented many control approaches from using the inverse. This paper presents a proof of a new stable inverse which gives the actual inverse at every time step except for a few time steps at the beginning equal to the number or zeros outside the unit circle. Having a stable inverse opens up many design approaches in ILC, RC, LMPC, and even one step ahead control can be made practical.

10:30 AAS 17-686 Improved Detumbling Control for Cubesat by using MEMS Gyro
Dong-Hyun Cho, KARI; Donghun Lee; Hae-Dong Kim

In general, satellite have to perform the detumbling attitude maneuver after it separated from the launch vehicle and a B-dot was widely used. Since the MEMS gyro is embedded in the on-board computer for cubesat, it is possible to measure the angular velocity for the detumbling controller. However, during the magnetic torquers are operating, it is difficult to measure the correct magnetic field for magnetic interference from magnetic torquers. Therefore, in this paper, we applied a simple filter to estimate the magnetic field and the switching time between magnetic sensor and actuator can be suggested by using covariance information.

10:50 AAS 17-691 Time Optimal Control of a Double Integrator Spacecraft Model With Feedback Dynamics
Colin Monk, Naval Postgraduate School; Mark Karpenko, Naval Postgraduate School

Optimal control solutions are typically implemented in open-loop based on nominal system and environmental parameters. However, ignorance of actual system parameters can invalidate the optimal control. While conventional feedback can compensate for uncertainty, this comes at the expense of optimality. This paper examines minimum time rotational maneuvers for a double integrator spacecraft model with a two degree-of-freedom control architecture consisting of a proportional-derivative feedback loop combined with a feed-forward signal. A real-time optimal control approach, which adapts to off-nominal responses is developed for computing the control signal using a combination of optimal control analysis and classical control analysis.

11:10 AAS 17-730 Fully-Coupled Dynamical Jitter Modeling of Variable-Speed Control Moment Gyroscopes
John Alcorn, University of Colorado; Cody Allard, University of Colorado; Hanspeter Schaub, University of Colorado

Control moment gyroscopes (CMGs) and variable-speed control moment gyroscopes (VSCMGs) are a popular method for spacecraft attitude control and fine pointing. Since these devices typically operate at high wheel speeds, mass imbalances within the wheels act as a primary source of angular jitter. A physically realistic dynamic model may be obtained by defining mass imbalances in terms of a wheel center of mass location and inertia tensor. The fully-coupled dynamic model allows for momentum and energy validation of the system. This paper presents a generalized approach to VSCMG imbalance modeling of a rigid spacecraft hub with N VSCMGs.

SESSION 4: LOW-THRUST TRAJECTORY DESIGN

Aug 22, 2017 Stevenson C/D

04 Low-Thrust Trajectory Design

Co Chair: Jon Sims

8:00 AAS 17-803 Shape-Based Approach Based on Fast Numerical Approximation of Invariant Manifolds for Cislunar Low-Energy Low-Thrust Trajectories Transfer

RENYONG ZHANG, Technology and Engineering Center for Space Utilization, Chinese Academy of Sciences; Jianjun Luo; Wang Wenbin

In this paper a shape-based approach for the design of low-energy, low-thrust trajectories transfer from high earth orbit (HEO) to cislunar invariant manifolds in the framework of the circular restricted three-body problem (CR3BP) is presented. Firstly, modified exponential sinusoid of shape functions are analytically determined; Secondly, using a fast numerical approximation of invariant manifolds to compute attainable sets; Finally, differential evolution algorithm is used to determine suitable values for the design variables of modified shape function parameters. Result shows the approach can efficaciously design optimal trajectories which need a great number of manifold insertion points have to be evaluated online.

8:20 AAS 17-609 Characteristics of Energy-Optimal Spiraling Low-thrust Escape Trajectories

Nicholas Bradley, NASA / CalTech - JPL; Daniel Grebow, NASA / Caltech JPL

We present and discuss trajectory characteristics of low-thrust spacecraft thrusting along the instantaneous velocity vector toward escape. The behavior of the osculating eccentricity is examined, in which eccentricity decreases to a minimum before quickly increasing toward escape. The argument of periapsis replaces true anomaly as the fast time variable, and the spacecraft escapes near an osculating true anomaly of 90 degrees. The dynamical theory governing these observations is discussed, and an actual as-flown trajectory from the Dawn mission is presented as a case study where these behaviors occurred in flight.

8:40 AAS 17-832 Efficient Low Thrust Trajectory Optimization in CRTBP with Human-in-the-Loop

Nathan Parrish, University of Colorado at Boulder; Daniel Scheeres, University of Colorado; Steven Hughes

The problem of low-thrust trajectory optimization in highly perturbed dynamics is a stressing case for many optimization tools. This paper describes a fast, robust method to

design a trajectory in the CRTBP, beginning with no or very little knowledge of the system. Two algorithms are used in tandem. Algorithm 1 is used to converge on the “minimum energy” solution from any arbitrary initial condition, even random noise. This is done with multiple shooting and a two-stage differential corrector. Algorithm 2 uses multiple shooting again, with mesh refinement, to find the nearby solution which minimizes the propellant mass.

9:00 AAS 17-766 Improvements to Sundman-Transformed HDDP Through Modified Equinoctial Elements

Jonathan Aziz, University of Colorado Boulder; Daniel Scheeres, University of Colorado

Previous efforts addressed the challenge of low-thrust many-revolution trajectory optimization by applying a Sundman transformation to change the independent variable of the spacecraft equations of motion to the eccentric anomaly and performing the optimization with Hybrid Differential Dynamic Programming (HDDP). Improvements to Sundman-transformed HDDP have been realized by representing the spacecraft state with modified equinoctial elements. This paper shows how the modified equinoctial element state representation enters the HDDP algorithm and presents improved results for example transfers from geostationary transfer orbit (GTO) to geosynchronous orbit (GEO).

9:20 AAS 17-623 Semi-analytic preliminary design of low-thrust missions

Javier Roa, NASA / Caltech JPL; Anastassios Petropoulos, NASA / Caltech JPL; Ryan Park, NASA / Caltech JPL

A new strategy for the preliminary design of low-thrust transfers is developed. It relies on a shape-based method using generalized logarithmic spirals, which provide a fully analytic solution to the dynamics. Thanks to admitting two conservation laws, equivalent to the equation of the energy and angular momentum, the design methodology is similar to that adopted in the purely impulsive case. A branch and pruning search methodology is implemented to find initial guesses for the low-thrust gravity-assist problem using this approach. The last step consists in optimizing the best candidates to build the final solution and validate the searching paradigm.

9:40 BREAK

10:10 AAS 17-727 Trajectory tracking guidance for low-thrust geosynchronous orbit insertion using piecewise constant control

Ran Zhang, Beihang University; Chao Han, Beihang University

Firstly, an indirect method is applied to optimize the optimal low-thrust transfer problem to geosynchronous orbit. A cubature Kalman filter parameter estimation algorithm is presented to solve the TPBVP, which does not rely on gradient information and is simple, robust. Then a guidance scheme based on tracking the reference orbit is developed to compensate the deviations of the real trajectory. Blending analytic thrust steering laws are used with a few weight coefficients which are determined based on the slope of the reference orbit, thus reducing the computing time significantly onboard the satellite.

10:30 AAS 17-626 Low-Thrust Transfer Design Based on Collocation Techniques: Applications in the Restricted Three-Body Problem

Robert Pritchett, Purdue University; Kathleen Howell, Purdue University; Daniel Grebow, NASA / Caltech JPL

Low-thrust transfers between stable periodic orbits are necessary to support the development of cislunar space. However, transfer design between such orbits cannot leverage unstable manifold structures typically employed in transfer design. Thus, a methodology for constructing these transfers, based on collocation, is demonstrated. Initial guesses comprised of coast arcs along periodic orbits and intermediate trajectory arcs are converged into feasible transfers. Transfers are then developed using continuation and optimization strategies. This process applies to various spacecraft configurations and the results are validated in a high-fidelity model. Overall, practical examples are offered to demonstrate a robust approach for computing low-thrust transfers.

10:50 AAS 17-729 SHAPE-BASED TRAJECTORY DESIGN OF LOW THRUST TO L1 HALO ORBIT OF EARTH-MOON SYSTEM

Dandan Zheng

Withdrawn.

11:10 AAS 17-740 Waypoint-based ZEM/ZEV Feedback Guidance: Applications to Low-thrust Interplanetary Transfer and Orbit Raising

Roberto Furfaro, The University of Arizona; Giulia Lanave, Politecnico di Milano; Francesco Topputo, Politecnico di Milano; Marco Lovera, Politecnico di Milano; Richard Linares, University of Minnesota

Low-thrust guided trajectories for space missions are extremely important for fuel-efficient autonomous space travel. In this paper, we design an optimized, waypoint-based, closed-loop solution for low-thrust, long duration orbit transfers. The Zero-Effort-Miss/Zero-Effort-Velocity (ZEM/ZEV) feedback guidance algorithm which has been demonstrated to exhibit great potential for autonomous onboard implementation is applied in a waypoint fashion. Performance in Low-thrust interplanetary transfer and orbit raising are evaluated.

11:30 AAS 17-757 Exploration of Low-thrust Trajectories to Earth-Moon Halo Orbits

Bindu Jagannatha, University of Illinois at Urbana-Champaign; Vishwa Shah, University of Illinois at Urbana-Champaign; Ryne Beeson, University of Illinois at Urbana-Champaign; Koki Ho, University of Illinois, Urbana-Champaign

Low-thrust trajectories to Earth-Moon halo orbits using their invariant manifolds can be divided into two phases -- the spiral thrust arc and the coast arc. Thus, the thrust strategy for spiral arc decides the propellant mass consumed for the transfer, but optimising this thrust arc is computationally expensive. In this work, the use of Q-law to design this spiral thrust arc will be quantified against a hybrid optimal control technique and the manifold explored for optimal insertion/departure points. The work is aimed at enabling quick top-level analysis for designing missions / campaigns to the cislunar space.

11:50 AAS 17-748 **Optimal Power Partitioning for Electric Thrusters**

Lorenzo Casalino, Politecnico di Torino - DIMEAS; Matthew Vavrina, a.i. solutions; Paul Finlayson, Jet Propulsion Laboratory; Anastassios Petropoulos, NASA / Caltech JPL

High power missions may employ more than one EP thruster and the problem of power partitioning among the thrusters becomes relevant. Space trajectories are controlled by the thrust vector. Optimization consists of finding the optimal control law for thrust magnitude and direction to maximize a specified performance index, while fulfilling given boundary conditions. The paper discusses methods to find the optimal power partitioning among the available thrusters. Different approaches based on indirect methods, direct methods, and evoutionary algorithms are presented. The paper compares the results for test cases related to missions to asteroids, and discusses merits and possible improvements.

Aug 22, 2017 Stevenson B

05 Space Situational Awareness

Co Chair: Rodney Anderson

8:00 **AAS 17-550** **Debris Cloud Containment Boundary Anomaly**
Brian Hansen, The Aerospace Corporation

A satellite breakup caused by a hypervelocity impact or explosion will create a large cloud of debris particles. One way to represent the evolving boundary of such a cloud is to construct a surface using fragments that all have the maximum breakup spreading speed, but in different directions. It has previously been shown that such a boundary surface will contain any lower-velocity fragments from the breakup event under certain assumptions. This paper investigates an anomaly that arises where those assumptions do not hold, allowing some lower-velocity fragments to escape the boundary at small distances and for small intervals of time.

8:20 **AAS 17-568** **Improved Reentry Predictions with High Fidelity Models**
Eric Eiler, The Aerospace Corporation; Roger Thompson, The Aerospace Corporation; Jason Reiter, Astrodynamics Research Group of Penn State (ARGoPS)

Space object reentry predictions are closely tied to uncertainties in multiple key parameters that define the reentering objects and their atmospheric environment. Efforts focusing on the uncertainty surrounding objects' ballistic coefficients are described, with the goal of providing more consistent and accurate lifetime predictions. Times of reentry were derived by high fidelity integration methods. By using an ensemble of runs rather than one single propagation run, trends and variations of multiple reentry prediction times were evaluated. Adjustments to the ballistic coefficient were made to achieve consistent reentry predictions. These predictions are compared to historical reentry data and other methods' predictions.

8:40 **AAS 17-592** **Debris Object Orbit Initialization using the Probabilistic Admissible Region with Asynchronous Heterogeneous Observations**
Waqar Zaidi, Applied Defense; Islam Hussein, Applied Defense Solutions; Matthew Wilkins, Applied Defense Solutions; Christopher Roscoe, Applied Defense Solutions; Weston Faber, Applied Defense Solutions; Paul Schumacher, Air Force Research Laboratory

The admissible region is defined as the set of physically acceptable orbits (e.g., orbits with negative energies) consistent with one or more observations of a space object. Given additional constraints on orbital semi-major axis, eccentricity, etc., the admissible region can be constrained, resulting in the constrained admissible region. Based on known statistics of the measurement process, one can replace hard constraints with a probabilistic admissible region (PAR). In all the work on the PAR to date, observations were collected concurrently and by the same sensor. In this paper, we explore scenarios including mixed and unmixed optical and radar synchronized and asynchronous observations.

9:00 **AAS 17-639** **Optical Data Association In a Multi-Hypothesis Framework With Maneuvers**

Weston Faber, Applied Defense Solutions; Islam Hussein, Applied Defense Solutions; John Kent, University of Leeds; SHAMBO BHATTACHARJEE, University of Leeds; Moriba Jah, The University of Texas at Austin

In Space Situational Awareness (SSA) one may encounter scenarios where the measurements received at a certain time do not correlate to a known Resident Space Object (RSO). Typically, tracking methods tend to associate uncorrelated measurements to new objects and wait for more information to determine the true RSO population. This can lead to the loss of object custody. The goal of this paper is to utilize a multiple hypothesis framework coupled with some knowledge of RSO maneuvers that allows the user to maintain object custody in scenarios with uncorrelated optical measurement returns.

9:20 **AAS 17-745** **The performance of a direction-based Bayesian filter in the orbital tracking problem**

John Kent, University of Leeds; SHAMBO BHATTACHARJEE, University of Leeds; Islam Hussein, Applied Defense Solutions; Moriba Jah, The University of Texas at Austin

The space debris tracking problem from a series of angles-only observations can be viewed as an example of Bayesian filtering. Bayesian filtering is easy to implement if the joint distribution of the state vector and the observation vector is normally distributed. Under Keplerian dynamics, the propagation of an initial normally-distributed point cloud does not tend to remain normal in various standard coordinate systems. Hence we propose using an “adapted structural coordinate system”, which preserves approximate normality much more successfully. We analyze the performance of a Bayesian filter in this new coordinate system.

9:40 **BREAK**

10:10 **AAS 17-808** **Maneuvering Detection and Prediction using Inverse Reinforcement Learning for Space Situational Awareness**

Richard Linares, University of Minnesota; Roberto Furfaro, The University of Arizona

This paper determines the behavior of Space Objects (SO) using inverse Reinforcement Learning (RL) to estimate the reward function that each SO is using for control. The approach discussed in this work can be used to analysis maneuvering SO from observational data. The inverse RL problem is solved using the Feature Matching approach. This approach determines the optimal reward function that an SO is using while maneuvering by assuming that observed trajectories are optimal with respect to the SO's own reward function. This paper using Two-Line-Element (TLE) data to determine the behavior of SOs in a data-driven fashion.

10:30 **AAS 17-809** **CONJUGATE UNSCENTED TRANSFORM BASED JOINT PROBABILITY DATA ASSOCIATION**

Manoranjan Majji, Texas A&M University, College Station; Puneet Singla, The Pennsylvania State University; Utkarsh Mishra, Texas A&M University

Conjugate Unscented Transformation (CUT) based Joint Probability Data Association (JPDA) algorithms are formulated for problems in Space Situational Awareness (SSA) applications. The paper presents recent advances in data association algorithms and considers an application of more advanced filtering algorithms to evaluate the performance of the association process. Metrics to evaluate the performance of the data association strategies are presented and the performance augmentation obtained by utilizing the CUT approach as opposed to traditional extended Kalman filtering (EKF) based soltuions are detailed. Representative examples are utilized to demonstrate the utility of the proposed approach.

10:50 **AAS 17-830** **Modern Differential Photometry Using Small Telescopes**

Ryan Coder, Air Force Research Laboratory

Recently released star catalogs from the European Space Agency's Gaia spacecraft hold the promise of enabling high accuracy differential photometry, also referred to as in-situ photometry. This work provides statistics on the number of stars detected and resultant zero points typical of small-telescope data using older catalogs. Simulations are provided to show how these results change incorporating the newer Gaia catalog with low signal-to-noise ratio detection algorithms, which maximize the number of detected stars in each simulated image. These results can then be used to inform the selection of commercial off the shelf components which constitute a small-telescope system.

11:10 **AAS 17-737** **Estimation of untracked geosynchronous population from short-arc angles-only observations**
Liam Healy, Naval Research Laboratory; Mark Matney, NASA Johnson Space Center

Telescope observations of the geosynchronous regime will observe two basic types of objects --- objects related to geosynchronous earth orbit (GEO) satellites, and objects in highly elliptical geosynchronous transfer orbits (GTO). Because telescopes only measure angular rates, the GTO can occasionally mimic the motion of GEO objects over short arcs. A GEO census based solely on short arc telescope observations may be affected by these ``interlopers". A census that includes multiple angular rates can get an accurate statistical estimate of the GTO population, and that then can be used to correct

11:30 **AAS 17-792** **Fusing Survey and Follow-up for SSA Sensor Tasking**
Carolin Frueh, Purdue University

Traditionally in the detection and tracking of space objects (at least) two observation modes are used. Survey for initial detection without a priori information and follow-up to allow for initial orbit determination following detection and for catalog maintenance. In this new framework, sensor tasking is formulated as an optimization problem under realistic conditions. It allows to find the optimal balance between sensor time to detect new objects and to secure and maintain them in the catalog. Probability regions are mapped out based on first principles. Simulations are used to compare traditional heuristic tasking with the new optimized framework.

11:50 **AAS 17-600** **Application of New Debris Risk Evolution And Dissipation (DREAD) Tool to Characterize Post-Fragmentation Risk**
Daniel Oltrogge, Analytical Graphics Inc; David Vallado, AGI/CSSI

The evolution of the debris field generated by an on-orbit explosion or collision fragmentation event is of critical concern to space operators and SSA organizations. Following AGI's recent development of the "Debris Risk Evolution And Dissipation" (DREAD) analysis tool, the authors apply that tool to simulate collision and explosion events, characterize 3D fragmentation cloud evolution, verify that DREAD results are in-family with SSN-based fragmentation tracks, and estimate subsequent risk to all active satellites. Significantly, the DREAD tool facilitates the rapid evaluation of fragmentation down-stream collision risk to active satellites as an SSA tool. Additional speed improvements and parallelization techniques to DREAD are examined.

SESSION 6: TRAJECTORY DESIGN

Aug 22, 2017 Stevenson A

06 Trajectory Design

Co Chair: Roby Wilson

8:00 **AAS 17-749** **Design of Lunar-Gravity-Assisted Escape Maneuvers**

Lorenzo Casalino, Politecnico di Torino - DIMEAS; Gregory Lantoine, NASA / Caltech JPL

Lunar gravity assist is a means to boost the energy and C3 of an escape maneuver. Two approaches are applied and tested for the design of trajectories aimed at Near-Earth asteroids. Maneuvers with up to two lunar gravity assists are considered and analyzed. First, the results of pre-computed maps of escape C3 are used for the analysis of the interplanetary leg. Indirect optimization of the heliocentric leg is combined to an approximate analysis of the geocentric phase in a reversed approach. Features are compared and suggestions about a combined use of the approaches are presented.

8:20 **AAS 17-694** **A Database of Planar Axi-Symmetric Periodic Orbits for the Solar System**

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

A database of planar, axi-symmetric three-body periodic orbits for planets and main planetary satellites in the Solar System is presented. The broad database, available online, includes periodic orbits that orbit only the secondary, periodic orbits that orbit only the primary (e.g. resonant orbits), and more complex ones that orbit both, allowing for transitions in between. The database includes a set of geometrical parameters and stability indexes which allows the user to easily identify and classify the orbits, providing a framework for trajectory design in multi-body environments.

8:40 **AAS 17-604** **Solar Probe Plus Navigation: One Year From Launch**

Paul Thompson, NASA / Caltech JPL; Troy Goodson, NASA / Caltech JPL; Min-Kun Chung, NASA/JPL; Drew Jones, Jet Propulsion Laboratory, Caltech; Eunice Lau, NASA / Caltech JPL; Neil Mottinger, NASA / Caltech JPL; Powtawche Valerino, NASA / Caltech JPL

Solar Probe Plus (SPP) will be the first spacecraft designed to fly deep within the sun's lower corona, becoming the fastest spacecraft flown. Launch is scheduled for next year, with a 20-day launch period beginning on 31 July 2018. SPP will be on a ballistic trajectory, requiring seven Venus flybys to progressively lower the perihelion over the seven-year mission. This near-solar environment can be particularly challenging from a spacecraft design as well as a navigation perspective. We discuss the navigation strategy needed to fly this mission, along with the analysis we conducted to demonstrate how to meet our navigation requirements.

9:00 AAS 17-631 Flight Path Control Analysis for Parker Solar Probe

Powtawche Valerino, NASA / Caltech JPL; Paul Thompson, NASA / Caltech JPL; Troy Goodson, NASA / Caltech JPL; Min-Kun Chung, Jet Propulsion Laboratory; Neil Mottinger, NASA / Caltech JPL; Drew Jones, Jet Propulsion Laboratory, Caltech

An unprecedented NASA mission to study the Sun, known as Parker Solar Probe (PSP), is under development. The primary objective of the PSP mission is to gather new data within 10 solar radii of the Sun's center. The purpose of this paper is to review the statistical analysis of trajectory correction maneuvers (TCMs) for PSP's baseline trajectory. The baseline mission includes a total of 42 TCMs that will be accomplished with a monopropellant propulsion system that consists of twelve 4.4 N thrusters. Assuming current navigation models, statistical analyses for each reference trajectory during the 20-day launch period result in a

9:20 AAS 17-776 MColl: Monte Collocation Trajectory Design Tool

Daniel Grebow, NASA / Caltech JPL; Thomas Pavlak, NASA / Caltech JPL

In this paper we describe a new low-thrust optimization software being developed at JPL. The software tool is based on a collocation algorithm where a trajectory discretization is fitted and adjusted until the dynamics equations of motion are satisfied. The resulting large scale non-linear programming problem is optimized with IPOPT or Knitro. The user specifies path constraints, boundary constraints, and objectives. We describe the underlying collocation algorithm as well as various mesh refinement methods, and apply the software tool to solve many low-thrust example problems. Results are compared to JPL's other low-thrust optimization tools MALTO and Mystic.

9:40 BREAK

10:10 AAS 17-588 A HIGH EARTH, LUNAR RESONANT ORBIT FOR SPACE SCIENCE MISSIONS

Gregory Henning, The Aerospace Corporation; Randy Persinger, The Aerospace Corporation; George Ricker, MIT Kavli Institute for Astrophysics and Space Research

To achieve an unobstructed view of space and a stable thermal environment, the Transiting Exoplanet Survey Satellite (TESS) science mission will insert, via lunar gravity assist, into a P/2-HEO Moon-resonant orbit when it launches in early 2018. Previous work yielded insight into this orbit's behavior, which can be used to optimally select robust mission designs. This paper examines the full orbit trade space to optimize specific

launch windows with the lowest possible delta-V and other key mission constraints. Eclipse avoidance is a particularly difficult challenge for this orbit, and a sensitivity study to initial conditions and maneuver errors was performed.

10:30 AAS 17-724 AUTOMATED NODE PLACEMENT CAPABILITY FOR SPACECRAFT TRAJECTORY TARGETING USING HIGHER-ORDER STATE TRANSITION MATRICES

Christopher Spreen, Purdue University; Kathleen Howell, Purdue University

Targeting and guidance are nontrivial but frequently accomplished by employing discretized representations of a trajectory via nodes along the path, reflecting the full state at specific times. In complex regimes, sensitivity to the startup arcs, through the node locations, requires experience and knowledge of the dynamical environment for efficient corrections. By building upon previous investigations, an updated, enhanced algorithm is developed to place nodes by leveraging the stability attributes of local Lyapunov exponents. The use of multicomplex numbers for higher-order numerical differentiation aides in the calculation of higher-order state transition matrices, which expand the capabilities and performance of this algorithm.

10:50 AAS 17-675 SCALING AND BALANCING FOR FASTER TRAJECTORY OPTIMIZATION

Isaac M. Ross; Qi Gong, University of California, Santa Cruz; Mark Karpenko, Naval Postgraduate School; Ronald Proulx, Naval Postgraduate School

It is well-known that proper scaling can increase the computational efficiency of trajectory optimization problems. In this paper we define and show that a balancing technique can significantly improve the computational efficiency of trajectory optimization problems. We also show that non-canonical scaling and balancing procedures may be used quite effectively to reduce the computational difficulty of some hard problems. A surprising aspect of our analysis shows that it may be inadvisable to use auto-scaling procedures employed in many nonlinear programming software packages.

11:10 AAS 17-842 Space and Time Continuous Algorithm for Fast Trajectory Optimization

Nitin Arora, JPL; Nathan Strange, Jet Propulsion Laboratory / California Institute of Technology; Anastassios Petropoulos, NASA / Caltech JPL

A time transformation based on vercosine of the change in eccentric anomaly, is introduced. This transformation, coupled with the F and G functions, explicitly defines the velocity vectors for a pair of position vectors. Using this property, a discretization strategy is formulated where continuous thrusting arcs are represented by set of impulses, implicitly realized by maintaining spatial continuity. Time discontinuity is propagated forward and removed at the last grid point via a Lambert arc. The trajectory is transformed into a NLP which is solved using existing solvers. Algorithm performance is studied and compared to JPL's Mission Analysis Low-Thrust Optimizer(MALTO).

11:30 AAS 17-828 Orbit Design Method Research on Transfer to the Retrograde GEO Orbit by Lunar Gravity Assist for Spacecraft

RENYONG ZHANG, Technology and Engineering Center for Space Utilization, Chinese Academy of Sciences; Yang Gao, Technology and Engineering Center for Space Utilization, Chinese Academy of Sciences

In this paper a design method for changing the inclination of an orbital spacecraft from the ascending orbit to the retrograde orbit is presented. Firstly, revealing the mechanism of the lunar gravity assist, and maximum change capability of the spacecraft orbit parameters will be obtained, based on the Lagrangian planetary equation or Hamilton equation; Secondly, studying the flight mechanism to transfer the geocentric orbital spacecraft to the geocentric retrograde orbit; Finally, the orbit technology from the forward GEO orbit to the retrograde GEO orbit is designed, and the technical application method in the actual orbit design project is proposed.

11:50 AAS 17-790 Approximate-optimal Feedback Guidance For Soft Lunar Landing Using Gaussian Process Regression

Pradipto Ghosh, Analytical Graphics Inc.; James Woodburn, AGI; Cody Short, Analytical Graphics Inc.

In this paper, a recently-developed optimal feedback synthesis method based on Gaussian Process Regression (GPR) is applied to soft lunar landing guidance. GPR can be used to construct surrogate models from input-output sets of computer experiments. When applied to a family of offline-computed extremals for a trajectory optimization problem, such a model can generate approximate-optimal controls at state values not necessarily part of the GPR model training trajectory set, thus demonstrating a state-feedback paradigm. Using a high-fidelity nonlinear dynamical model, it is demonstrated that the GPR-based guidance algorithm is highly effective in compensating for imperfectly-known initial conditions of the lander.

SESSION 7: ADVANCES IN SPACECRAFT DESIGN

Aug 22, 2017 Stevenson B

07 Advances in Spacecraft Design

Co Chair: Brian Gunter

13:40 AAS 17-734 LABORATORY EXPERIMENTS ON THE CAPTURE OF A TUMBLING OBJECT BY A SPACECRAFT-MANIPULATOR SYSTEM USING A CONVEX-PROGRAMMING-BASED GUIDANCE

Josep Virgili-Llop, Naval Postgraduate School; Costantinos Zagaris, Naval Postgraduate School; Richard Zappulla, Naval Postgraduate School; Andrew Bradstreet, Naval Postgraduate School; Marcello Romano, Naval Postgraduate School

Spacecraft equipped with robotic manipulators may be tasked with the capture of Resident Space Objects. The highly nonlinear dynamics of spacecraft-manipulator systems make the optimization of the capture maneuver a challenging task. In a previous paper, the authors presented an optimization-based guidance and control approach suitable for real-time implementation. The proposed approach relies in convex-programming to obtain deterministic convergence properties. In this follow-on paper, this proposed approach is experimentally demonstrated on the POSEIDYN air bearing test bed. In these experiments, an autonomous robotic vehicle executes the capture maneuver, solving, in real-time, the resulting convex optimization problems.

14:00 AAS 17-747 Dynamic Modeling of Folded Deployable Space Structures With Flexible Hinges

JoAnna Fulton; Hanspeter Schaub, University of Colorado

This paper develops modeling techniques capturing the three-dimensional deployment dynamics of complex folded deployable structures on spacecraft. For cases where the deployed structure is several factors greater in size than the spacecraft bus, the dynamics of the deployment and the effect on the bus is of significant concern. This paper provides an initial investigation on how to model flexible hinges that connect stored rigid panels for folded structures. The nonlinear multi-body dynamics will be studied and described using an energy-based approach and parameterizations developed for attitude dynamics. The scope of this paper considers single-layers of panels on spacecraft in open kinematic configurations.

14:20 **AAS 17-797** **Cis-Lunar Mission Design for SmallSats**

Vishwa Shah, University of Illinois at Urbana-Champaign; Joshua Aurich, University of Illinois at Urbana-Champaign; Ryne Beeson, University of Illinois at Urbana-Champaign; Kaushik Ponnapalli, University of Illinois at Urbana-Champaign

The scientific advances in the past decade have led to astonishing growth in the SmallSat industry, with new missions stretching far beyond Earth sciences and observation. With strong industry and research support, CubeSat form factor satellites possess the technology to venture out into the cis-lunar region. However, the limited power, propulsion and control authority of these satellites coupled with constantly evolving launch conditions mission design complex and challenging. This paper will present CubeSat mission concepts in the cis-lunar region similar to those targeted for EM-1, and an optimization framework to enable rapid search of this space.

14:40 **AAS 17-618** **Applicability of the Multi-Sphere Method to Flexible One-Dimensional Conducting Structures**

Jordan Maxwell, CU Boulder; Hanspeter Schaub, University of Colorado

Electrostatic forces and torques are being exploited in space mission concepts such as charged formation flying, inflatable membrane structures, as well as space debris mitigation technologies. The analysis of these concepts requires faster-than-realtime electrostatic force and torque modeling. The recently developed Multi-Sphere Method (MSM) approximates the electrostatic field about finite bodies using optimally configured conducting spheres as base function. This paper investigates how much the rigid shape assumption can be relaxed by studying the charged deformation on flexible one-dimensional structure. The results show that the impact on the approximation is promisingly low, on the order of less than 1-10%.

15:00 **AAS 17-636** **Stabilization Methodology of Tethered Space Tug Using Electrical Propulsion System**

Yu Nakajima, Japan Aerospace Exploration Agency; Naomi Murakami, Japan Aerospace Exploration Agency; Toru Yamamoto, Japan Aerospace Exploration Agency; Koji Yamanaka, Japan Aerospace Exploration Agency

Tethered tugging approach for low thrust system such as electrical propulsions is proposed. Unlike the high power thrust such as chemical propulsions, the system get unstable easily because it is difficult to keep the tether in tension. Therefore, the active debris removal satellite is putted on radial axis, thus the tether gets stable because the gravity gradient torque affect the tether to keep its attitude aligned on the radial axis in the long run. The proposed approach tries to take advantage of this physical nature to tug the debris stably with cost effective low thrust propulsions.

15:20 BREAK

15:50 AAS 17-638 RESEARCH ON DYNAMIC CHARACTERISTICS AND CONTROL SCHEME OF LOX/KEROSENE SPACE PROPULSION SYSTEM FOR ORBIT CONTROL

Xuan Jin, Science and Technology on Scramjet Laboratory, College of Aerospace Science and Engineering, National University of Defense Technology; Chi-bing Shen, National University of Defense Technology; Xianyu Wu, Science and Technology on Scramjet Laboratory, College of Aerospace Science and Engineering, National University of Defense Technology

Withdrawn.

16:10 AAS 17-706 OPTIMAL BLADE PITCH PROFILE FOR AN AUTOROTATIVE ENTRY VEHICLE

Dario Modenini, University of Bologna; Paolo Tortora, University of Bologna; Marco Zannoni, University of Bologna

We consider the Entry Descent and Landing problem for a vehicle equipped with an unpowered rotary decelerator, having Mars as planetary target. We aim at computing an optimal blade pitch profile to maximize the overall decelerating effect exerted by the rotor. To this end, we set up an optimization problem with one state variable (the altitude) specified at an unknown terminal time, with the landing speed as the objective function to be minimized. Preliminary results show the effectiveness of the proposed approach in reducing the terminal velocity with respect to what achieved when using simple constant pitch settings.

16:30 AAS 17-722 Parametric Study of Electron Collection Efficiency of Curved Electrodynamic Tethers

George Zhu, York University; Gangqiang Li, York University

The paper conducted a parametric study of electron collection efficiency of a curved electrodynamic tether in deorbit process by a coupled multiphysics finite element method. Different from the existing approaches, the current method discretizes and solves the orbital motion limited theory of electrodynamic tether and the dynamics of elastic flexible tether simultaneously. Analysis results show that the effects of flexible tether geometry and the parameters of electric circuit at cathodic end have a significant impact on the electron collection efficiency of electrodynamic tether system. Finally, the possibility of the battery's drain out should be considered in the mission analysis.

16:50 **AAS 17-725** **design of obstacle avoiding in high tracking accuracy for spatial manipulator**

Tingting Sui, School of Astronautics, Beihang university; Jun Guo, School of Astronautics, Beihang university; Jian Guo, Baicheng Ordnance Test Center of China; Xiao Ma, Baicheng Ordnance Test Center of China

Aiming at the shortage of traditional obstacle avoidance algorithm, an obstacle avoidance algorithm based on spatial operator algebra which applicable to multiple obstacles is put forward in this paper. The algorithm uses SOA to simplify Jacobian complexity of manipulator, improve the stylization. And with the minimum distance between the obstacle and the manipulator, as the optimization index of gradient projection method, escape speed is obtained by the Jacobian transpose matrix of each bar. Then combining tracking control of actuator position at the end, the task of multi obstacle avoidance in spatial manipulator is accomplished in high position accuracy.

17:10 **AAS 17-726** **CubeSat Deorbit Mission Using an Electrodynamic Tether**

George Zhu, York University

This paper describes a mission design for a cubesat flying with an electrodynamic tether (EDT) to achieve a set of engineering and scientific objectives. The basic mission task involves two Cubesats connected by 100-meter long aluminum EDT. The engineering objectives of this mission are to perform a pioneering mission to demonstrate deployment and stabilization of an EDT with an end-mass, current collection using bare EDT, field effect electron emission, and spacecraft de-orbiting by EDT technology. In addition, the mission will provide a new approach to improve the interpretation of convective motion in the F-region ionosphere at high latitudes.

17:30 **AAS 17-824** **Stability Analysis of Generalized Sail Dynamics Model**

Go Ono, Japan Aerospace Exploration Agency; Shota Kikuchi, The University of Tokyo; Yuichi Tsuda, Japan Aerospace Exploration Agency

This paper addresses a stability analysis for attitude dynamics of a non-spinning momentum-biased solar sail spacecraft under strong influence of solar radiation pressure (SRP). A model called the Generalized Sail Dynamics Model (GSDM) developed by Ono et al. provides an attitude model for a momentum-biased solar sail spacecraft with arbitrary shape and optical reflectance properties. In this paper, the stability of the GSDM is investigated, and general conditions for stability are derived analytically by an eigenvalue analysis. The outcome of this paper is of interest for the design of spacecraft that applies the GSDM.

Session 8: Attitude Control II

Aug 22, 2017 Cascade A

08 Attitude Control II

Co Chair: Kyle DeMars

13:40 **AAS 17-615** **Model Predictive Control and Model Predictive Q-Learning for Structural Vibration Control**

Minh Phan, Dartmouth College; Seyed Mahdi Basiri Azad, Thayer School of Engineering

This paper describes the relationship between Model Predictive Control (MPC) and Q-Learning, and formulates an algorithm called Model Predictive Q-Learning that integrates the two concepts. As a unifying theme, the paper explains how the Linear Quadratic Regulator (LQR), MPC, Q-Learning, and Model Predictive Q-Learning solve the same structural vibration control problem, and how the Q-Learning approach naturally handles both continuous and discrete-action inputs. The relationship between Model Predictive Q-Learning and standard Q-Learning is analogous to the relationship between MPC and LQR.

14:00 **AAS 17-670** **ZERO LOCATIONS IN DISCRETE-TIME NON-MINIMUM PHASE SYSTEMS AS A FUNCTION OF SAMPLE RATE**

Wenxiang Zhou, Nanjing University of Aeronautics and Astronautics; Richard Longman, Columbia University

Repetitive control and indirect adaptive control initially seek zero tracking error by inverting a transfer function. Converting transfer functions to discrete time often introduces non-minimum phase zeros outside the unit circle, and some systems are already non-minimum phase in continuous time. The resulting zeros outside the unit circle are a challenge to the control design. This paper studies the locus of discrete time zero locations as a function of sample rate showing it can have very unexpected behavior. A discrete time zero can go to positive infinity then appear at negative infinity and vice versa multiple times.

14:20 **AAS 17-774** **Minimum-Power Attitude Steering**

Harleigh Marsh, University of California Santa Cruz; Mark Karpenko, Naval Postgraduate School; Qi Gong, University of California, Santa Cruz

This paper examines the effectiveness of reducing the energy consumption of a reaction-wheel array over the course of a slewing maneuver by steering the attitude of the spacecraft, in situations where it is not possible to command the reaction wheel torque directly. To explore this avenue, a set of constrained nonlinear nonsmooth L1 optimal-control problems are formulated and solved. It is demonstrated that energy consumption, dissipative losses, and peak-power load, of the reaction-wheel array can each be reduced substantially, by controlling the input to the attitude control system through attitude steering, thereby avoiding software modifications to flight software.

14:40 AAS 17-775 **Stochastic Attitude Control of Spacecraft under Thrust Uncertainty**

Alen Golpashin, University of Illinois Urbana-Champaign; Koki Ho, University of Illinois, Urbana-Champaign; N. Sri Namachchivaya, University of Illinois at Urbana-Champaign

This study aims to address the problem of attitude control of spacecraft in presence of stochastic thrust fluctuations. Many satellites and spacecraft rely on electric propulsion and other low thrust mechanisms to control and maintain attitude. The thrust magnitude uncertainty may arise from sources such as power fluctuations, faulty thrusters, etc. It is our intention to propose a control method which will address the source of input uncertainty. Through the proposed stochastic optimal control method, we aim to mitigate the effect of the thrust uncertainties and stochastic accelerations, thus stabilizing the spacecraft attitude.

15:00 AAS 17-806 **A Sparse Collocation Approach for Optimal Feedback Control for Spacecraft Attitude Maneuvers**

Mehrdad Mirzaei, MAE; Puneet Singla, The Pennsylvania State University; Manoranjan Majji, Texas A&M University, College Station

In this paper, sparse collocation approach is sued to develop optimal feedback control laws for spacecraft maneuvers. The effective collocation process is accomplished by utilizing the recently developed Conjugate Unscented Transformation to provide a minimal set of collocation points. In conjunction with the minimal cubature points, an l_1 norm minimization technique is employed to optimally select the appropriate basis functions from a larger complete dictionary of polynomial basis functions. Both infinite and finite time attitude regulation problems are considered. Numerical simulations involve asymmetric spacecraft equipped with four reaction wheels.

15:20 BREAK

15:50 AAS 17-816 **Time-Optimal Reorientation using Neural Network and Particle Swarm Formulation**

Kaushik Basu, Pennsylvania State University; Robert Melton, The Pennsylvania State University

A neural network will be developed to supplement a particle swarm algorithm to find near-minimum-time reorientation maneuvers in the presence of path constraints. The method employs a quaternion formulation of the kinematics, using B-splines to represent the quaternions. Dynamic Inversion will be used in the supervised training of the neural network.

16:10 AAS 17-819 EFFECTS OF ROTOR GEOMERY ON THE PERFORMANCE OF VIBRATING MASS CONTROL MOMENT GYRPOSCOPES

Ozan Tekinalp, METU Aerospace Engineering Dept.; Burak Akbulut, Middle East Technical University, Aerospace Engineering Department; Ferhat Arberkli, METU Mechanical Engineering Dept.; Kıvanç Azgın, METU Mechanical Engineering Dept.

Elimination of unwanted oscillations on the satellite body is addressed. It is mathematically shown that proper rotor inertia selection removes the unwanted oscillations on the output axis of the CMG. Simulation results carried out in ADAMS environment are given and discussed.

SESSION 9: COLLISION AVOIDANCE

Aug 22, 2017 Stevenson C/D

09 Collision Avoidance

Co Chair: Carolin Frueh

13:40 AAS 17-556 A Monte-Carlo Study of Conjunction Analysis Using Paramat

Darrel Conway, Thinking Systems, Inc.

This study uses the numerical engine in GMAT, driven from the parallel processing tool Paramat, to model a conjunction between two spacecraft on eccentric, nearly coincident trajectories. The covariance matrix of the initial state data is used to perturb each spacecraft. A Monte-Carlo study of the close approach separations and the probability of collision is presented using these perturbed states. The modeling is performed using several different force models, and the results of each configuration are shown to be similar. Performance data for the study is presented, along with a discussion of the methodology and of the tools used.

14:00 AAS 17-559 Conjunction Assessment Screening Volume Sizing and Event Filtering in light of Natural Conjunction Event Development Behaviors

Matthew Hejduk, Astrorum Consulting LLC; Daniel Pachura, Omitron Inc

Conjunction Assessment uses volumetric screening volumes to identify conjunctions, and it is always an open question how large these volumes should be and what pre-filtering techniques should be employed to classify certain conjunctions as “not serious” and thus dismiss them. The present study examines a specially empirical dataset of screening results generated using extremely large screening volumes in order to determine recommended volume sizes and filtering possibilities that will adjudicate the tension between trying to keep screening volumes and conjunction candidate sets small while identifying as early as possible conjunctions that are likely to develop into serious events.

14:20 AAS 17-567 Remediating Non-Positive Definite State Covariainces for Collision Probability Estimation

Doyle Hall, Omitron, Inc.; Matthew Hejduk, Astrorum Consulting LLC; Lauren Johnson, Omitron

The NASA Conjunction Assessment Risk Analysis system estimates the probability of collision (P_c) for a set of high-value Earth-orbiting satellites. The P_c estimation software processes satellite position+velocity states and their associated covariance matrices. On occasion, the software encounters *non-positive definite* (NPD) state covariances, which can adversely affect or prevent the P_c estimation process. Interpolation inaccuracies appear to account for the majority of such covariances, although other mechanisms could contribute also. This paper investigates the origin of NPD state covariance matrices, three different methods for remediating these covariances when and if necessary, and the associated effects on the P_c estimation process.

14:40 AAS 17-582 Stochastic Dynamics of and Collision Prediction for Low Altitude Earth Satellites

William Wiesel, Air Force Institute of Technology; Adam Rich, Air Force Insititute of Technology; Kenneth Stuart, Air Force Institute of Technology

Air drag factors B* from earth satellite element sets often show the characteristic near Gaussian distribution and autocorrelation exponential decay typical of a first order Gauss-Markov process. Assuming the ``most current'' set of orbital elements are correct, earlier elements can be used to construct covariance matrices as a function of prediction time into the future. If resolved in cylindrical orbit frame coordinates, these are remarkably structured, essentially showing only in-track error growth. Often the in-track position covariance element growth follows a fourth power in time rule, and is apparently forced by the uncertainty in the air drag factor.

15:00 **AAS 17-590** **Optimal collision avoidance maneuvers for spacecraft proximity operations via discrete-time Hamilton-Jacobi theory**

Kwangwon Lee, Yonsei University; Youngho Eun, Yonsei University; Chandeok Park, Yonsei University

This study presents a sub-optimal control algorithm that implements real-time collision avoidance maneuvers for spacecraft in proximity operations. The penalty function for avoiding collision with an obstacle is first incorporated into the performance index of a typical optimal tracking problem in discrete-time domain. Then, the infinite-horizon control law is derived as an explicit function of the states of terminal conditions and obstacles by employing generating functions based on the discrete-time Hamilton-Jacobi theory without initial guess and iterative procedure. Numerical simulations demonstrate that the proposed algorithm is suitable for implementing optimal collision-free transfers in real-time.

15:20 **BREAK**

15:50 **AAS 17-614** **Relevance of the American Statistical Society's Warning on p-Values for Conjunction Assessment**

Russell Carpenter, NASA/Goddard Space Flight Center; Salvatore Alfano, Center for Space Standards and Innovation; Doyle Hall, Omitron, Inc.; Matthew Hejduk, Astrorum Consulting LLC; John Gaebler, University of Colorado at Boulder; Moriba Jah, The University of Texas at Austin; Rebecca Besser, KBRwyle; Russell DeHart; Matthew Duncan, SpaceNav LLC; Syed Hasan, Honeywell Technologies; Marrisa Herron, NASA Goddard Space Flight Center; William Guit

On March 7, 2016, the American Statistical Association issued an editorial paper on the ``context, process, and purpose of p-values."  According to the paper, ``the statement articulates in non-technical terms a few select principles that could improve the conduct or interpretation of quantitative science, according to widespread consensus in the statistical community." These principles would appear to have some relevance to the spacecraft conjunction assessment community.

16:10 **AAS 17-650** **The Evolution of Secondary Object Position in 18SCS Conjunction Data Messages**

Barbara Braun, The Aerospace Corporation

Satellite owners evaluate conjunctions with on-orbit objects every day, and rely on conjunction data messages produced by the 18^{th} Space Control Squadron (formerly known as JSpOC) to make maneuver decisions. Each conjunction assessment relies on predicting the position of both the primary and secondary object at the time of closest approach. This paper examines the position predictions of all secondary objects conjuncting with three primary satellites over a six-month period. The data illustrates interesting characteristics of 18SCS secondary object position prediction, including the differences between orbital regimes, the impact of increased tracking, and the prevalence of repeating conjunctions.

16:30 AAS 17-703 Maneuver Optimization and Collision Probability Estimation Using Separated Representations

Marc Balducci, CCAR - CU Boulder; Brandon Jones, The University of Texas at Austin

In crowded orbit regimes due to debris or inoperable satellites, operators of spacecraft must confront the possibility of a conjunction with another space object and decide whether the risk should be mitigated or accepted. Often, the decision to maneuver or not is decided by the probability of collision. This paper presents Separated representations for estimating the probability of collision between two satellites, and the design of a collision avoidance maneuver while accounting for propagated uncertainty. Separated representations is a polynomial surrogate method that has a computation cost largely linear with respect to dimension, allowing the consideration of high-dimension stochastic systems.

16:50 AAS 17-782 REDUCING THE RISK OF SPACE DEBRIS COLLISIONS USING CONDITIONS FOR PERFORMANCE SIMULTANEOUS OPERATIONS IN MINIMUM TIME.

Antonio Delson Jesus, UEFS - Universiade Estadual de Feira de Santana; Jorge Nascimento, INPE -National Institute for Space Research

Space vehicle missions in operational regions are subject to collisions with space debris. The possibility of catastrophic accidents between these space objects is confirmed in the perspective of increasing the density of the debris with the constant growth of the launch rates [1]. This risk is increasing in several layers of the regions, especially in LEO. In this way, debris mitigation policies must be implemented to guarantee minimum viability to space missions, with a reduction in the density of these objects [2]. For decades, space agencies have been preoccupied with this environmental problem and have thought about creating a space

Aug 22, 2017 Stevenson A

10 Planetary Exploration

Co Chair: Nitin Arora

13:40 AAS 17-608 Families of Io-Europa-Ganymede Triple Cyclers

Sonia Hernandez, Jet Propulsion Laboratory; Drew Jones, Jet Propulsion Laboratory, Caltech; Mark Jesick, Jet Propulsion Laboratory

Ballistic cycler trajectories that repeatedly encounter the Jovian moons Io, Europa, and Ganymede are investigated. The 1:2:4 orbital resonance among these moons allows for trajectories that periodically fly by the three bodies, and, in an ideal world, can repeat indefinitely. An initial search method is implemented to determine if the location of the moons in a specific geometry can give way to a possible cycler. Lambert's problem is then solved to determine the legs connecting consecutive encounters, allowing a maneuver at periapsis of the encounter if necessary. Many families of solutions are found, and high fidelity examples are shown.

14:00 AAS 17-699 Mission Design for the Emirates Mars Mission

Jeff Parker, Advanced Space; Omar Hussain, Mohammed Bin Rashid Space Centre; Nathan Parrish, University of Colorado at Boulder; Michel Loucks, Space Exploration Engineering

The United Arab Emirates is launching the Emirates Mars Mission (EMM) to Mars in 2020 to explore the atmospheric dynamics of Mars on a global, diurnal, sub-seasonal scale. The mission design involves a Type I transfer to Mars, coordinated with many other simultaneous Mars missions, most of whom share the same network of ground tracking stations. The Mars Orbit Insertion places the EMM Observatory, Amal, into a very large, elliptical capture orbit. Three Transition to Science Maneuvers are optimized under uncertainty to transfer the spacecraft into a unique 20,000 km x 43,000 km, ideal to achieve the EMM science objectives.

14:20 AAS 17-728 A Catalog of Gravity-Assist Trajectories to Uranus for Launch Dates from 2023 to 2073

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

Ballistic and chemical-impulsive trajectories to Uranus are investigated for launch dates spanning 50 years. Nearly 100 distinct gravity-assist paths are considered for ballistic trajectories and---for cases where no ballistic trajectories exist---a single deep space maneuver (DSM) up to 3 km/s is applied. For each launch year, the most desirable trajectory is identified and cataloged. The trajectories are found using a patched-conic propagator with an analytical ephemeris model. Jupiter is unavailable as a gravity-assist body until the end of the 2020's but alternative gravity-assist paths exist, providing feasible trajectories even in years when Jupiter is not available.

14:40 AAS 17-651 A Tool for Identifying Key Gravity-Assist Trajectories from Broad Search Results

James Moore, Purdue University; Alec Mudek, Purdue University; James Longuski, Purdue

We present a tool that identifies desirable trajectory candidates from among tens of thousands of gravity-assist trajectories. A broad trajectory search technique creates an exhaustive set of possible trajectories to a given planet. From this dataset, our tool reveals candidate trajectories with user-defined characteristics. Typical discriminating characteristics are launch V-infinity, time-of-flight, and delivered mass. Mission planners evaluate and plot interesting trajectories from within the tool. Our tool generates catalogs of selected trajectories for further evaluation with higher-fidelity trajectory solvers. This paper outlines the key features of the tool and gives examples of typical analyses.

15:00 AAS 17-777 LOW-COST OPPORTUNITY FOR MULTIPLE TRANS-NEPTUNIAN OBJECT RENDEZVOUS AND CAPTURE - "CERBERUS"

Glen Costigan, University of Tennessee, Knoxville; Brenton Ho, University of Tennessee, Knoxville; Nicole Nutter, Undergraduate Student; Katherine Stamper, University of Tennessee, Knoxville; James Evans Lyne, Univ of Tennessee

The mission proposed herein allows three separate New Horizons-type spacecraft to reach three trans-Neptunian object systems with the use of a single launch vehicle. This was accomplished by performing a ΔVEGA maneuver at the beginning of the trajectories which reduced the required launch C3 from over 100 m2/s2 to under 30 m2/s2. Two of the proposed target systems, binary systems 2002 UX25 and 1998 WW31, intercept their assigned spacecraft 17.3 and 25.3 years after launch, respectively. The third spacecraft is equipped with a high-thrust engine which enables it to capture into orbit around the trinary TNO system 1999 TC36 26.3 years after launch.

15:20 BREAK

15:50 AAS 17-804 Enceladus Sample Return Mission

Rekesh Ali, The University of Tennessee, Knoxville; Andrew Bishop, The University of Tennessee, Knoxville; Braxton Brakefield, The University of Tennessee, Knoxville; Shelby Honaker, The University of Tennessee, Knoxville; Brier Taylor, The University of Tennessee, Knoxville

Enceladus has a subsurface liquid ocean and hydrothermal vents that may support life, as well as geysers that eject water into space. In this study, we propose the use of multiple small pods that would be released from a bus before an Enceladus flyby. These pods would collect ejected material during flyby and each return to Earth independently, reducing the possibility of single point failure. The pods would enter Earth's atmosphere at 15.7 km/s, faster than any Earth entry. The small size of the pods tends to reduce their ballistic coefficient, making such a high entry speed potentially feasible.

16:10 AAS 17-696 Practical Methodologies for Low Delta-V Penalty, On-Time Departures to Arbitrary Interplanetary Destinations from a Medium-Inclination Low-Earth Orbit Depot

Michel Loucks, Space Exploration Engineering; John Carrico, SEE; Jonathan Goff, Altius Space Machines

The authors present a 3-burn injection method that enables manned and robotic spacecraft to depart for interplanetary destinations from a Low-Earth Orbit propellant depot with only minor DV penalties. In this paper, the authors will: 1) provide a literature review on related injection methodologies, 2) illustrate the underlying concept behind this three-burn injection method, 3) discuss implications of using this method, including potential mission safety benefits, and 4) present some details on estimates of the worst-case DV penalty for performing this sort of departure maneuver, compared with a traditional one-burn departure from a LEO parking orbit.

16:30 AAS 17-847 Optimizing Parking Orbits for Roundtrip Mars Missions

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

The selection of a Mars parking orbit is crucial to the mission design of a roundtrip Mars mission; not only can the parking orbit choice drastically impact the ΔV requirements of the transportation system but also it must be properly aligned to target the desired surface or orbital destinations. This paper presents a method that can optimize the Mars parking orbits while enforcing constraints to satisfy other architecture design requirements such as co-planar sub-periapsis descent to planned landing sites, due east or co-planar ascent back to the parking orbit, or low cost transfers to and from Phobos and Deimos.

16:50 AAS 17-708 **Robust Miniature Probes for Expanded Atmospheric Planetary Exploration**

Eiji Shibata, Purdue University

For future atmospheric planetary exploration, a robust miniature probe can be used as a way to provide additional in-situ measurements, while minimizing the additional cost and risk the mission takes on. These probes can take advantage of technologies being developed in the small satellite field, and apply those new technologies to atmospheric probe entry.

17:10 AAS 17-849 **PATH PLANNING AND CONTROL USING STATE DEPENDENT NAVIGATION FUNCTIONS FOR PLANETARY ROVERS**

Paul Quillen, The University of Texas at Arlington; Josue Munoz, Air Force Research Laboratory; Kamesh Subbarao, The University of Texas at Arlington

The purpose of this paper is to present a new path-planning algorithm for planetary rovers that can make use of state information for a given system. In particular, this work will make use of a special class of artificial potential functions called navigation functions which are guaranteed to be free of local minimum. The navigation functions utilized will be constructed using wavefront expansion and will be made state dependent by changing the metric of the potential calculation from one based on distance to one governed by the control effort of the system. The results will include an example of a simple linear system as well as a more complex nonlinear system. The results will demonstrate the effectiveness of the algorithm with path planning and obstacle avoidance. Furthermore, each case will have trajectory tracking controller to drive the example systems to their desired goals.

Aug 23, 2017 Cascade A

11 Attitude Estimation

Co Chair: Ryan Russell

8:00 AAS 17-845 Attitude Estimation and Control of Spacecraft in Formation Flying Using Relative Measurement on Earth Magnetic Field and SDRE-Based Neuro-Fuzzy Controller

Sung-Woo Kim, Satrec Initiative

This paper presents relative attitude estimation and control of spacecraft in a formation flying using relative measurements of Earth magnetic field. The relative magnetic field measurement model is derived and applied with relative attitude dynamics to estimate orientation of each spacecraft in a formation. The control technique is a neuro-fuzzy controller based on State-Dependent Riccati Equation (SDRE) controller which provides training data set for the neuro-fuzzy controller. The simulation of attitude synchronization for 5 spacecraft is performed and the results show the enhanced accuracy of relative attitude estimation compared to absolute attitude estimation.

8:20 AAS 17-673 SPACECRAFT ATTITUDE ESTIMATION USING UNSCENTED KALMAN FILTERS, REGULARIZED PARTICLE FILTER AND EXTENDED H INFINITY FILTER

William Reis Silva, Technological Institute of Aeronautics (ITA) ; Roberta Veloso Garcia, Universidade de São Paulo; Hélio Kuga, Instituto Nacional de Pesquisas Espaciais; Maria Zanardi, Federal University of ABC (UFABC)

The attitude model used in this work is described by quaternions and the estimation methods used were: the Uncented Kalman Filter transforms a set of points through known nonlinear equations and combines the results to estimate the mean and covariance of the state; Regularized Particle Filter a statistical approach that often works well for problems that are difficult for the conventional filters; and the Extended H Infinity Filter provides a rigorous method for dealing with systems that have model and noise uncertainties. The results show that one can reach accuracies in attitude determination within the prescribed requirements.

8:40 **AAS 17-554** **Treatment of Measurement Variance for Star Tracker-Based Attitude Estimation**

Erik Hogan, SSL; Byoungsam Woo, SSL

In this paper, proper treatment of measurement variance for star tracker-based attitude estimation routines is considered. Specifically, a modified Rodrigues parameter (MRP) additive extended Kalman filter (EKF) is used in combination with one or more star trackers and a rate gyro to perform attitude estimation. In prior work, the differences between noise characteristics about the three star tracker sensing axes are not considered, and the effects of measurement latency are not addressed. Considering these effects, as well as star tracker alignments, the correct way to compute the measurement variance for the measurement residuals in the additive MRP EKF is provided.

9:00 **AAS 17-591** **Tuning the Solar Dynamics Observatory Onboard Kalman Filter**

Julie Halverson, NASA GSFC; Russell Carpenter, NASA/Goddard Space Flight Center; Rick Harman, NASA GSFC; Devin Poland, NASA GSFC

The Solar Dynamics Observatory (SDO) is in a geosynchronous orbit and provides nearly continuous observations of the sun. SDO is equipped with star trackers, sun sensors, and inertial reference units (IRU). Due to battery degradation concerns the IRU heaters were not used and the onboard filter was tuned to accommodate noisier IRU data. Two IRUs have experienced increased currents, one was powered off. Recent ground battery tests indicate the heaters may not harm the battery, after 6 years they were turned on. This paper presents the analysis and results to update the filter tuning parameters for the new thermal environment.

9:20 **AAS 17-637** **ADVANCED ATTITUDE DETERMINATION ALGORITHM FOR ARASE: PRELIMINARY MISSION EXPERIENCE**

Halil Ersin Soken, Japan Aerospace Exploration Agency; Sakai Shin-ichiro, Japan Aerospace Exploration Agency ; Kazushi Asamura, Japan Aerospace Exploration Agency; Yosuke Nakamura, Japan Aerospace Exploration Agency; Takeshi Takashima, Japan Aerospace Exploration Agency

JAXA's Arase Spacecraft, which is formerly known as Exploration of Energization and Radiation in Geospace (ERG), was launched on 20 December 2016. The spacecraft is spin-stabilized at ~7.5rpm spin rate. Its mission is exploring how relativistic electrons in the radiation belts are generated during space storms. Two on-ground attitude determination algorithms are used for the mission: a conventional simple algorithm that inherits from old JAXA missions and an advanced algorithm that is newly designed. This paper discusses the design of the advanced attitude determination algorithm and presents the preliminary results that we obtained after the launch.

9:40 **BREAK**

10:10 AAS 17-723 SPACECRAFT HIGH ACCURACY ATTITUDE ESTIMATION:PERFORMANCE COMPARISON OF QUATERNION BASED EKF, UF AND PF

Divya Bhatia, Institute of Flight Guidance, Technische Universität Braunschweig

Demand for high accuracy attitude estimation of the order better than tens of milliarcsec is growing for the future spacecraft missions. To this end, this paper compares the performance characteristics of quaternion based Extended Kalman filter (EKF), Unscented filter (UF) and Particle filter (PF) for three-axes attitude estimation of the spacecraft. Quaternions are appealing parameters for attitude representation owing to their bilinear kinematic equation and singularity-free property. Performance parameters like robustness, computational efficiency, convergence and pointing accuracy of the three filters are compared for the fusion of a high accuracy three-axis gyroscope and two simultaneously operating high accuracy star trackers.

10:30 AAS 17-767 Inverse Dynamics Particle Swarm Optimization Applied to Bolza Problems

Dario Spiller, Sapienza University of Rome; Robert Melton, The Pennsylvania State University; Fabio Curti

The Inverse Dynamics Particle Swarm Optimization is an optimal control algorithm based on a differentially flat approach. So far, this method has been successfully applied to solve minimum-time reorientation maneuver and reconfiguration maneuvers for satellite formations. In this work, minimum fuel and minimum energy reorientation maneuvers are addressed considering end-point conditions and path-constraints. Transcribing the original problem into a differentially flat form, the originally convex cost function may become non-convex, thus making the solution more difficult to obtain. However, this work shows that non-convexity problems may be overcome by using the proposed approach, obtaining the solution with the minimum number of involved parameters.

Aug 23, 2017 Stevenson A

12 Orbital Dynamics

Co Chair: Angela Bowes

8:00 AAS 17-572 CRITICAL INCLINATIONS FOR THE ROTO-ORBITAL DYNAMICS OF A RIGID BODY AROUND A SPHERE

Francisco Crespo, Universidad del Bio-Bio; Sebastian Ferrer, Facultad Informatica, Universidad de Murcia

We study the roto-orbital motion of an arbitrary rigid body and a massive sphere through variables referred to the total angular momentum. Our model is obtained from a fast-angle-averaged second order expansion of the gravitational potential. Relative equilibria show that the rotational dynamics, though still formally given by the classical Euler equations, experiences changes of stability in the principal directions since the coefficients depend on the integrals. Moreover, considering a relative equilibria of the body dynamics, particular sets of initial conditions for which the orbital and rotational planes are fixed may be found, which extends to roto-orbital dynamics the well known *frozen-orbits* conditions associated to orbital dynamics.

8:20 AAS 17-579 Application of Multi-Hypothesis Sequential Monte Carlo for Breakup Analysis

Weston Faber, Applied Defense Solutions; Waqar Zaidi, Applied Defense; Islam Hussein, Applied Defense Solutions; Matthew Wilkins, Applied Defense Solutions; Christopher Roscoe, Applied Defense Solutions; Paul Schumacher, Air Force Research Laboratory

The goal of this paper is to increase breakup analysis capabilities by providing a tractable solution to the multiple space object tracking problem that is statistically rigorous. This paper employs the Sequential Monte Carlo (SMC) approach coupled with random hypothesis generation techniques to provide a computationally tractable solution to the multi-object tracking problem applicable to RSO breakup scenarios. An SMC-based Particle Gaussian Mixture (PGM) approach is used to perform filtering. The approach will be demonstrated on breakup scenarios modeled according to the NASA standard breakup model.

8:40 **AAS 17-613** **A new concept of stability in orbit propagation, useful for quantifying numerical errors**

Javier Roa, NASA / Caltech JPL; Hodei Urrutxua, University of Southampton; Jesus Pelaez, Technical University of Madrid (UPM)

We present the concept of topological stability in the numerical propagation of orbits, and discuss its practical consequences. The concept applies to any problem in orbital dynamics, and can be extended to any three-dimensional system of differential equations of second order. In order to assess the topological stability of a given integration a special metric is introduced, which can be used to estimate the global numerical error robustly. The method is particularly useful for dealing with strongly perturbed and chaotic systems. The construction is based on the constraint imposed by the Hopf map that supports the Kustaanheimo-Stiefel transformation.

9:00 **AAS 17-659** **Analytical State Propagation of Oblate Spheroidal Equinoctial Orbital Elements for Vinti Theory**

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

Equinoctial orbital elements have been generalized from spherical geometry to the oblate spheroidal geometry of Vinti theory, a satellite theory that accounts exactly for oblateness and optionally J_3. For the symmetric potential, these nonsingular elements resolve the usual problems found in the classical elements associated with angle ambiguities. But their introduction is incomplete without developing an analytical solution in these nonsingular elements. In the present study, state propagation in time is investigated as a separate and self-contained endeavor, including derivations of the equinoctial constants of the motion and techniques to solve a generalized Kepler's equation. Multiple examples are presented.

9:20 **AAS 17-581** **A methodology for reduced order modeling and calibration of the upper atmosphere**

Piyush Mehta, University of Minnesota; Richard Linares, University of Minnesota

Accurately predicting drag for objects that traverse LEO is critical to Space Situational Awareness. Atmospheric density represents a major uncertainty for drag prediction. Empirical models for density are fast to evaluate but are highly inaccurate, while physics models are assumed accurate, but require extensive computational resources. This paper presents a new methodology based on proper othrogonal decomposition (POD) towards development of a quasi-physical, predictive, reduced order model that combines the speed of empirical and accuracy of physics-based models. The methodology is developed with MSIS and the model is calibrated with CHAMP and GRACE densities. Good performance is observed for modeling and calibration.

9:40 BREAK

10:10 AAS 17-628 Orbital Lifetime and Collision Risk Reduction for Tundra Disposal Orbits

Alan Jenkin, The Aerospace Corporation; John McVey; James Wilson, The Aerospace Corporation

Tundra orbits are high-inclination, moderately eccentric, 24-hour period orbits. A constellation of two Tundra satellites can provide similar ground coverage as a single traditional geosynchronous satellite. However, Tundra orbits are strongly affected by lunisolar perturbations, and the resulting excursions in eccentricity can eventually lead to atmospheric re-entry. Effective disposal can therefore be achieved by moving to a nearby disposal orbit. This is in contrast to the stability of near-geosynchronous storage disposal orbits, which results in indefinite accumulation of disposed geosynchronous satellites. A study was performed to determine the potential reduction of orbital lifetime and collision risk for Tundra disposal orbits.

10:30 AAS 17-553 A KAM Tori Algorithm for Earth Satellite Orbits

William Wiesel, Air Force Institute of Technology

This paper offers a new approach for constructing Kolmogorov - Arnold - Moser (KAM) tori for orbits in the full potential for a non-spherical planet. The Hamilton - Jacobi equation is solved numerically by a Newton-Rhapson iteration, achieving convergence to machine precision, and still retaining literal variable dependence. Similar iteration methods allow correcting the orbital frequencies, and permits the calculation of the state transition matrix for the full problem. Some initial numerical examples are offered.

10:50 AAS 17-756 Cell Mapping Orbit Search for Mission Design at Ocean Worlds Using Parallel Computing

Dayung Koh, Jet Propulsion Laboratory; Rodney Anderson, Jet Propulsion Laboratory / Caltech

In this study, a cell mapping approach is applied to various systems in the circular restricted three-body problem to obtain a rapid understanding of the global dynamics. The method is generic for various classes of problems including non-autonomous systems and different types of periodic solutions. The cell mapping method also does not require previously known solutions as inputs, which is typical of continuation approaches, and no symmetric constraints are imposed. In this study, the initial orbit search is applied to obtain an understanding of the orbit trade space at selected ocean worlds.

11:10 **AAS 17-827** **Accelerated Picard-Chebyshev Integration with Error Feedback and Adaptive Segmentation**

Robyn Woollands, Texas A&M University ; John Junkins, Texas A&M University

We present a new approach for solving initial and two-point boundary value problems using an adaptive segmentation modified Chebyshev-Picard integration that also includes an error feedback term. This new formulation can be implemented for both first order and second order systems of differential equations. Including the error feedback term leads to about a factor of two reduction in the number of iterations required for convergence to a machine precision solution. We discuss the subtle but significant distinction between the error feedback formulation for systems that are naturally first order, systems that are naturally second order but can be numerically integrated

SESSION 13: SMALL BODY EXPLORATION

Aug 23, 2017 Stevenson C/D

13 Small Body Exploration

Co Chair: Jay McMahon

8:00 **AAS 17-662** **Selected Trajectory Options to 2016 HO3**

Brian Kaplinger, Florida Institute of Technology; Anthony Genova, NASA

This paper presents the results of three different search strategies for trajectories to 2016 HO3 in the timeframe 2019-2029. Since many solvers result in impulses to this target exceeding 6 km/s due to the high solar inclination, a strategy utilizing the gravity of the Earth was proposed. The initial model used is the circular, restricted, three-body problem (CR3BP) between the Sun and Earth-Moon barycenter. Trajectories were discovered near the stable manifolds for osculating periodic orbits, transit through L1/L2, and via Venus gravity assist. Selected example are modeled in higher fidelity, resulting in a required impulse of 3.5 km/s.

8:20 **AAS 17-731** **Orbit Design for a Phobos-Deimos Cycler Mission**

Bolys Sabitbek, Georgia Institute of Technology; Brian Gunter, Georgia Institute of Technology

This study explores a class of stable cycler orbits intended to visit the Martian moons Phobos and Deimos on a regular cadence, and can be tuned to fly-by one moon more frequently, or to improve surface coverage. While the orbits described can be reached by a dedicated spacecraft, the motivation here is that the spacecraft is already in an initial insertion orbit, such as a small-satellite rideshare on an existing Mars mission. Under this assumption, the results presented illustrate that the exploration of both Phobos and Deimos is possible with a spacecraft with capabilities of modern nanosatellites (cubesats).

8:40 **AAS 17-640** **Optimization Process of Target Selection for Multiple Asteroid Encounters in the Main Belt**

Alena Probst, Bundeswehr University Munich; Roger Foerstner, University of the German Armed Forces Munich

The relevancy of the research on asteroids is mirrored in the growth and progress of scientific fields over the last two centuries. The results obtained connect the knowledge of their origin and development to the two big questions in science: *How did life develop?* and *How did the solar system evolve to its current appearance?*. Hence, asteroid characterization missions are more important than ever. Here, two target sequence optimization methods for multiple asteroid rendezvous missions are introduced and compared to enhance the flexibility and automation of sequential target selection based on S/C position, remaining fuel stock and time of departure.

9:00 **AAS 17-698** **Robust Optimization of Descent Trajectories on Irregular-Shaped Bodies in the Presence of Uncertainty**

Pablo Machuca, Master's Student, Purdue University; Daniel Gonzalez-Arribas, Ph.D. Candidate - Universidad Carlos III de Madrid; DAVID MORANTE, University Carlos III (Madrid); Manuel Sanjurjo-Rivo, Universidad Carlos III; MANUEL SOLER ARNEDO, UNIVERSITY CARLOS III MADRID

High levels of uncertainty are associated to the characterization of the environment around small bodies in the Solar System. In an effort to develop efficient methods to consider uncertainty in the analysis of missions to irregular bodies, we address the problem of robust and efficient optimization of descent trajectories in the presence of uncertainty. As a high-fidelity, less expensive alternative to Monte Carlo simulations, we optimize the distribution of mascons to accurately and efficiently model the irregular gravitational field, and then apply a tychastic methodology to discretize uncertain parameters in the system and solve a single, augmented deterministic optimization problem.

9:20 **AAS 17-721** **EVALUATION OF A RAPID TRANSFER DESIGN APPROACH FOR SMALL BODY APPLICATIONS**

Benjamin Villac, a.i.solutions, Inc.; Rodney Anderson, Jet Propulsion Laboratory / Caltech

This paper discusses the challenges in applying a periodic orbit based rapid trajectory design method to the case of small body orbiters. Using a sample mission scenario, a transfer design method based on pre-computed elementary transfers is applied to various orbital regimes, from distant encounter to close proximity operations. The computation of the elementary transfer dataset and the application of the associated combinatorial optimization highlight the key challenges, such as the down-selection of intermediary orbits, or the application of constraints to obtain relevant transfer. The study is applied to the case of asteroid EV5.

9:40 **BREAK**

10:10 **AAS 17-584** **Investigation of transfers to stable spacecraft orbits in a CR3BP model of a binary asteroid system**

Kristen Tetreault, Virginia Tech; Ian Elliot, Virginia Tech; Ann Catherine Bokinsky, Virginia Tech; Jonathan Black; Shane Ross

A scenario of a spacecraft maneuvering to enter an orbit around the main body of a binary asteroid system is analyzed. In this simulation, a low thrust engine is used on a spacecraft entering this three-body system via a series of finite-time burns. An optimization problem is formulated to control the burn characteristics of the spacecraft as it attempts to enter a stable orbit about the primary body from a parking trajectory about the asteroid system. To ensure a realistic model, the Didymos binary asteroid from NASA's Asteroid Impact and Deflection Assessment (AIDA) mission will serve as the binary system.

10:30 **AAS 17-762** **On the use of Mean Motion Resonances to explore the Haumea System**

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

In this work, Mean Motion Resonances (MMR) are used to create highly eccentric co-orbital orbits with Namaka, the inner moon of the dwarf planet Haumea. We found a region of instability nearby Namaka, caused by the quasi-superposition of the critical semi-major axis of Haumea-Namaka (23,576.573 km) and Haumea-Hi'iaka (22,422.929 km). These orbits need to be retrograde, since prograde orbits cross the region of instability due to the variation of their semi-major axis. We used the method of the integral of the disturbing acceleration to analyze the region of instability.

Session 14: Special Session: Outer Planet Exploration

Aug 23, 2017 Stevenson B

14 Special Session: Outer Planet Exploration

Co Chair: Paul Thompson

8:00 **AAS 17-633** **Initial JOI and PRM Plans for Juno**

Jennie Johannesen, Jet Propulsion Laboratory, California Institute of Technology; Thomas Pavlak, NASA / Caltech JPL; John Bordi, NASA / Caltech JPL

This paper describes the initial plans for the New Frontiers Juno mission at Jupiter. It includes the considerable contingency planning for mission recovery if the Jupiter Orbit Insertion (JOI) burn to place Juno into a large capture orbit were interrupted or terminated on a burn timer setting, and the options for the mission if the Period Reduction Maneuver (PRM) burn to achieve the final orbit period were terminated early. These analyses were based on the assumption that 14-day orbits were the desired operational orbit period.

8:20 **AAS 17-573** **Juno Trajectory Redesign Following PRM Cancellation**

Thomas Pavlak, NASA / Caltech JPL; John Bordi, NASA / Caltech JPL

In October 2016, the Juno spacecraft was operating in 53.5-day capture orbits and final preparations were underway for a Period Reduction Maneuver (PRM) to achieve the planned 14-day science orbits. However, one week before PRM execution, a main engine propulsion system anomaly prompted an indefinite PRM delay and immediate updates to the Juno reference trajectory. This paper outlines "stop-gap" trajectory design activities immediately following PRM delay and longer-term trajectory redesign considerations including various possible PRM epochs, orbit period, longitude grid characteristics, and eclipse avoidance strategies that culminated in the decision to cancel PRM and adopt a new 53-day reference trajectory.

8:40 **AAS 17-564** **Maneuver Operations During Juno's Approach, Orbit Insertion, and Early Orbit Phase**

Paul Stumpf, Jet Propulsion Laboratory; Ramachandra Bhat; Thomas Pavlak, NASA / Caltech JPL

The Juno spacecraft was launched on August 5, 2011 for a 1795-day journey to Jupiter, and arrived on July 5, 2016 with the successful Jupiter Orbit Insertion (JOI) maneuver. This paper will discuss the maneuver operations that took place starting from the Jupiter approach phase (specifically TCM11 on February 3, 2016) through JOI, and the first year of Juno orbital operations through OTM07.

9:00 AAS 17-595 Juno Orbit Determination Experience During First Year At Jupiter

Shadan Ardalan, JPL; John Bordi, NASA / Caltech JPL; Nicholas Bradley, Jet Propulsion Laboratory; Davide Farnocchia; Yu Takahashi, Jet Propulsion Laboratory; Paul Thompson, NASA / Caltech JPL

The Juno spacecraft successfully entered into orbit around Jupiter on 5-July-2016. The mission plan was for Juno to perform two 53.5-day capture orbits before executing a Period Reduction Maneuver to place the spacecraft into its intended 14-day science orbits. This maneuver was canceled due to a concern with the propulsion system. As a result, the Juno spacecraft will remain in its longer orbit period for rest of its mission. This paper will discuss the spacecraft's navigation experience, orbit determination strategy, challenges fitting the data during perijove, and reconstructed trajectory during Juno's first year in orbit.

9:20 AAS 17-714 JUICE: When Navigation DeltaV Cost is Reduced via Tour Redesign

Arnaud Boutonnet, ESA / ESOC; Amedeo Rocchi, GMV at ESA/ESOC; Johannes Schoenmaekers, ESA / ESOC

JUICE is the next ESA L-class mission towards Jupiter and its Galilean moons. After capture the spacecraft is injected into a series of Ganymede resonant transfers aiming at preparing the Europa science phase. The navigation of the Jupiter insertion is very costly due to many sources of uncertainties. The navigation DeltaV cost is usually reduced through optimal placement of stochastic manoeuvres or combined deterministic/stochastic manoeuvres. This paper presents an innovative approach allowing for a reduction of the DeltaV via the optimal selection among a set of modified tours. In other words deterministic and stochastic DeltaVs are optimised together

9:40 BREAK

10:10 AAS 17-596 Cassini Maneuver Experience Through the Final Targeted Titan Flyby and the Grand Finale

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

Amassing valuable scientific information about the Saturnian system for 13 years, the Cassini spacecraft is now in the last phase of its mission. The Grand Finale, a series of 22 orbits with Cassini passing through a gap between Saturn's innermost ring and its upper atmosphere, began after the last targeted Titan flyby on April 22, 2017 and ends with the spacecraft plunging into Saturn on September 15, 2017. This paper reports on the maneuvers performed to achieve the final targeted Titan encounter and the maneuvers used to maintain the Grand Finale orbits.

10:30 AAS 17-625 **OPTICAL NAVIGATION THROUGH CASSINI'S SOLSTICE MISSION**
Kevin Criddle, JPL / Caltech; Julie Bellerose, Jet Propulsion Lab / Caltech; Duane Roth, Jet Propulsion Laboratory; William Owen, NASA / Caltech JPL; Dylan Boone, NASA / Caltech JPL; Rodica Ionasescu, Jet Propulsion Laboratory; Zahi Tarzi, Jet Propulsion Laboratory

Optical Navigation images of Saturn's satellites against a background of known stars greatly augmented the radio metric Doppler and range data from NASA's Deep Space Network in Cassini's orbit determination process. By the end of the Prime Mission, with satellite uncertainties significantly reduced, the optical navigation effort evolved into a background task to maintain Saturn's satellite ephemerides to prevent runoff errors from building up over time. Cassini's extended mission objectives aggressively pursued further encounters with Saturn's icy moons, especially Enceladus and its plumes. Opnavs played a vital role, achieving acceptable flybys and assuring science objectives could still be met.

SESSION 15: EARTH ORBITERS

Aug 23, 2017 Stevenson A

15 Earth Orbiters

Co Chair: Christopher Roscoe

13:40 AAS 17-692 **Constrained Burn Optimization for the International Space Station**
Aaron Brown, NASA; Brandon Jones, The University of Texas at Austin

In long-term trajectory planning for the International Space Station (ISS), translational burns are currently targeted sequentially to meet the immediate trajectory constraints, rather than simultaneously to meet all constraints, do not employ gradient-based search techniques, and are not optimized for a minimum total delta-v (Dv) solution. An analytic formulation of the constraint gradients and an initial guess generator are developed and used in an optimization solver to overcome these obstacles. Several trajectory examples are explored, highlighting the advantage of the proposed method over the current approach, as well as the potential Dv and propellant savings to the ISS program.

14:00 **AAS 17-818** **Multiobjective Trajectory Optimization during Orbit Raising with Combined Chemical-Electric Propulsion**

DAVID MORANTE, University Carlos III (Madrid); MANUEL SOLER ARNEDO, UNIVERSITY CARLOS III MADRID; Manuel Sanjurjo-Rivo, Universidad Carlos III

The problem of designing the optimal orbit raising trajectory to a Geostationary orbit with combined chemical-electrical onboard propulsion is formulated as a Hybrid Optimal Control Problem and solved by a two level sequential approach. In the first step, a heuristic algorithm including a simplified dynamical model and relaxed constraints provides a whole set of pareto quasi-optimal solutions in terms of payload mass, time of flight and total radiation flux. In the second step, given the tentative propulsive sequence provided by the previous step, a direct method is applied to obtain high fidelity solution transfers that meet the complex mission requirements.

14:20 **AAS 17-635** **Impulsive Orbit Control for Multi-Target Acquisition**

Sung-Hoon Mok, Korea Advanced Institute of Science and Technology (KAIST); Hyochoong Bang, Korea Advanced Institute of Science and Technology (KAIST)

An impulsive control method for multi-target acquisition is studied. The goal is to obtain the optimal impulse firing instants and magnitudes for impulse sum minimization while making the controlled orbit overfly the designated ground targets. The solution is given in terms of the longitude differences between the nominal (uncontrolled) orbit and the ground targets. A suboptimal semi-analytical solution is achieved, and the proposed method could give physical insight in the target acquisition problem as well as saving the computation time. In addition, the given impulsive set could be used as an initial guess to the numerical optimization method leading to more fuel-effective solution.

14:40 **AAS 17-563** **The SSL-100: ADCS & GNC for the Next Generation of Low-Cost, Agile LEO Spacecraft**

Erik Hogan, SSL; Byoungsam Woo, SSL; Michael Homer, SSL

To support increasing demand in the 75-750 kilogram class of satellites, the SSL-100 bus was developed from the ground up. In contrast to the typical large geostationary satellites that SSL is known for, the SSL-100 is intended to serve as a platform for a variety of agile LEO mission profiles that require a high level of autonomy at a low cost point. In this paper, we highlight our approach to the design of the ADCS and GNC systems for the SSL-100 and discuss the challenges inherent in developing a highly-capable, reusable design using low-cost, off-the shelf components.

15:00 **AAS 17-778** **CloudSat at 11—Now What?**

Theodore H Sweetser, Jet Propulsion Laboratory; Mona Witkowski, Jet Propulsion Laboratory; Deborah Vane, Jet Propulsion Laboratory

The CloudSat mission has completed eleven years on orbit to provide radar profiles of the vertical structure of clouds as a member of the A-Train, an international constellation of Earth-science satellites with an ascending node at 1:30 PM local time. Along the way the CloudSat spacecraft survived a near-death experience when its battery developed a current restriction. Changes to the operations of the spacecraft after recovery allow it to continue providing unique weather- and climate-related data. But a number of challenges will prevent it from continuing forever. We discuss the science, the history, and options for the future of CloudSat.

15:20 **BREAK**

15:50 **AAS 17-779** **The Design of the Reference Orbit for NISAR, the NASA-ISRO Synthetic Aperature Radar mission**

Theodore H Sweetser, Jet Propulsion Laboratory; Sara Hatch

The NISAR mission plans to use a 12-day-repeating sun-synchronous orbit for repeat-pass interferometry at multiple time scales using SAR data. The orbits must repeat pair-wise within a critical baseline, which happens if all of them are within a fixed tube around a reference orbit. This paper describes the choice of dynamical models used in defining such a reference orbit, the perturbative effects of dynamics not considered in the repeat orbit, and the process of designing the orbit to repeat. We also describe our method for sharing the repeat orbit among multiple mission participants who use different models and software.

16:10 **AAS 17-783** **The GOES In-Situ Geomagnetism Experiment Reimagined**

David Fellows, MIT; Matthew Heacock; Bereket Abraham, Carnegie Mellon University; Casey Thomas, ASRC Federal Space and Defense; Marco Concha, Relative Dynamics, Inc.; Gustave Comeyne, NOAA/NESDIS; Sivakumara Tadikonda, Constellation Software Engineering; Donald Chu

The Geostationary Operational Environmental Satellites (GOES) carry several instruments each with its own requirements. Because accommodating all of them is difficult, there is interest in putting some on their own smaller platforms. The simplest instruments are the magnetometers. These are small and have low communication, attitude control and cleanliness requirements. Getting on-station and operating in close proximity with another satellite, however, requires significant propulsion capabilities. This paper describes a CubeSat mission that goes from geo-transfer to geostationary orbit, operates next to a GOES spacecraft and re-enters to dispose of itself. Requirements, a notional design and performance predictions are provided.

16:30 **AAS 17-796** **High Altitude Sun-Synchronous Orbits as Solutions of the Circular Restricted Sun-Earth-Moon-Satellite 4-Body Problem**

Kazuaki Ikemoto, The University of Tokyo; Jun'ichiro Kawaguchi, Japan Aerospace Exploration Agency

The altitudes of the well-known Sun-Synchronous Orbits (SSOs) are limited up to a few thousand kilometers. This is because the synchronousness is realized by the J2-term of the geopotential. In this study, as solutions of the circular restricted 4-body (Sun, Earth, Moon and satellite) problem, new SSOs at altitudes on the order of magnitude of a million kilometers are reported. The lunar gravity assist plays an important role. Symmetries in the system are utilized to ease the numerical process.

Besides the scientific interest, the result could be practical for reducing the variation of the heat input from the earth to satellites.

16:50 **AAS 17-713** **MODELING OF THERMAL HEATING AND THERMAL RADIATION PRESSURE DUE TO SUN AND ALBEDO WITH APPLICATION TO GRACE ORBIT AND ACCELEROMETER DATA**

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

The precise modeling and knowledge of non-gravitational forces is of big interest to many scientific space missions. Thermal radiation pressure is often omitted even though it can be 5 to 25% of solar radiation pressure. We show a high precision modeling approach considering heat fluxes origin from Sun, albedo, Earth and the satellite itself. We employ a finite element model with optical and thermal properties of the GRACE gravity recovery mission in a pre-processing step. Results are compared to GRACE accelerometer data and simulated effects on orbit of all non-gravitational disturbances are compared and distinguished.

Aug 23, 2017 Cascade A

16 Orbit Determination

Co Chair: Stefano Casotto

13:40 AAS 17-750 Batch Sequential Estimation with Non-Uniform Measurements and Non-Stationary Noise

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

Sequential estimation using the traditional discrete Kalman filter typically assumes the measurement time and state update time are coincident. This is often a poor assumption in realistic measurement scenarios where the data can be received from multiple sources at differing times. This paper develops the necessary algorithm adjustments needed for the Kalman filter to readily process measurement data that arrive at varying times and with nonstationary noise. The algorithm is applied to a relevant problem of orbit determination using one-way uplink radiometric tracking of a spacecraft (in the present case approaching Mars and then orbiting).

14:00 AAS 17-755 GAUSSIAN MIXTURE KALMAN FILTER FOR ORBIT DETERMINATION USING ANGLES-ONLY DATA

Mark Psiaki, Virginia Tech

A Gaussian mixture nonlinear Kalman filter is developed for satellite orbit determination using angles-only data. It is designed for space situational awareness based on sparsely available data. The algorithm implements an extended Kalman filter for each of its mixands. A re-sampling step between the dynamic propagation and the measurement update enforces an upper bound on each mixand's covariance. Re-sampling enables the filter to maintain a good approximation of the underlying Bayesian conditional probability density despite nonlinearities. A truth-model simulation of a near-geosynchronous case demonstrates reliable convergence and good accuracy when using once-per-night data arcs of 20 seconds duration.

14:20 AAS 17-793 Interpolation on the Unit Sphere in Laplace's Method

Ethan Burnett, University of Arizona; Andrew Sinclair, Air Force Research Laboratory

This paper proposes an alternative interpolation approach for the line-of-sight measurements in Laplace's method for angles-only orbit determination. Traditional methods of applying Lagrange interpolation to the unit vectors or angle parameterizations results in nonphysical or nonintuitive behavior in the interpolation. The alternative approach is based on a previously developed method that iteratively applies spherical linear interpolation. The derivatives of the resulting interpolation can be computed, and the remainder of Laplace's method is evaluated as normal. The paper will investigate the accuracy of the resulting orbit solution when using the alternative interpolation.

14:40 AAS 17-794 Optimal Linear Orbit Determination

Andrew Sinclair, Air Force Research Laboratory; Alan Lovell

Modern methods for angles-only orbit determination traditionally write the line-of-sight measurement as a nonlinear function of the object's instantaneous position. An alternative is to consider taking a cross product of the measured line-of-sight vector with the instantaneous position. This leads to a rigorously linear measurement model, and suggests an alternative problem de nition to minimize the residuals in these cross-product equations. This approach is analogous to the optimal linear attitude estimator. This paper analyzes the covariance of this optimal linear orbit determination, and considers the appropriate weighting scheme for the cross-product residuals.

15:00 AAS 17-810 AN IMPROVED REPRESENTATION OF MEASUREMENT INFORMATION CONTENT VIA THE DISTRIBUTION OF THE KULLBACK-LEIBLER DIVERGENCE

Matt Gualdoni, Missouri University of Science and Technology; Kyle DeMars, Missouri University of Science and Technology

Proper utilization of sensor networks is key in target-dense or measurementscarce environments, such as in the creation and maintenance of reliable records for space objects in Earth orbit. There have been many investigations of utilizing different information theoretic measures as performance measures in allocating sensor tasks to maximize the information gained, more specifically, information divergences. typically only the expected information gain with respect to the measurement likelihood is considered, while the rest of the distribution of the divergence is disregarded. This work studies the full distribution of the Kullback-Leibler distribution and how to effectively utilize this when committing to an action.

15:20 BREAK

15:50 AAS 17-815 Minimum Divergence Filtering Using A Polynomial Chaos Expansion

Christine Schmid, Missouri University of Science and Technology; Kyle DeMars, Missouri University of Science and Technology

Bayesian filters for discrete-time systems make use of the Chapman-Kolmogorov equation and Bayes' rule to predict and update the uncertainty of a state. For nonlinear filtering problems, the Bayesian recursion is not guaranteed to close. An assumed density framework can be used to force the recursion to close, where one such realization is the minimum divergence filter, which seeks to minimize the Kullback-Leibler divergence of the assumed density with respect to the reference state density. This results in a moment matching problem, where the moments are traditionally approximated using Gauss-Hermite quadrature. An alternative solution is presented by replacing the Gauss-Hermite

16:10 **AAS 17-624** **Preliminary Analysis of Ground-Based Orbit Determination Accuracy for the Wide Field Infrared Survey Telescope (WFIRST)**

Brad Sease, Omitron Inc.; Jessica Myers; Cassandra Webster, NASA Goddard Space Flight Center; John Lorah, Omitron Inc.

The Wide Field Infrared Survey Telescope is a 2.4-meter telescope planned for launch to the Sun-Earth L_2 point in 2025. This paper details a preliminary study of the achievable accuracy for WFIRST from ground-based orbit determination routines. The analysis here is divided into two segments. First, a linear covariance analysis of routine operations provides an estimate of the tracking schedule required to meet mission requirements. Second, a ``simulated operations'' scenario gives insight into the expected behavior of a daily Extended Kalman Filter orbit estimate over the first mission year given a variety of potential momentum unloading schemes.

16:30 **AAS 17-668** **Research and Demonstration of △DOR Tracking by Sparse Calibration**

songtao han, Beijing Aerospace Control Center; Zhang Zhongkai, Zhengzhou Institute of Surveying and Mapping

This paper presents the differential interferometric tracking by China Deep Space Network which works under sparse calibration mode. Both deep space antennas keep pointing at the spacecraft while the target is in view of the tracking stations. Interruption of telemetry and telecommand by traditional short-alter-scan mode can be avoided. During CE'3 100x15km encircle lunar orbit, interferometric tracking was conducted with China DSN, the residual delays are less than 1ns, corresponding a maximum angular error of 97 nano radians. The accuracy is in the same order with the accuracy from similar geometric baseline of China VLBI Net.

16:50 **AAS 17-647** **COMPARING DOUBLE DIFERENCE GLOBAL NAVIGATION SATELLITE SYSTEMS AT MID LATITUDE**

Krysta Lemm, US Naval Research Lab; Gregory Carbott, US Naval Research Lab

With the completion of the Russian GLONASS and the initial deployment of the European Space Agency's Galileo, it is important to evaluate the accuracy of each system, as well as combinations of these new Global Navigation Satellite Systems (GNSS) with the

United States Navstar Global Navigation System (GPS). Specifically, this paper will focus on post-processed double-differenced precision of a stationary land point located at mid-Atlantic latitude over several collection time spans.

SESSION 17: SMALL BODY MODELING

Aug 23, 2017 Stevenson C/D

17 Small Body Modeling

Co Chair: Roberto Furfaro

13:40 AAS 17-557 A Comparison of Gravity Models used for Navigation Near Small Bodies
James Miller, Consultant; Gerald Hintz, University of Southern California

A number of gravity models are used for trajectory design, scientific investigations and navigation of spacecraft. Some gravity models are approximate and others are exact. Approximate models are generally adequate for trajectory design and some scientific investigations, but high precision models are required for navigation, particularly orbit determination. The most demanding gravity model requirements are for orbit determination around large irregularly-shaped bodies. Several gravity models are are analyzed and compared to determine their suitability for navigation. Accuracy, number of parameters and speed of computation are factors that must be considered.

14:00 AAS 17-619 Autonomous Shape estimation and navigation about small bodies using Lidar observations
Benjamin Bercovici, University of Colorado Boulder; Ann Dietrich, University of Colorado Boulder; Jay McMahon, University of Colorado

Spacecraft missions bound to small-bodies typically operate in a ground-in-the-loop fashion.
Indeed, both science and GNC tasks still require ground-data processing or human decision making before being performed.
Enabling spacecraft to operate more autonomously is thus a key goal, that could double the science return out of such missions.
Lidar sensors are some of the key enablers that could allow this breakthrough, as they can be used to perform shape estimation and relative navigation about the target of interest. This paper presents the functioning of such a framework, carrying out these two tasks autonomously about asteroid Itokawa.

14:20 **AAS 17-743** **Mascon Models for Small Body Gravity Fields**

Patrick Wittick, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin

In the context of small bodies, mascon models can be attractive because they are simple to compute, implement, and parallelize. However, to achieve a reasonable surface accuracy, mascon models typically require too many elements to be competitive with other models. Here, mascon models are revisited, with the intent to minimize the number of elements, optimize the placement of the elements, and modify the base model of elements in order to improve computational efficiency, while enabling their use at low altitudes. The new models provide fast, accurate field evaluations to enable rapid small body trajectory searches.

14:40 **AAS 17-763** **Improved Gravity Model Performance by using Mixed Fidelity Shape Models for Irregularly Shaped Small Bodies**

Jay McMahon, University of Colorado

Accurate gravity field modeling near the surface of an irregularly shaped body, such as asteroids, comets, and small moons, is crucial for planning and executing low-altitude and/or landing trajectories on these bodies. The most widely used model for accurate gravity representation is the polyhedral gravity model, which gives the exact potential and gravity for a given triangular-faceted shape model. This paper explores how a multi-resolution facet shape model can be used to speed up the gravity field evaluation without sacrificing accurate gravity representation in localized regions. Incorporation of non-polyhedral shape models for the low-fidelity evaluation will be investigated as well.

15:00 **AAS 17-768** **Modelling asteroids to assist in orbiting and landing missions**

Flaviane Venditti, Arecibo Observatory; Evandro Rocco

Since asteroids are mostly objects with asymmetric distribution of mass, the gravitational field around them may act different from orbits around spherical bodies. Before sending a spacecraft to orbit or land on an asteroid, it is crucial that the environment around it is carefully mapped. In order to study the gravitational field around these objects it is necessary to have a physical model. A new methodology consisting of a shape model built with barycenter of volumes, which is built after observational data to give good approximation of the real shape, is presented.

15:20 **BREAK**

15:50 AAS 17-658 Parallelized small-body lander/hopper simulations with distributed contact and procedural noise

Stefaan Van wal, University of Colorado Boulder; Daniel Scheeres, University of Colorado; Robert Reid, Jet Propulsion Laboratory, California Institute of Technology

We derive a contact model for the interaction between a lander/hopper spacecraft and a targeted small body. The target surface is represented implicitly, allowing for fast distance computations to high-resolution shape models. Spring-damper units attached to vertices covering the spacecraft's exterior generate distributed normal reaction, Coulomb friction, and rolling resistance forces and torques. The transition between slip and stick in these interactions is smoothed using regularization techniques. Fractal noise is procedurally generated onto the implicit target shape model to account for statistical features on the surface. We demonstrate relevant applications of spacecraft operating on small bodies.

16:10 AAS 17-781 Practical Galerkin Variational Integrators for Orbital Dynamics About Asteroids

Dante Bolatti, Ryerson University; Anton de Ruiter, Ryerson University

A practical approach to a class of higher order symplectic integrators known as Galerkin variational integrators is presented. These integrators preserve energy in Hamiltonian conservative systems, and are highly accurate for long term integration. By properly configuring the control points and quadrature functions used to construct the integrator, practical equations of motion can be obtained for orbital trajectory propagation that are suitable for the study of spacecraft dynamics about small bodies. Simulations obtained with these methods are compared to the traditional non-symplectic Runge-Kutta fourth-order method and a second-order variational integrator, focusing on the implications of energy conservation and accuracy.

16:30 AAS 17-823 Stability Analysis of Coupled Orbit-Attitude Dynamics around Asteroids Using Finite-Time Lyapunov Exponents

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

This study investigates coupled orbit-attitude dynamics around asteroids subject to solar radiation pressure and gravity irregularity. The solutions of Sun-synchronous orbits with Sun-tracking attitude motion are analytically derived by applying linearization and averaging. To verify the validity of the analytical solutions, numerical simulations are performed based on non-linear coupled orbit-attitude equations of motion. In addition, the stability of such a coupled motion is analyzed using finite-time Lyapunov exponents. It is demonstrated that the Sun-synchronous orbit-attitude coupled motion exhibits long-term stability under certain conditions, and thus, they are useful and feasible options for asteroid missions.

16:50 AAS 17-825 Filter Robustness of Flash Lidar Based Navigation Around Small Bodies

Ann Dietrich, University of Colorado Boulder; Jay McMahon, University of Colorado

Due to the irregular shape, small size, and distance from Earth of small celestial bodies, research is directed toward spacecraft autonomy for future small body missions. A flash lidar instrument was studied for relative measurements around an asteroid, in order to perform orbit determination and simplify the navigation process such that it could be placed onboard the spacecraft. This paper tests the robustness of various filtering techniques to shape modeling errors and random pointing jitter. Introducing shape modeling errors subsequently introduced biased range measurements, and therefore a biased estimator framework and a zero-mean covariance were implemented to account for a small, bounded measurement bias.

17:10 AAS 17-720 Geometric Control for Autonomous Landing on Asteroids

Shankar Kulumani, George Washington University; Taeyoung Lee, George Washington University

This paper considers the coupled orbit and attitude dynamics of a dumbbell spacecraft around an asteroid. Geometric methods are used to derive the equations of motion, defined on the configuration space of the special Euclidean group, and then a nonlinear controller is designed to enable trajectory tracking of desired landing trajectories. Rather than relying on sliding mode control or optimization based methods, the proposed approach avoids the increased control utilization and computational complexity inherent in other techniques. The stability of the proposed geometric controller is proven using a rigorous Lyapunov analysis.

Session 18: Special Session: Constrained Global Trajectory Optimization

Aug 23, 2017 Stevenson B

18 Special Session: Constrained Global Trajectory Optimization

Co Chair: Jacob Englander
Co Chair: Jonathan Aziz

13:40 AAS 17-598 Walking the Filament of Feasibility: Global Optimization of Highly-Constrained, Multi-Modal Interplanetary Trajectories Using a Novel Stochastic Search Technique

Arnold Englander, Englander & Associates; Jacob Englander, NASA Goddard Space Flight Center

Interplanetary trajectory optimization problems are highly complex and are characterized by a large number of decision variables and equality and inequality constraints as well as many locally optimal solutions. Stochastic global search techniques, coupled with a large-scale NLP solver, have been shown to solve such problems but are inadequately robust when the problem constraints become very complex. In this work, we present a novel search algorithm that takes advantage of the fact that equality constraints effectively collapse the solution space to lower dimensionality. This new approach "walks the filament" of feasibility to efficiently find the global optimal solution.

14:00 AAS 17-605 GRAVITY-ASSIST TRAJECTORIES TO THE ICE GIANTS: AN AUTOMATED METHOD TO CATALOG MASS- OR TIME-OPTIMAL SOLUTIONS

Kyle Hughes, NASA Goddard Space Flight Center; Jeremy Knittel, NASA Goddard Space Flight Center

This work presents an automated method of calculating mass (or time) optimal gravity-assist trajectories without a priori knowledge of the flyby-body combination. Since gravity assists are particularly crucial for reaching the outer Solar System, we use the Ice Giants, Uranus and Neptune, as example destinations for this work. Catalogs are provided that list the most attractive trajectories found over launch dates ranging from 2024 to 2038. The tool developed to implement this method, called the Python EMTG Automated Trade Study Application (PEATSA), iteratively runs the Evolutionary Mission Trajectory Generator (EMTG), a NASA GSFC in-house trajectory optimization tool.

14:20 AAS 17-654 Global, Multi-objective Trajectory Optimization with Parametric Spreading

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

Mission design problems are often characterized by multiple, competing trajectory optimization objectives. Recent multi-objective trajectory optimization formulations enable generation of globally-optimal, Pareto solutions via a multi-objective genetic algorithm. A byproduct of these formulations is that clustering in design space can occur in evolving the population towards the Pareto front. This clustering can be a drawback, however, if parametric evaluations of design variables are desired. This effort addresses clustering by incorporating operators that encourage a uniform spread over specified design variables while maintaining Pareto front representation. The algorithm is demonstrated on low- and high-thrust examples, and multidimensional visualization strategies are presented.

14:40 AAS 17-715 Stochastic Event-Robust Deoptimization Technique for Low Thrust Trajectory Design

Yuichi Tsuda, Japan Aerospace Exploration Agency

This paper describes a methodology to find almost-optimum trajectories which are robust against inflight stochastic events, such as navigation/guidance error and unexpected missed thrust due to temporal spacecraft malfunctions. A particle-based solution search technique was developed which can generate a multi-objective optimum trajectory by deoptimizing the original solution. Arbitrary practical control constraints can be imposed, and one can obtain a solution range in the neighborhood of the original solution which improves the stochastic events-robustness. The technique was applied to an asteroid sample-return mission Hayabusa2 to improve the missed-thrust recoverability, which are presented in detail in this paper.

15:00 AAS 17-785 Automated Solution of Low Energy Trajectories

Ryne Beeson, University of Illinois at Urbana-Champaign; Vishwa Shah, University of Illinois; Joshua Aurich, University of Illinois at Urbana-Champaign; Donald Ellison, University of Illinois at Urbana-Champaign Aerospace Engineering Department

In this paper we introduce a complete framework for the automated solution of low-energy trajectories. We are interested in the solution of global spacecraft trajectory optimization problems in multibody regimes that leverage the natural global transport of the multibody dynamical system. A main difficulty in automated global solution of this type of problem has been automating dynamical systems techniques to find ideal candidate boundary conditions and then connecting these structures in a natural way for global and local optimization schemes to be successful. We demonstrate the capability of our framework by solving several cislunar trajectory problems.

15:20 BREAK

15:50 AAS 17-788 Applications of the Multiple-Shooting Differential Dynamic Programming Algorithm with Path and Terminal Constraints

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

The first multiple-shooting transcription of a Differential Dynamic Programming algorithm was presented in the first part of this paper series. In the present paper, the Multiple-Shooting Differential Dynamic Algorithm is applied to a wide class of constrained nonlinear optimal control problems. Path and terminal constraints are treated using the Augmented Lagrangian approach of Powell, Hestenes, and Rockafellar for equalities and inequalities. The constraints treatment is developed and validated, and completes the algorithm of Part 1. The performance of the MDDP algorithm is evaluated.

16:10 AAS 17-814 Fast and Reliable Approximations for Interplanetary Low-Thrust Transfers

Damon Landau, Jet Propulsion Laboratory

A three-step process bridges the gap between lower-fidelity solutions that ignore optimal dynamics and fully optimized solutions that are computationally expensive to generate. First, analytic solutions for transfers with free time and angle characterize the evolution of the shape and orientation of the orbit. Next, optimal control theory supplies the thrust vector with variable Isp while satisfying flight time and transfer angle constraints. Transfers with the additional constraint of constant Isp then provide a more realistic thruster model for preliminary trade studies. These approximations deliver a hundredfold improvement in run time at the expense of a 2% error in mass.

16:30 AAS 17-833 Synthesis of highly inclined and short period solar polar orbit with electric propulsion

Takehiro Koyanagi, The University of Tokyo; Jun'ichiro Kawaguchi, Japan Aerospace Exploration Agency

A method called E-2-I conversion has been proposed, which ballistically increases the inclination angle and reduce trajectory simultaneously by repeating Earth flyby after Jupiter flyby. But this method has a problem that it takes many years to reach the final orbit. In this research, we prove that we can reduce the flight time of the whole mission

while increasing the degree of freedom of orbital selection by using continuous promotion. This result shows feasibility of composite mission of solar polar observation and solar approach.

16:50 **AAS 17-837** **Space Trajectory Optimization using Embedded Boundary Value Problems**

David Ottesen, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin

The proposed algorithm for preliminary trajectory design is a gradient-based, direct method that minimizes a sequence of impulsive maneuvers. The fast and successful solution to multiple embedded boundary value problems between impulsive maneuvers guarantees position continuity for every optimization iteration, reducing the burden on any outer-loop nonlinear solver. Cost boundary value problem partial derivatives are derived, extending previous work in the context of a single two-body dynamics segment. The algorithm is generalized for arbitrary spacecraft dynamics, including approximations for low-thrust propulsion. The algorithm draws from several legacy works including primer vector theory. Representative examples are provided to demonstrate performance.

17:10 **AAS 17-701** **Low Thrust Trajectory Optimization Applications to Debris Removal Mission Design**

Jason Reiter, Astrodynamics Research Group of Penn State (ARGoPS); Davide Conte, The Pennsylvania State University; Andrew Goodyear, Penn State University; Ghanghoon Paik, Pennsylvania State University; Guanwei He, Pennsylvania State University; Matthew Shaw, Pennsylvania State University; Jeffrey Small; Jason Everett, Pennsylvania State University

The density of debris in Low Earth Orbit makes operating a spacecraft more difficult with the addition of every new satellite. Kessler proposed a scenario in which the density becomes high such that collisions between objects cascade and cause further collisions. Inspired by the 9th Global Trajectory Optimization Competition, a mission is proposed that employs low-thrust propulsion to optimally rendezvous with and deorbit debris to prevent such a scenario from ever occurring. A beam search clustering method was used to select a series of individual missions that maximize the number of debris pieces removed while minimizing the fuel cost.

Aug 24, 2017 Stevenson C/D

19 Constellations and Formations

Co Chair: Matthew Wilkins

8:00 AAS 17-760 Results of the Apogee-Raising Campaign of the Magnetospheric Multiscale Mission

Trevor Williams, NASA/Goddard Space Flight Center; Neil Ottenstein, a.i. solutions, Inc.; Eric Palmer, ai Solutions, Inc.; Jacob Hollister, ai Solutions, Inc.

MMS is flying four spacecraft in high-eccentricity orbits to study magnetic reconnection around the Earth. Insertion occurred into orbits with apogee radius 12 Earth radii, from which the spacecraft studied reconnection in the bowshock. Later measurements are to be taken in the magnetotail: in order to achieve this, apogee radius must first be increased to 25 Earth radii. This is challenging, given the small MMS thrusters and the fact that the spacecraft must finish in a configuration from which they can be maneuvered efficiently back into formation. The paper will describe the results of the recently successfully completed apogee-raising campaign.

8:20 AAS 17-661 MAINTENANCE OF ORBITAL ELEMENTS OF SATELLITES CONSTELLATIONS IN TUNDRA ORBIT

Osama Mostafa Abdelaziz ALI, Kyushu University; Toshiya Hanada, Kyushu University

This work is going to study how to maintenance the drift happened to right ascension of the ascending node for the Sirius satellites constellation by doing maneuver to compensate the coverage gap to get a better continues coverage at high latitudes with a reasonable propellant budget. The result obtained that a maneuver for only one satellite (Sirius 1) will consume the gap happened. This fact means the satellites constellations in Tundra orbit need less maneuvers to maintain the drift caused by third-body perturbations, and reduce the mission cost as well.

8:40 **AAS 17-607** **Satellite Constellation Orbit Design to Enable a Space-Based Radio Interferometer**

Sonia Hernandez, Jet Propulsion Laboratory; Stephen Broschart, NASA / Caltech JPL; David Garza, Jet Propulsion Laboratory; Sebastian Herzig, Jet Propulsion Laboratory; Steve Chien, Jet Propulsion Laboratory; Jeffrey Stuart, Jet Propulsion Laboratory

The design of a networked constellation of small satellites for a space-based interferometer is presented. A mothership acts as a relay for the constellation of thirty-two daughter spacecrafts. The Clohessy-Wilthsire equations are used as an initial design tool, followed by conversion to a two-body model. Discrepancies between the linear and nonlinear solutions are minimized in the conversion process. All spacecraft have the same period, with slightly varying eccentricities and inclination. In a mothership relative, rotating frame, the constellation appears as periodic ellipses of varying sizes. Deployment, reconfiguration of the formation using propulsive maneuvers, and station keeping costs are addressed.

9:00 **AAS 17-761** **Autonomous Operations of Large-Scale Satellite Constellations and Ground Station Networks**

Giovanni Minelli, Naval Postgraduate School; Isaac M. Ross; Mark Karpenko, Naval Postgraduate School; James Newman, Naval Postgraduate School

A dynamic optimization algorithm is developed to aid operators of large-scale satellite constellations with mission planning and data collection. The algorithms utilize the DIDO pseudospectral optimal control solver to produce ground antenna slew trajectories as a function of parameters and constraints used commonly by satellite operators. These parameters include space to ground link budgets, mission priority, asset availability, and onboard health. Algorithms and approaches were developed to optimally slew antennas between multiple satellites that are simultaneously in view of one or more ground stations. The algorithms were tested using orbiting CubeSats and the Mobile CubeSat Command and Control (MC3) network.

9:20 **AAS 17-565** **Deployment and Control Algorithms for Wheel Cluster Formation Satellites**

Chia-Chun Chao, The Aerospace Corporation; Victor Lin, The Aerospace Corporation

A simple and elegant algorithm to populate a cluster of satellites around a center satellite was derived based on the concept of wheel formation in the same orbit plane. The algorithm of using small eccentricity vector separation to place those satellites on single or multiple sub-orbits gives desirable relative motion to the center satellite with safe distance among all the companion satellites. A set of optimized control strategies were developed and simulated for keeping the satellites in closed formation. Without out-of-plane deviations and control, the cost of fuel consumption is minimized. This method can be applied to all types of orbits.

9:40 **BREAK**

10:10 **AAS 17-601** **Long-Term Stability of Common-Inclination Satellite Clusters**
Stuart Gegenheimer, The Aerospace Corporation

A cluster of satellites is a group of satellites in carefully specified close orbits, such that the satellites passively remain within a specified bounded area. In this paper, we examine several strategies for initial cluster setup to minimize formation deformation due to orbital perturbations. These strategies primarily focus on matching the initial mean elements of the cluster satellites by making adjustments to the initial nominal osculating elements. Additionally, we use these strategies to assess the passive stability of several cluster types in multiple orbital regimes using a high fidelity orbit propagator.

10:30 **AAS 17-813** **Heterogeneous constellation design methodology applied to a Mars-orbiting communications and positioning constellation**
Katherine Mott, Virginia Tech; Jonathan Black

With the increasing popularity of small satellites, the viability of launching several satellites to do a task instead of a single large satellite is increasing. Traditional constellation design methodology and tools are not equipped to compare the performance of a typical constellation of identical satellites to that of a heterogeneous constellation comprised of satellites of different capabilities. This research uses new model-based systems engineering design optimization to determine a near-optimal configuration of satellites to accomplish the given mission. As a test scenario, the problem of designing a constellation of Mars-orbiting satellites to perform communications and positioning tasks is considered.

SESSION 20: LOW-ENERGY MISSION DESIGN

Aug 24, 2017 Stevenson B

20 Low-Energy Mission Design

Co Chair: Diane Davis

8:00 AAS 17-784 **RAPID APPROXIMATION OF INVARIANT MANIFOLDS USING MACHINE LEARNING**

Vishwa Shah, University of Illinois at Urbana-Champaign; Ryne Beeson, University of Illinois at Urbana-Champaign

Low-energy mission design in the three-body model leverages invariant manifolds to obtain low-propellant solutions. Optimizing these trajectories requires generating manifolds and searching for the optimal manifold insertion point. Typically, manifolds are generated using numerical methods which can take up to several seconds, thus making the generation of these structures in an optimization framework computationally intractable. In this paper we will explore the application of machine learning algorithms to enable rapid approximation of these structures. The regression models will then be used within an optimization framework. The robustness, accuracy and computational advantages will be benchmarked against Cubic Convolution based approximation methods.

8:20 AAS 17-746 **Trajectory Optimization to the Halo Orbit in Full Force Model using Evolutionary Technique**

Gaurav Vaibhav, INDIAN SPACE REASEARCH ORGANIZATION; B.S. Kiran, ISRO Satellite Centre (ISAC),ISRO; Kuldeep Negi, ISRO Satellite Centre (ISAC),ISRO, India

Aditya-L1 is the first solar mission of India. Spacecraft is supposed to be placed in a halo orbit around Sun-Earth L1 liberation point for continuous observation of Sun. Evolutionary technique has been used for both halo orbit design and optimized transfer trajectory design to it. Selection of the halo orbit has been done considering scientific and mission requirements. Optimized trajectory results have been obtained using backward propagation in CRTBP that have been fed as input parameters to full force model for forward analysis. Tuning of these parameters is done to obtain optimal transfer to achieve suitable halo orbit insertion condition in full force model.

8:40 **AAS 17-597** **Dynamical Structures in a Combined Low-Thrust Multi-Body Environment**

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

Low-thrust trajectory design is challenging as the spacecraft position, velocity, and control histories must be specified simultaneously. Traditional approaches typically generate a single trajectory and control law via optimization algorithms. However, such solutions generally depend strongly on a feasible design that is input to the optimization process. Rather than seeking an optimal control law for each specific design problem, the focus of this investigation is additional insight from the exploration of a combined low-thrust multi-body dynamics model to guide the preliminary design process. Advantageous heuristics and dynamical properties are identified by applying dimension reduction techinques, including Poincaré mapping.

9:00 **AAS 17-695** **Patched Periodic Orbits: A Systematic Strategy for Low Energy Transfer Design**

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

The design of low energy transfers is in general a tedious, time consuming task due to the high dynamical complexity of multi-body environments. A new systematic strategy, which seeks to ease the complexity of this task, is presented. In this model, we show how precomputed three-body periodic orbits can be simply patched together to give rise to complex trajectories. The work focuses on the design of capture and escape trajectories, as well as transfers around the minor body of the three-body system. Several examples are presented, with emphasis in the Jupiter-Europa and Earth-Moon systems.

9:20 **AAS 17-697** **Computing Libration Point Hyperbolic Invariant Sets Using Isolating Blocks**

Rodney Anderson, Jet Propulsion Laboratory / Caltech; Robert Easton; Martin Lo, JPL

Earlier work focused on computing isolating blocks around the libration points in the circular restricted three-body problem and using these isolating blocks to compute the stable and unstable manifolds of the hyperbolic invariant set around the libration points. In this study, the hyperbolic invariant set, or the invariant three-sphere of solutions, is studied using the asymptotic approaches of the stable manifold to the periodic and quasiperiodic orbits contained within the invariant three-sphere. An additional bisection method is used to compute trajectories that follow the invariant three-sphere, which allows us to study these trajectories in more detail.

9:40 **BREAK**

10:10 AAS 17-759 Efficient NRHO to DRO transfers in cislunar space

Gregory Lantoine, NASA / Caltech JPL

There has been recently a growing interest in cislunar missions, in particular for supporting human deep space exploration. Understanding the dynamical environment between various cislunar orbits is therefore useful. The current study is focused on finding efficient transfer trajectory options between a Near-Rectilinear Halo Orbit (NRHO) and a Distant Retrograde Orbit (DRO) in the Earth-Moon system. A general methodology is introduced to design these transfers in a systematic way, including the use of solar perturbations and lunar flybys. Representative solutions are presented and compared in terms of delta-v and flight time, including a transfer requiring 56 m/s only.

10:30 AAS 17-653 Trajectory Design and Station-Keeping Analysis for the Wide Field Infrared Survey Telescope (WFIRST) Mission

Natasha Bosanac, University of Colorado Boulder; Cassandra Webster, NASA Goddard Space Flight Center; Kathleen Howell, Purdue University; David Folta, NASA Goddard Space Flight Center

The Wide Field Infrared Survey Telescope (WFIRST) mission is an upcoming NASA-led observatory that will perform wide-field imaging and near-infrared sky surveys from the Sun-Earth L2 region. To identify a feasible mission trajectory, subject to geometric and maneuver constraints, a trajectory design procedure supported by dynamical systems techniques is developed. This rapid and well-informed approach is implemented as a module of Purdue University's Adaptive Trajectory Design tool. In this paper, a feasible mission trajectory is constructed and output to a higher fidelity modeling environment. Furthermore, a station-keeping analysis is performed using knowledge of the unstable mode along a trajectory.

10:50 AAS 17-587 Disposal Investigations for ESA's Sun-Earth Libration Point Orbiters

Florian Renk, European Space Agency; Stijn Lemmens, European Space Agency

The European Space Agency has been and is currently operating spacecraft about the Sun-Earth Libration Points 1 and 2. Since the Sun-Earth Libration point orbits are unstable a dedicated strategy is required to minimize the risk of the S/C returning towards the Earth and penetrating the LEO and GEO protected regions. For the heliocentric disposal a one- or two-manoeuvre strategy can be chosen with different drift times between the two manoeuvres. The general results for the trade between manoeuvre sizes and drift duration (if applicable) and in addition the detailed LISA Pathfinder disposal investigations will be presented.

11:10 AAS 17-687 From GTO to Ballistic Lunar Capture using an Interior Lagrange Point Transfer

Anthony Genova, NASA; Brian Kaplinger, Florida Institute of Technology

The presented trajectory design connects a geosynchronous transfer orbit to lunar orbit via ballistic lunar capture. This design utilizes two lunar flybys to raise perigee to lunar distance and enter a high-Earth orbit (HEO) to set up an interior transfer through the Earth-Moon Lagrange points L1 and L2. This design is compatible with spacecraft equipped with propulsion systems that lack sufficient thrust to enter lunar orbit from a traditional lunar orbit transfer. Additionally, the utilized HEO can act as a cislunar staging orbit with the ability to send supplies from Earth to a manned space station in lunar orbit.

11:30 AAS 17-593 Dynamics and Stability of Sun-Driven Transfers from LEO to GEO

Stijn De Smet, University of Colorado; Daniel Scheeres, University of Colorado; Jeff Parker, Advanced Space

This paper discusses the design of transfers from low-Earth to geostationary orbits. Classically, the inclination changes on the transfer trajectories are performed using out-of-plane maneuvers. For this research, all inclination change is performed through the use of solar gravity. For high initial inclinations, the required ΔV can be significantly lowered, as compared to the more classic geostationary transfer trajectories. A characterization of the transfers' response to missed and imperfect maneuvers is performed to identify the robustness of the transfers.

11:50 AAS 17-711 Solar Sailing at the L4/L5 Libration Points

Ariadna Farres, University of Barcelona; Narcis Miguel Banos, Universitat de Barcelona

In this talk we focus on the dynamics of a solar sail in the vicinity of the Lagrangian points L4/L5. These points are linearly stable and so are the families of periodic orbits around them. Moreover, there is a region of effective stability around them, where the trajectory of a satellite will remain there for more than 1000 years. We will describe these regions and see how the solar radiation pressure affects them. A good understanding of these regions and how to reach them would enable a novel space weather mission concept by placing two sailcrafts at L4 and L5.

SESSION 21: RELATIVE MOTION

Aug 24, 2017 Stevenson A

21 Relative Motion

Co Chair: Renato Zanetti

8:00 **AAS 17-641** **Relative Motion Equations in the Local-Vertical Local-Horizon Frame for Rendezvous in Lunar Orbits**

Giovanni Franzini, University of Pisa - Department of Information Engineering; Mario Innocenti, University of Pisa - Department of Information Engineering

In this paper, a set of equations for relative motion description in lunar orbits is presented. The local-vertical local-horizon frame is selected to describe the relative dynamics of a chaser approaching a target in lunar orbit, allowing the development of guidance and navigation systems. The model considers the gravitational influence of the Earth and the Moon on the two spacecraft, which are assumed to have negligible masses. The proposed equations are intended for the study of rendezvous missions with a future cis-lunar space station, whose development is currently investigated by several space agencies as the next step for space exploration.

8:20 **AAS 17-688** **Orbital Element-Based Relative Motion Guidance on J2-Perturbed Eccentric Orbits**

Bradley Kuiack, Carleton University; Steve Ulrich, Carleton University

This paper addresses the problem of nonlinear analytical guidance for spacecraft formation flying reconfiguration maneuvers. Specifically, a nonlinear analytical solution for predicting the radial, along-track, and cross-track relative motion on J2-perturbed elliptical orbits is first obtained and then used in a back-propagation scheme for closed-loop guidance purposes. The relative orbital element-based guidance solution is then combined with an impulsive controller to demonstrate its efficiency in terms of propellant savings to execute a reconfiguration maneuver over a period of ten orbits.

8:40 **AAS 17-704** **Distributed spacecraft path planning and collision avoidance via reciprocal velocity obstacle approach**

Sittiporn Channumsin, Geo-Informatics and Space Technology Development Agency (Public Organization); Gianmarco Radice, University of Glasgow; Matteo Ceriotti

This paper will present and implement the reciprocal velocity obstacle (RVO) approach for real-time spacecraft formation control. Velocity obstacle defines the set of all velocities that will result in a collision between two spacecraft at some point in time; selecting

a velocity that lies outside the velocity obstacle to ensure that no collision will occur. This approach is investigated in the context of the orbital dynamics of multiple nanosatellites in circular low Earth orbit. Different test cases will be analysed to evaluate the collision avoidance performance. It will be shown that this method guarantees safe and collision-free manoeuvres for all.

9:00 ~~**AAS 17-736**~~ ~~**Multiple Sliding Surface Guidance in SE(3) for Autonomous Rendezvous and Docking**~~

~~*Roberto Furfaro, The University of Arizona; Eric Butcher, University of Arizona; Morad Nazari, New Mexico State University; Tansel Yucelen, Department of Mechanical Engineering, University of South Florida*~~

Withdrawn

9:20 ~~**AAS 17-738**~~ ~~**CONTROL STRATEGIES FOR CONSTRAINED HOVERING ORBITS USING CONTINUOUS CONSTANT LOW-THRUSTS**~~

~~*XIAOQING GAO, Beihang University; Chao Han, Beihang University*~~

Withdrawn

9:40 BREAK

10:10 **AAS 17-739** **Waypoint-Optimized Closed-Loop Guidance for Spacecraft Rendezvous in Relative Motion**

Roberto Furfaro, The University of Arizona; Roberto Ruggiero, Politecnico di Milano; Francesco Topputo, Politecnico di Milano; Marco Lovera, Politecnico di Milano; Richard Linares, University of Minnesota

In this paper, we develop a closed-loop, waypoint-based, quasi-optimal algorithm that can be employed to execute autonomous rendezvous guidance in relative motion. The approach is based on using ZEM/ZEV feedback guidance algorithm to target a sequential set of states for the relative motion dynamics. A series of optimization problems, based on the minimization of the fuel consumption constrained by the need to achieve high level of position and velocity accuracy, are formulated and solved.

10:30 **AAS 17-758** **A New Time-Explicit J2-Perturbed Nonlinear Relative Orbit Model with Perturbation Solutions**

Eric Butcher, University of Arizona; Ethan Burnett, University of Arizona; Alan Lovell

A new J2-perturbed time-explicit relative orbit model is developed including the effects of nonlinearities up to third order, chief orbit eccentricity, and J2 perturbation of both the chief and deputy orbits. Advantages and disadvantages compared with previous relative orbit models are discussed and numerical simulations are employed to determine the accuracy of the proposed model. Finally, a previously used perturbation technique is used to obtain approximate solutions in which the J2 perturbation, chief orbit eccentricity, and the normalized separation distance are expanded separately. Previously obtained perturbation solutions for relative motion are shown to be special cases of the solution obtained.

10:50 AAS 17-791 Approximate Closed Form Solutions of Spacecraft Relative Motion via Abel and Riccati Equations

Ayansola Ogundele; Andrew Sinclair, Air Force Research Laboratory; S. C. Sinha, Auburn University

Visualizing the relative motion using the Keplerian orbital elements simplifies the orbit description better than the use of Hill frame coordinates. Rather than using position and velocity the use of orbital elements has benefit of having only one term (anomaly) that changes with time out of the six orbital elements and this reduced the number of terms to be tracked from six to one. In this paper, with appropriate transformations, the evolution nonlinear equation of motion, which describes the dynamics of the relative motion of deputy spacecraft with respect to the chief spacecraft in terms of the orbit element differences,

Session 22: Spacecraft GNC I

Aug 24, 2017 Cascade A

22 Spacecraft GNC I

Co Chair: Sean Wagner

8:00 AAS 17-576 **Orbit Determination Covariance Analyses for the Parker Solar Probe Mission**

Drew Jones, Jet Propulsion Laboratory, Caltech; Paul Thompson, NASA / Caltech JPL; Troy Goodson, NASA / Caltech JPL; Min-Kun Chung, Jet Propulsion Laboratory; Neil Mottinger, NASA / Caltech JPL; Powtawche Valerino, NASA / Caltech JPL; Eunice Lau, NASA / Caltech JPL

This paper details pre-launch navigation covariance analyses for the Parker Solar Probe mission. Baseline models and error assumptions are outlined. The results demonstrate how navigation will satisfy requirements and are used to define operational plans. A few sensitivities are identified and the accompanying investigations are described. Predicted state uncertainty results show that most requirements are met with substantial margin. Moreover, navigation sensitivities may be accommodated operationally and this has been incorporated into project planning. Detailed results are presented only for select launch dates, however twenty unique trajectories (one per launch opportunity) have been assessed.

8:20 AAS 17-580 **MAGNETOSPHERIC MULTISCALE MISSION NAVIGATION PERFORMANCE DURING APOGEE-RAISING AND BEYOND**

Mitra Farahmand, a.i. solutions, Inc.; Jacob Hollister, ai Solutions, Inc.

The primary objective of the Magnetospheric Multiscale (MMS) Mission is to study the magnetic reconnection phenomena in the Earth's magnetosphere. The MMS mission consists of four identical spinning spacecraft with the science objectives requiring a tetrahedral formation in highly eccentric orbits. The MMS spacecraft are equipped with onboard orbit and time determination, provided by a weak-signal Global Positioning System (GPS) Navigator receiver hosting the Goddard Enhanced Onboard Navigation System (GEONS) software. This paper will present the results of MMS navigation performance analysis during the Phase 2a apogee-raising campaign and Phase 2b science segment of the mission.

8:40 **AAS 17-599** **Optical-based Kinematic Positioning for Deep-Space Navigation**

Stephen Broschart, NASA / Caltech JPL; Nicholas Bradley, NASA / CalTech - JPL; Shyam Bhaskaran, NASA / Caltech JPL

Current state-of-the-art for deep space navigation relies heavily on ground-based assets. We seek to eliminate up to 90% of radiometric tracking time by relying primarily on on-board optical navigation. Using only optical observations of natural bodies, we compute kinematic spacecraft position fix accuracy throughout the solar system. Knowledge in the inner solar system is hundreds of kilometers, which is comparable with ground-based navigation solutions. On approach to planets, using moons as targets can decrease uncertainty to tens of kilometers. A case study of the InSight cruise to Mars is also presented.

9:00 **AAS 17-660** **Assessing Orbit Determination for a Lunar CubeSat Mission**

Adonis Pimienta-Penalver, Emergent Space Technologies, Inc.; Sun Hur-Diaz, Emergent Space Technologies

A low-thrust lunar CubeSat mission has been proposed to satisfy the requirements of NASA's CubeQuest Challenge. Due to mission and system-imposed limitations, the proposed nominal trajectory encompasses several orbital regimes, such as a fast lunar flyby, long-duration interplanetary coast arcs, and a slow spiral down into a stable lunar orbit, each of which calls for a distinct tracking approach. This paper presents a preliminary evaluation of the orbit determination requirements of each of the stages of the nominal trajectory using the batch filter and measurement type modelling capabilities in NASA's General Mission Analysis Tool (GMAT) software.

9:20 **AAS 17-672** **Mathematics used for Deep Space Navigation**

James Miller, Consultant; Gerald R. Hintz

Navigation of spacecraft requires science and mathematics equations to be programed onto a digital computer. For deep space navigation, the science content is somewhat less than 10 percent and the mathematics content is somewhat greater than 90 percent. Science is defined here as any mathematical expression that is observed and cannot be proved. We start with these science mathematical expressions and other mathematical expressions that are accepted as true and manipulate them until we obtain a result that is useful. Some results lead to analytic solutions and some lead to computer solutions. We are interested in computer solutions.

9:40 **BREAK**

10:10 **AAS 17-684** **Pulsar Navigation: Defining an Upper Bound for Distance From Reference**

Stoian Borissov, Texas A&M University; Daniele Mortari, Texas A&M University; Victoria Wright, Texas A and M; William Vlasak, Texas A and M; Jeffrey Butcher, Texas A and M; Steve Mena, Texas A and M; Grayson Bridges, Texas A and M

This paper first explains in detail the problem of ambiguous measurements in pulsar navigation and then derives the upper bound for distance from a reference point. This upper bound is dependent on both detector and pulsar characteristics and defines the size of the reference volume. An algorithm for calculating size of the reference volume is presented along with a detailed development of how the size is affected by pulse model uncertainty and detector noise. Different detector/pulsar pairing configurations are also examined. Finally, example calculations are presented using cataloged pulsars and the existing X-ray detector hardware defined by the NICER/SEXTANT mission.

10:30 **AAS 17-667** **Fringe Fitting for DOR Tones in geodetic VLBI**

songtao han, Beijing Aerospace Control Center; Zhang Zhongkai, Zhengzhou Institute of Surveying and Mapping

Spacecraft is usually equipped with DOR transponder to support high accuracy interferometric tracking. Some space agencies, such as ESA/NASA, adopt correlator based on phase locking or local correlation algorithm to process DOR tones. While geodesy and astronomy agencies usually deploy correlator(Difx,K5..), post-processing software(HOPS/AIPS..) mainly for quasar observation. As DOR tones vary narrow spectrum are totally different from quasar continuum spectrum, here comes the problem: is the fringe fitting still effective for DOR tones signal? In this paper, we discuss the fringe fitting algorithms suitable for DOR tones and make a comparison with experiment data.

10:50 **AAS 17-690** **Comparative Study of Tracking Controllers Applied to Martian Aerocapture**

Benjamin Margolis, University of California, Davis; Mohammad Ayoubi, Santa Clara University

In this paper, we present a comparison of three tracking controllers applied to a martian aerocapture vehicle following an arbitrary trajectory: a Takagi-Sugeno Fuzzy Model (TSFM) based discrete time model predictive controller (MPC), a TSFM based parallel distributed controller (PDC), and a time-varying linear quadratic regulator (LQR). The change in velocity required to bring the orbit of the controlled exit conditions to the orbit of the reference trajectory exit conditions is evaluated over a range of initial condition errors.

11:10 **AAS 17-669** **Station-keeping of Libration Point orbits with Sequential Action Control technique**

Dandan Zheng; Zixuan Xiong, Xidian University; Jianjun Luo

Three-dimensional orbits in the vicinity of the interior libration point (L1) of the Sun-Earth/Moon barycenter system are currently being considered since 1990s. But the unstable orbit about the L1 libration-point requires stationkeeping maneuvers to maintain the nominal path. In this study, L1 libration-point orbit stationkeeping is studied using Sequential Action Control(SAC), SAC has shown promise in simulation as a closed-loop receding horizon style controller that can compute optimal actions in real-time for nonlinear systems. The controller is designed such that the actual trajectory tracks a predetermined reference orbit with good accuracy. Numerical results employing this method demonstrate the potential.

SESSION 23: PROXIMITY OPERATIONS

Aug 24, 2017 Stevenson A

23 Proximity Operations

Co Chair: Jacob Darling

13:40 ~~**AAS 17-716**~~ ~~**Range-Only Relative Orbit Estimation for Close-in Proximity Operations**~~

~~*Baichun Gong, Nanjing University of Aeronautics and Astronautics*~~

Withdrawn

14:00 **AAS 17-665** **HOVERING ORBIT CONTROL BASED ON CONTINUOUS THRUST**

Yinrui Rao, China Academy of Engineering Physics; Ran Zhang, Beihang University; Chao Han, Beihang University

The region hovering orbit formed by periodic impulse control has been concerned in recent years. Applicability of the impulsive control approach for hovering orbit is limited because of its high fuel consumption. In this study, the hovering orbit control problem based on continuous thrust is exhaustively researched. Based on the Gaussian perturbed equation, an analytic constant continuous thrust control strategy for hovering orbit is derived. With the proposed method, the fuel consumption can be effectively reduced. The effect of the selected control points on the required thrust is analyzed. Numerical simulations are conducted to demonstrate the proposed method's efficacy.

14:20 **AAS 17-574** **Navigation System and Trajectory Analysis for Active Debris Removal Mission**

Naomi Murakami, Japan Aerospace Exploration Agency; Toru Yamamoto, Japan Aerospace Exploration Agency

JAXA has been studying active debris removal (ADR) missions to deorbit large rocket bodies in LEO. In the current scenario, the chaser satellite is required to rendezvous with the non-cooperative debris and attach deorbit devices to it. Navigation is the key for the safe and robust non-cooperative rendezvous, however, the functions and performances required to the navigation system have not been clarified. In this paper, a practical rendezvous scenario for ADR missions is proposed and the requirement for the navigation system is discussed using Linear Covariance Analysis method. The trajectory safety in both nominal and off-nominal situations are also considered.

14:40 **AAS 17-733** **Preliminary GNC Design for the On-orbit Autonomous Assembly of NanoSatellite Demonstration Mission**

Jing Pei, NASA Langley Research Center

Small spacecraft autonomous rendezvous and docking is an essential technology for future space structure assembly missions. The On-orbit Autonomous Assembly of Nanosatellites (OAAN) team at NASA Langley Research Center (LaRC) intend on demonstrate the technology to autonomously dock two nanosatellites to form an integrated system. The overall main OAAN Mission can be separated into the following phases: 1) Launch, checkout, and drift, 2) Far Field Rendezvous or Drift Recovery, 3) Proximity Operations, 4) Docking. This paper discusses the preliminary GNC design and simulation results for each phase of the mission.

15:00 **AAS 17-753** **Simulated Formation Control Maneuvers for the RANGE CubeSat Mission**

Daniel Groesbeck, Georgia Institute of Technology; Brian Gunter, Georgia Institute of Technology; Kenneth Hart, Georgia Institute of Technology

The RANGE mission will fly two 1.5U CubeSats in a leader-follower formation, using only differential drag to control their relative separation distance. To prepare for mission operations, a simulation capability was developed that involved the creation of a high-precision orbit propagation plugin that considered rarefied flow. The development, testing, and validation of these simulations will be presented, in addition to the expected performance and control maneuvers for RANGE.

15:20 **BREAK**

15:50 **AAS 17-787** **Autonomous Guidance Algorithms for Formation Reconfiguration Maneuvers**
Theodore Wahl, Purdue University; Kathleen Howell, Purdue University

Spacecraft formations operating autonomously have the potential to support a wide variety of missions. An autonomous guidance algorithm for formation reconfiguration maneuvers is updated and expanded in this investigation. The guidance algorithm separates the maneuver into 2 problems: assigning and then delivering the spacecraft. An improved auction process is used to assign the spacecraft to new positions, and two methods of delivering the spacecraft are included. One is based on Artificial Potential Function (APF) guidance, and the other is based on Model Predictive Control (MPC) guidance. The performance of the guidance algorithm and its constituent pieces are assessed through simulations.

16:10 **AAS 17-821** **Semi-analytical Methods for Computing Delta-V and Time Optimal Rendezvous Maneuvers in Cis-lunar Halo Orbits**
Davide Conte, The Pennsylvania State University; David Spencer, Penn State University

This paper presents solution techniques for finding time- and Δv-optimal maneuvers to rendezvous with a target spacecraft in cis-lunar halo orbits. These families of orbits were chosen due to the rising interest in cis-lunar space for human and robotic exploration. The dynamics and the stability of relative motion in the Circular Restricted Three-Body Problem (CR3BP) are analyzed using Floquet theory while in order to determine optimal maneuvers that the chaser spacecraft needs to accomplish to rendezvous with the target spacecraft. Various heuristic optimization techniques are compared with semi-analytical solutions.

16:30 ~~**AAS 17-839**~~ ~~**Angles-Only Navigation for Autonomous On-Orbit Servicing Applications**~~
~~*Joshua Sullivan, Space Rendezvous Laboratory, Stanford University; Connor Beierle, Stanford University; Simone D'Amico, Stanford University*~~

Withdrawn.

16:50 **AAS 17-841** **Development and Validation of a GNC Algorithm Using a Stereoscopic Imaging Sensor in Close Proximity Operations**
Jill Davis, Missouri University of Science and Technology; Pavel Galchenko, Missouri University of Science and Technology; Henry Pernicka, Missouri University of Science and Technology

The stereoscopic imaging system used for proximity operations of an inspector satellite near a noncooperative resident space object is validated using AGI's Systems Tool Kit and the MATLAB/Simulink environment. The control algorithms of the system are implemented using MATLAB/Simulink, while the graphical modeling and visualization is provided by STK. STK will also be used as the truth propagation of the orbit. The stereoscopic imaging system is modeled by sensors with the specified field of view.

17:10 AAS 17-848 OPTIMAL FORMATION ESTABLISHMENT AND RECONFIGURATION USING METAHEURISTIC OPTIMIZATION METHODS

Eric Prince, Air Force Institute of Technology; Richard Cobb, Air Force Institute of Technology

This paper will utilize metaheuristic methods to produce initial guesses for and/or provide standalone solutions to optimal control problems of an inspector satellite with unique control constraints operating in geosynchronous orbit. The goal of the inspector satellite is to inject itself into a natural motion circumnavigation orbit about a target, defined by an exclusion cone, and then transfer to an orthogonal one in order to obtain views from all eight octants surrounding the target. The control used is a body-fixed engine where the satellite has maximum slew rates, and thus the optimal translational trajectory is subject to rotational control constraints. Both direct and indirect applications of metaheuristic methods will be used to find the optimal control for both minimum time and minimum fuel formulations. Specifically, particle swarm optimization will be used by parameterizing the control and also to solve for the optimal costates and control via the recently developed indirect heuristic method. The developed algorithms are expected to produce initial guesses for a pseudospectral method or solve the problem entirely, providing mission planners with multiple tools to obtain comparable optimal guidance. The developed algorithms' performance will be analyzed and compared, discussing the pros and cons of each method.

17:30 AAS 17-799 Geometric Camera Calibration Using Near-Field Images of the ISS Centerline Docking Plate

Andrew Rhodes; John Christian, Rensselaer Polytechnic Institute
Shane Robinson, GSFC

The next generation of spacecraft will be capable of autonomously docking with the International Space Station (ISS) and other space assets. While a variety of sensing solutions exist, camera-based methods are an especially promising option. Achieving these relative navigation objectives, however, requires the camera to be well calibrated. Preflight estimates of the geometric calibration parameters may be available, but on-orbit recalibration may be necessary due to environmental effects. Here, we propose that geometric calibration for a navigation camera may be performed using a collection of images of the ISS's centerline docking plate.

Session 24: Spacecraft GNC II

Aug 24, 2017 Cascade A

24 Spacecraft GNC II

Co Chair: Christopher DSouza

13:40 AAS 17-800 Perspective Projection of Ellipses and Ellipsoids with Applications to Spacecraft Navigation

John Christian, Rensselaer Polytechnic Institute

The use of cameras for spacecraft navigation has received considerable interest in recent years. Furthermore, such image-based navigation solutions have been proposed for certain aspects of both the absolute navigation and relative navigation problems. Within both of these application domains, it is common to encounter object contours with an elliptical shape. Elliptical arcs occur frequently because both ellipses (or circles) and ellipsoids (or spheres) appear as an ellipse in an ideal image formed by perspective projection (i.e. the pinhole camera model). This paper investigates this concept in detail and a number of important scenarios are considered.

14:00 AAS 17-555 A Methodology for Optimizing the Orbital Location of Prime and Backup Maneuvers

Juan Arrieta, Nabla Zero Labs

Designing backup maneuver locations is a delicate balance between maintaining the nominal trajectory close to optimal and ensuring that no single backup maneuver can derail the entire mission. We propose a methodology for optimizing the orbital location of prime and backup maneuvers. The methodology is based on deriving a cost function that relates the change in delta-v due to time-shifting a maneuver location, and using such function to optimize the location of both prime and backup maneuvers in a manner that minimizes the expected delta-v change.

14:20 AAS 17-676 AUTONOMOUS PLANNING OF CONSTRAINED SPACECRAFT REORIENTATION MANEUVERS

Travis Lippman, Naval Postgraduate School; James Kaufman, Naval Postgraduate School; Mark Karpenko, Naval Postgraduate School

Planning attitude constrained spacecraft reorientation maneuvers can be done autonomously by constructing and solving a nonlinear optimal control problem. Attitude constraints, in the form of keep-out or keep-in cones are added as path constraints. Since the control variables do not appear in the path constraint equations, it can be difficult to obtain numerical solutions. In this paper, the constrained spacecraft reorientation problem Is solved using guess-free Pseudospectral optimal control theory. The behavior of the dual variables, and in particular the path covectors, is studied and some connections between computation time and the nature of the dual space is discussed.

14:40 AAS 17-589 Enhanced Q-Law Lyapunov Control for Low-Thrust Transfer and Rendezvous Design

Demyan Lantukh, The Aerospace Corporation; Chris Ranieri, The Aerospace Corporation; Marc DiPrinzio, The Aerospace Corporation; Peter Edelman, The Aerospace Corporation

Improvements to proximity quotient (Q-law) Lyapunov feedback for generating low-thrust transfers are demonstrated in terms of both numerical properties and the ability to do full six-state targeting. Numerical improvements include the use of a deadband for chatter reduction and an L-infinity norm based effectivity parameter. Fast variable targeting is accomplished by augmenting the semimajor axis target with a scaled bias to promote simultaneous convergence of the semimajor axis and true longitude.

15:00 AAS 17-811 Optimization of Impulsive Transfer Trajectories to Europa Capture using Primer Vector Theory

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

The problem of optimizing transfer trajectories to capture at Europa is investigated, using a combination of primer vector theory and direct optimization techniques. Starting from intial guess trajectories, primer vector theory is used to determine if coasting arcs along the initial and capture orbits will reduce transfer cost. If the resulting transfer remains suboptimal, interior impulses are added to the trajectory. The location and time of these impulses are initially determined from the primer vector, then optimized directly with analytic derivatives in a gradient line search. Several problems are considered, including transfers from resonant orbits beyond Europa.

15:20 BREAK

15:50 AAS 17-771 Decentralized Fusion with Finite Set Statistics for Landing Navigation

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

This paper proposes the use of SLAM tools formulated using finite set statistics to perform terrain-aided navigation for planetary landers. Further, the methodology is designed to augment, rather than replace, standard extended Kalman filter-based navigation architectures via decentralized fusion with feedback, enabling a SLAM-Fusion procedure with substantially lower development costs than replacing existing approaches altogether. The resulting approach enables significant performance improvements in existing navigation filters with little to no modification of the existing scheme. The theoretical results are supported via simulation of a lunar descent trajectory and the proposed SLAM-Fusion procedure.

16:10 AAS 17-718 Operational Experience and Assessment of the Implementation of the Maplet Technique for Rosetta's Optical Navigation

Francesco Castellini, European Space Agency; Klaas Vantournhout, CGI Deutschland, located at ESOC; Ramon Pardo; Mathias Lauer, ESA / ESOC

For more than two years, the Rosetta spacecraft successfully navigated around comet 67P, using landmark observations obtained from daily processing of images from its navigation cameras as main orbit determination observables. The landmark observations were made using a set of small digital elevation and albedo maps, called ‘maplets’. This paper analyses the vast available data set (1.2 million observations of 10835 landmarks in more than 12000 images) in combination with performance metrics and operational experience, to assess in details the performances and robustness of the maplets technique for optical navigation, showing its relevance in the success of the Rosetta mission.

16:30 AAS 17-831 Precision Formation Flying and Spacecraft Pointing Using Plasmonic Force Propulsion

Pavel Galchenko, Missouri University of Science and Technology; Henry Pernicka, Missouri University of Science and Technology

Precision formation flying and spacecraft pointing for swarm mission concepts requires micropropulsion technologies and robust control solutions. Plasmonic force propulsion can provide nanonewtons of thrust with which some spacecraft control can be realized. This study considers the feasibility of providing precision pointing and orbit control using an array of plasmonic force thruster configurations within the constraints of system level design requirements of the CubeSat platform (with applicability to micro/nano/pico-satellites in general). Results show that pointing and relative position can be maintained for a range of swarm precision formation flight missions.

16:50 AAS 17-835 Orbit Transfer Trajectory Design Using Finite-Burn Maneuver Under Steering-angle Constraints

Donghun Lee

An orbit transfer problem using finite-burn maneuvers without or under a con-straint on steering-angle of the thruster is considered. The time history of steer-ing-angle is important in order to minimize delta-V loss for a finite burn maneu-ver. In this paper, the steering-angle profiles are designed both in the inertial reference frame and rotating frame, respectively. In addition, steering-angle profiles such as anti-velocity direction and anti-tangential direction are also investigated, which can be easily applicable to a real space exploration mission. As an example, lunar orbit insertion maneuvers are studied to prepare for the future lunar exploration mission.

17:10 AAS 17-707 LOW-THRUST GEO ORBIT TRANSFER GUIDANCE USING SEMI-ANALYTIC METHOD

Xian Li; Ran Zhang; Chao Han, Beihang University

A low thrust GEO orbit transfer guidance is proposed based on the concept of semi-analytic satellite theory. Three weights every loop of the orbital elements of a continuous low thrust transfer are introduced, by changing which, shorter orbit transfer time and corresponding attitude angles of the spacecraft can be obtained. These parameters are computed from the minimum-time transfer employing unscented Kalman filted parameter estimation. This algorithm is simple and effective, to significantly reduce the computation load for the long-duration, many revolution trajectories. A numerical simulation of a GTO-GEO transfer is presented to demonstrate the proposed guidance scheme.

17:30 AAS 17-742 CONJUGATE UNSCENTED TRANSFORMATION BASED APPROACH TO COMPUTE HIGHER ORDER STATE TRANSITION MATRIX FOR NONLINEAR DYNAMIC SYSTEMS: APPLICATIONS TO ESTIMATION AND CONTROL

Taewook Lee, University at Buffalo; Puneet Singla, The Pennsylvania State University; Manoranjan Majji, Texas A&M University, College Station

Conjugated Unscented Transformation (CUT) based approach is presented to compute higher order state transition matrices (STMs) in a derivative free manner and a computationally attractive manner. The proposed approach is non-intrusive in nature and is similar to stochastic collocation methods (SCM). The connection between SCM and higher order STMs approaches are discussed. The computed STMs are valid over the desired domain represented by a density function rather than valid along a single trajectory of a dynamical system. Benchmark problems corresponding to uncertainty propagation and optimal control are considered to demonstrate the numerical efficiency and accuracy of the proposed ideas.

Aug 24, 2017 Stevenson C/D

25 Spaceflight Mechanics

Co Chair: Andrew Sinclair

13:40 AAS 17-552 Atmospheric Density Estimation with Limited Orbit Tracking Data
Jinjun Shan, York University; Yuan Ren

In this paper, an atmospheric density calibration algorithm is developed to improve the accuracy of traditional deterministic density models. Simulations are conducted to verify the effectiveness of the proposed method.

14:00 AAS 17-610 Deflection Assessment for a Gravity Tractor Spacecraft
Shyam Bhaskaran, NASA / Caltech JPL

One proposed method to deflect a potential Earth impacting asteroid is via the "gravity tractor" method. Here, a spacecraft, hovering close to an asteroid using ion engines, uses its gravitational pull to change the asteroid's orbit away from an impacting path. The proposed Asteroid Redirect Robotic Mission was slated to demonstrate the feasibility of this technique on the asteroid 2008EV5, and measure the amount of deflection. In this paper, we examine the questions of how long the tractoring needs to be to cause a measurable deflection, and how the spacecraft can be used to measure it.

14:20 AAS 17-611 Converting to Physical Coordinates With or Without a Full Set of Sensors by Eigen-Decomposition of Identified State-Space Models
Dong-Huei Tseng; Minh Phan, Dartmouth College; Richard Longman, Columbia University

This paper presents a method to convert an identified state-space model of a structure to physical coordinates. The procedure is part of a process to recover the structure mass, stiffness, and damping matrices from input-output measurements. The present method overcomes the high dimensionality associated with a Kronecker-based solution for systems with high degrees of freedom. Furthermore, a full set of sensors is not required. Sensors can be exchanged for actuators, and at least one collocated pair of sensor and actuator is necessary for unique conversion of an identified state-space model to physical coordinates.

14:40 AAS 17-612 Mass, Stiffness, and Damping Matrices From State-Space Models in Physical Coordinates By Eigen-Decomposition of a Special Matrix

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

This paper presents a method to recover the mass, stiffness, and damping matrices from an identified state-space model of a flexible structure in physical coordinates. The proposed solution is simple yet practical for high degree-of-freedom systems. The computational requirement is minimal, and the method preserves the symmetry of the mass, stiffness, and damping matrices in the presence of noise. A complete set of solutions is provided in the sense that any combination of displacements, velocities, accelerations can be used as measurements.

15:00 AAS 17-663 Study of Lunar Librations by Chang'E-3 Lunar lander VLBI Observations

Zhang Zhongkai, Zhengzhou Institute of Surveying and Mapping; Songtao Han, Beijing Aerospace Control Center

2013, Chang'E-3 successfully landed on the Moon, which provides an opportunity to observe the Moon with VLBI. During 2014 ~ 2016, 12 VLBI sessions were conducted with a number of VLBI stations to observe the Chang'E-3 lunar lander. Since VLBI has a high sensitivity in the transverse direction, the information of lunar libration can be obtained from the observations. The models of VLBI observing the lunar lander were built including the partial derivatives of parameters related with librations. With some initial group delays and simulation, the librations of the Moon from VLBI observations were analysed.

15:20 BREAK

15:50 AAS 17-664 USE OF ADVANCED STATISTICAL TECHNIQUES FOR MISSION ANALYSIS: CASE STUDY FROM A GOOGLE LUNAR X TEAM (SPACEIL)

David Shteinman, Industrial Sciences Group & Space IL; Ian Ting, Industrial Sciences Group

Lunar X prize teams, competing to be the first non-governmental spacecraft to soft land on the Moon, all have small budgets that are severe restrictions for mission designers. Hence it is necessary to rely heavily on historical data analysis and simulation to characterize and quantify *expected* performance of mission components. Statistical methods such as *Time Series Analysis* and *Design & Analysis of Computer Experiments* (DACE) are ideally suited to the task of delivering maximum information on the operating windows of expected performance at minimum cost. We present a case study from a Lunar X prize team that illustrates this.

16:10 AAS 17-666 The study of online learning Recognition Method of the Space Tumbling Non-cooperstive Target Based On Small Satellite Platform

Zixuan Xiong, Xidian University; Dongzhu Feng, Xidian University; Hang Yu

This paper develops a recognition method for the space tumbling non-cooperative target based on small satellite platform. The method is based on a support vector machine algorithm to recognize a space tumbling target. Online learning as a part of the algorithm improves the accuracy of recognition. A simulation system is established based on C++/STK to verify the validity and evaluate, the performance of the proposed algorithm. With comparisons of 3 different recognition algorithms, the cinclusion is that the tumbling non-cooperative target can be accurately recognized on real-time by taking the advantage of the proposed algorithm.

16:30 AAS 17-678 TIMING COEFFICIENT AND SOLAR LUNAR PLANETARY EPHEMERIS FILES VALID OVER VERY LONG TIME INTERVALS AND THEIR APPLICATION IN NUMERICAL AND SEMIANALYTICAL ORBIT PROPAGATION

Zachary Folcik, MIT Lincoln Laboratory; Paul Cefola, University at Buffalo, State University of New York

Time differences and solar, lunar, and planetary (SLP) ephemeris files are used in precision orbit determination applications. The GTDS program uses polynomial approximations to represent the time differences between the atomic, UTC, and UT1 time systems. Polynomial approximations also are used to represent the SLP ephemerides and precession and nutation rotation matrices. These approximations reduce storage and runtime for orbit propagation. Previously, representation of 50 years of timing and third body positional data has been demonstrated. The current work reproduces the timing coefficient and SLP files using a Linux version of the TRAMP program and extends the time duration to 200 years.

16:50 AAS 17-683 POISSON-DARBOUX PROBLEM'S EXTENDED IN DUAL LIE ALGEBRA

Daniel Condurache, Technical University of Iasi

This main goal of this research is the development of a new approach of Poisson-Darboux problem solution in dual Lie algebra. Using the ismorphism between the Lie group of the rigid displacements and Lie group of the orthogonal dual tensors, a closed form solution of the problem is given by recovering the rigid motion knowing its twist. The solution is the replica of the classical Poisson-Darboux problem in the algebra of dual numbers. The results are applied for giving a representation theorem of the six degrees of freedom relative orbital motion problem, using the n-th order Cayley transformation.

17:10 **AAS 17-780** **Using Spherical Harmonics to Model Solar Radiation Pressure Accelerations**

Ariadna Farres, University of Barcelona; David Folta, NASA Goddard Space Flight Center; Cassandra Webster, NASA Goddard Space Flight Center

Solar Radiation Pressure (SRP) is the acceleration produced by the impact of the Sun light photons on the surface of a satellite. The incident photons are absorbed and reflected by the different components on its surface, where the rate of absorption and reflection depends on the properties of the surface material. The acceleration produced by SRP plays an important role on Libration Point orbits and interplanetary trajectories. In this paper we introduce an alternative way to obtain high fidelity models for the SRP acceleration using a Spherical Harmonic approximation.

Session 26: Special Session: Human Missions Beyond Earth Orbit

Aug 24, 2017 Stevenson B

26 Special Session: Human Missions Beyond Earth Orbit

Co Chair: Raymond Merrill

13:40 **AAS 17-652** **Low-Thrust Trajectory Maps (Bacon Plots) to Support a Human Mars Surface Expedition**

Ryan Woolley, NASA / Caltech JPL; Damon Landau, NASA / JPL; John Baker, Jet Propulsion Lab; Kevin Post, The Boeing Company

Planning the logistics of multiple launches to support a Mars surface expedition requires good trajectory design tools. Traditional ballistic transfers are well characterized by performance maps known as porkchop plots. However, the transportation of cargo can benefit from the use of low-thrust solar electric propulsion, both in terms of mass delivered and the flexibility of flight durations and dates. This paper describes the design and use of bacon plots (the low-thrust analog to porkchop plots) and their application to the architectural design of a human Mars surface expedition.

14:00 AAS 17-826 Stationkeeping and Transfer Trajectory Design for Spacecraft in Cislunar Space

Diane Davis, a.i. solutions, Inc.; Sean Phillips; Kathleen Howell, Purdue University; Srianish Vutukuri, Purdue University; Brian McCarthy

NASA's Deep Space Gateway (DSG) will serve as a staging orbit for human missions beyond the Earth-Moon system and a proving ground for inhabited deep space flight. With a Near Rectilinear Halo Orbit (NRHO) serving as its primary long-term orbit, the DSG is planned to execute excursions to other destinations in cislunar space. Characterized by complex multibody dynamics, the orbits under consideration present various design challenges. The current study explores the cost of stationkeeping the primary and destination orbits and employs Poincaré maps in a visual design process for preliminary transfer design between candidate orbits in cislunar space.

14:20 AAS 17-577 Low Excess Speed Triple Cyclers of Venus, Earth, and Mars

Drew Jones, Jet Propulsion Laboratory, Caltech; Sonia Hernandez, Jet Propulsion Laboratory; Mark Jesick, Jet Propulsion Laboratory

Ballistic cycler trajectories that repeatedly encounter Earth and Mars, could enhance the feasibility of a human Mars transportation architecture. Triple cyclers involving flybys of Venus, Earth, and Mars are computed and analyzed for the first time. The cycler trajectories are constructed to yield low excess speed for Earth-Mars transit legs, and therefore reduce the cost of hyperbolic rendezvous. Numerous solutions are identified with average transit leg excess speed below 5 km/sec, independent of encounter epoch. The energy characteristics are lower than previously documented cyclers not involving Venus, but the repeat periods are generally longer.

14:40 AAS 17-630 Single-Cycler Trajectories for Mars Exploration

Buzz Aldrin; Brian Kaplinger, Florida Institute of Technology; Anthony Genova, NASA; Robert Potter, Purdue University; Alec Mudek, Purdue University; Archit Arora, Purdue University; Sarag Saikia, School of Aeronautics and Astronautics, Puurdue University; James Longuski, Purdue University

This paper presents several options for Earth-Mars cycling trajectories that could be conducted using a single cycler vehicle. Current cycling architectures propose at least two vehicles in order to ensure both short Earth-Mars and Mars-Earth deep space travel time. The options presented include both countable ballistic solutions as well as continuous families of ballistic solutions. Representative trajectories from the initial ballistic and near-ballistic solution sets from a circular-coplanar model are demonstrated under higher fidelity dynamics, and a mission architecture utilizing this type of trajectory is proposed.

15:00 AAS 17-648 Hyperbolic Abort Options for Human Missions to Mars

Paul Witsberger, Purdue University; Buzz Aldrin; Robert Potter, Purdue University; Archit Arora, Purdue University; James Millance, Purdue University; Sarag Saikia, School of Aeronautics and Astronautics, Puurdue University; Brian Kaplinger, Florida Institute of Technology; James Longuski, Purdue University

Cycler trajectories have become an important component of Earth-to-Mars transportation systems. A salient feature of such trajectories is the necessity of achieving hyperbolic rendezvous, a requirement that if not met can result in loss-of-crew. The concept of hyperbolic rendezvous has been met with skepticism. In this paper, we review standard methods for hyperbolic rendezvous and introduce some new approaches that allow for improved abort options. The abort options considered also apply to human missions to Mars that do not involve cycler trajectories.

15:20 BREAK

15:50 AAS 17-586 Operational Aspects and Low Thrust Transfers for Human-Robotic Exploration Architectures in the Earth-Moon System and Beyond

Florian Renk, European Space Agency; Markus Landgraf, European Space Agency; Max Rödelsperger, Technische Universität Darmstadt

In the frame of the International Space Exploration Coordination Working Group the European Space Agency is participating in the planning of future exploration architectures. While many orbit types in the Earth-Moon system as well as the associated transfer scenarios are well studied from a theoretical point of view, this paper will focus on the operational aspects. Since the initial exploration hub will only be man-tended, the transfers between different orbits are not required to be fast, but the hub can use solar electric propulsion (SEP) for the orbit manoeuvres to reduce the required propellant mass and thus reduce logistic costs.

16:10 AAS 17-643 Navigation Design and Analysis for the Orion Exploration Mission 2

Christopher D'Souza, NASA - Johnson Space Center; Renato Zanetti, The University of Texas at Austin

This paper will detail the navigation and dispersion design and analysis of the first Orion crewed mission. The optical navigation measurement model will be described. The vehicle noise includes the residual acceleration from attitude deadbanding, attitude maneuvers, CO2 venting, waste-water venting, ammonia sublimator venting and solar radiation pressure. The maneuver execution errors account for the contribution of accelerometer scale-factor on the accuracy of the maneuver execution. Particular attention will be paid to the accuracy of the delivery at Earth Entry Interface and at the Lunar Flyby.

CONFERENCE ATTENDEE PLANNING TOOL: MONDAY

Monday, August 21, 2017

Session	Room	Doc. #	Presenter		Title
01 Poster Session	Stevenson Ballroom	AAS 17-680	Alessandra Ferreira	-	USING TETHERS TO BUILD A “CAPTURE PORTAL” FOR THE PLANETS
01 Poster Session	Stevenson Ballroom	AAS 17-674	Elfego Pinon	-	Improvements to a Hierarchical Mixture of Experts System Used for Characterization of Resident Space Objects
01 Poster Session	Stevenson Ballroom	AAS 17-671	Robert Potter	-	Features and Characteristics of Earth-Mars Bacon Plots
01 Poster Session	Stevenson Ballroom	AAS 17-560	Dongxia Wang	-	Error suppression data processing method on Inter-satellite link measurement
01 Poster Session	Stevenson Ballroom	AAS 17-562	Dongxia Wang	-	Research on fault diagnosis and fault-tolerant technology for GNSS navigation satellites
01 Poster Session	Stevenson Ballroom	AAS 17-578	Robert Haw	-	Navigation Automation for the Soil Moisture Active Passive Observatory
01 Poster Session	Stevenson Ballroom	AAS 17-583	Melissa McGuire	-	Low Thrust Cis-Lunar Transfers using a 40 kW-Class Solar Electric Propulsion (SEP) Spacecraft
01 Poster Session	Stevenson Ballroom	AAS 17-585	Melissa McGuire	-	Overview of the Mission Design Reference Trajectory for NASA’s Asteroid Redirect Robotic Mission (ARRM)
01 Poster Session	Stevenson Ballroom	AAS 17-594	Changxuan Wen	-	A Volumetric Integral Based Method of Calculating Satellites Collision Probability for Long-term Encounters
01 Poster Session	Stevenson Ballroom	AAS 17-620	Liam Smith	-	Engagement Heuristics for Optimizing the Effect of Ground Based Lasers on Orbital Debris in LEO
01 Poster Session	Stevenson Ballroom	AAS 17-632	Dale Stanbridge	-	LUCY: NAVIGATING A JUPITER TROJAN TOUR
01 Poster Session	Stevenson Ballroom	AAS 17-700	Florent Deleflie	-	Analytical and statistical characterizations of the long term behavior of a cloud of debris generated by a break-up in orbit.
01 Poster Session	Stevenson Ballroom	AAS 17-702	Yoola Hwang	-	ANALYSIS OF GEOSTATIONARY SATELLITE CONJUNCTION MONITORING
01 Poster Session	Stevenson Ballroom	AAS 17-717	Chong Sun	-	The space debris revolution chaos analysis and the low-cost disposal strategy design
01 Poster Session	Stevenson Ballroom	AAS 17-719	hengwang zhao	-	Binocular Vision Observation Based Accuracy Position and Pose Calculation for Space Station Accompanying Satellite
01 Poster Session	Stevenson Ballroom	AAS 17-735	Geraldo Magela Couto Oliveira	-	DETERMINING LOCATIONS AND TRANSFERS OF ARTIFICIAL EQUILIBRIUM POINTS IN A DOUBLE ASTEROID SYSTEM
01 Poster Session	Stevenson Ballroom	AAS 17-751	Antonio Fernando Bertachini Prado	-	Dynamics of Space Tether on Binary Asteroids

01 Poster Session	Stevenson Ballroom	AAS 17-752	Antonio Fernando Bertachini Prado	-	IMPULSIVE AERO-GRAVITY ASSISTED MANEUVERS IN VENUS AND MARS TO CHANGE THE INCLINATION OF A SPACECRAFT
01 Poster Session	Stevenson Ballroom	AAS 17-764	José Silva Neto	-	ON THE USE OF SOLAR RADIATION PRESSURE TO EJECT A SPACECRAFT ORBITING THE ASTEROID 65803 DIDYMOS (1996 GT)
01 Poster Session	Stevenson Ballroom	AAS 17-769	Bryan Little	-	COMPARISON OF OPTIMIZERS FOR GROUND BASED AND SPACE BASED SURVEY SENSORS
01 Poster Session	Stevenson Ballroom	AAS 17-772	Christoph Bamann	-	Orbit Prediction Uncertainty of Space Debris due to Drag Model Errors
01 Poster Session	Stevenson Ballroom	AAS 17-805	Robyn Woollands	-	Minimum-Time Low Thrust Orbit Transfers using the Method of Particular Solutions and Integral Collocation
02 Student Design Competition	Stevenson Ballroom x2	AAS 17-765	Ashton Meginnis	-	Affordable Missions to Asteroid HO3 2016
02 Student Design Competition	Stevenson Ballroom x2	AAS 17-621	Andrew Goodyear	-	The Astrodynamics Research Group of Penn State (ARGoPS) Solution to the 2017 Astrodynamics Specialist Conference Student Competition
02 Student Design Competition	Stevenson Ballroom x2	AAS 17-744	Chandrakanth Venigalla	-	A CU Boulder Team for the first AAS/AIAA Student Design Competition
02 Student Design Competition	Stevenson Ballroom x2	AAS 17-754	Jigisha Sampat	-	AIAA/AAS Student Design Competition - UIUC (WIA) Team
02 Student Design Competition	Stevenson Ballroom x2	AAS 17-770	Matthew Heacock	-	SPACECRAFT AND MISSION DESIGN TO ASTERIOD (469219) 2016 HO3 EARTH'S NEWLY DISCOVERED "QUASI-SATELLITE" MOON
02 Student Design Competition	Stevenson Ballroom x2	AAS 17-817	Paul Witsberger	-	Near-Earth Asteroid Survey Mission Trajectory and Spacecraft Design
02 Student Design Competition	Stevenson Ballroom x2	AAS 17-820	Nikunj Patel	-	MISSION AND SPACECRAFT DESIGN TO ASTEROID (469219) 2016 HO3
02 Student Design Competition	Stevenson Ballroom x2	AAS 17-829	Mark Moretto	-	Proposed Mission to Characterize Asteroid (469219) 2016 HO3
02 Student Design Competition	Stevenson Ballroom x2	AAS 17-843	Brian Kaplinger	-	Student Competition Intent - Florida Tech

02 Student Design Competition	Stevenson Ballroom x2	AAS 17-846	Kristofer Drozd	-	Spacecraft and Mission Design to Asteroid (469219) 2016 HO3 Abstract

CONFERENCE ATTENDEE PLANNING TOOL: TUESDAY

Tuesday, August 22, 2017

Session	Room	Doc. #	Presenter		Title
03 Attitude Control I	Cascade A	AAS 17-571	Byoungsam (Andy) Woo	8:00 - 8:20	POINTING JITTER CHARACTERIZATION FOR VARIOUS SSL 1300 SPACECRAFTS WITH SIMULATIONS AND ON-ORBIT MEASUREMEN
04 Low-Thrust Trajectory Design	Stevenson C/D	AAS 17-803	RENYONG ZHANG	8:00 - 8:20	Shape-Based Approach Based on Fast Numerical Approximation of Invariant Manifolds for Cislunar Low-Energy Low-Thrust Trajectories Transfer
05 Space Situational Awareness	Stevenson B	AAS 17-550	Brian Hansen	8:00 - 8:20	Debris Cloud Containment Boundary Anomaly
06 Trajectory Design	Stevenson A	AAS 17-749	Lorenzo Casalino	8:00 - 8:20	Design of Lunar-Gravity-Assisted Escape Maneuvers
03 Attitude Control I	Cascade A	AAS 17-622	Li Jinyue	8:20 - 8:40	Decentralized finite-time attitude control for multi-body system with terminal sliding mode
04 Low-Thrust Trajectory Design	Stevenson C/D	AAS 17-609	Nicholas Bradley	8:20 - 8:40	Characteristics of Energy-Optimal Spiraling Low-thrust Escape Trajectories
05 Space Situational Awareness	Stevenson B	AAS 17-568	Eric Eiler	8:20 - 8:40	Improved Reentry Predictions with High Fidelity Models
06 Trajectory Design	Stevenson A	AAS 17-694	Ricardo Restrepo	8:20 - 8:40	A Database of Planar Axi-Symmetric Periodic Orbits for the Solar System

03 Attitude Control I	Cascade A	AAS 17-646	Jianzhong Zhu	8:40 - 9:00	LOCAL ITERATIVE LEARNING CONTROL DESIGN
04 Low-Thrust Trajectory Design	Stevenson C/D	AAS 17-832	Nathan Parrish	8:40 - 9:00	Efficient Low Thrust Trajectory Optimization in CRTBP with Human-in-the-Loop
05 Space Situational Awareness	Stevenson B	AAS 17-592	Waqar Zaidi	8:40 - 9:00	Debris Object Orbit Initialization using the Probabilistic Admissible Region with Asynchronous Heterogeneous Observations
06 Trajectory Design	Stevenson A	AAS 17-604	Paul Thompson	8:40 - 9:00	Solar Probe Plus Navigation: One Year From Launch
03 Attitude Control I	Cascade A	AAS 17-656	Tianyi Zhang	9:00 - 9:20	ON THE RANGE OF DIFFICULTIES PRODUCED BY SAMPLING ZEROS IN DESIGNING REPETITIVE CONTROL COMPENSTORS
04 Low-Thrust Trajectory Design	Stevenson C/D	AAS 17-766	Jonathan Aziz	9:00 - 9:20	Improvements to Sundman-Transformed HDDP Through Modified Equinoctial Elements
05 Space Situational Awareness	Stevenson B	AAS 17-639	Weston Faber	9:00 - 9:20	Optical Data Association In a Multi-Hypothesis Framework With Maneuvers
06 Trajectory Design	Stevenson A	AAS 17-631	Powtawche Valerino	9:00 - 9:20	Flight Path Control Analysis for Parker Solar Probe
03 Attitude Control I	Cascade A	AAS 17-657	Chao Sheng	9:20 - 9:40	DYNAMIC CHARACTERISTICS AND PERFORMANCES ANALYSIS OF THE MAGNETIC SUSPENSION VIBRATION ISOLATION SYSTEM
04 Low-Thrust Trajectory Design	Stevenson C/D	AAS 17-623	Javier Roa	9:20 - 9:40	Semi-analytic preliminary design of low-thrust missions
05 Space Situational Awareness	Stevenson B	AAS 17-745	Islam Hussein	9:20 - 9:40	The performance of a direction-based Bayesian filter in the orbital tracking problem
06 Trajectory Design	Stevenson A	AAS 17-776	Daniel Grebow	9:20 - 9:40	MColl: Monte Collocation Trajectory Design Tool

BREAK 9:40 - 10:10

03 Attitude Control I	Cascade A	AAS 17-681	Xiaoqiang Ji	10:10 - 10:30	Proof of a New Stable Inverse of Discrete Time Systems
04 Low-Thrust Trajectory Design	Stevenson C/D	AAS 17-727	Ran Zhang	10:10 - 10:30	Trajectory tracking guidance for low-thrust geosynchronous orbit insertion using piecewise constant control
05 Space Situational Awareness	Stevenson B	AAS 17-808	Richard Linares	10:10 - 10:30	Maneuvering Detection and Prediction using Inverse Reinforcement Learning for Space Situational Awareness

06 Trajectory Design	Stevenson A	AAS 17-588	Gregory Henning	10:10 - 10:30	A HIGH EARTH, LUNAR RESONANT ORBIT FOR SPACE SCIENCE MISSIONS
03 Attitude Control I	Cascade A	AAS 17-686	Dong-Hyun Cho	10:30 - 10:50	Improved Detumbling Control for Cubesat by using MEMS Gyro
04 Low-Thrust Trajectory Design	Stevenson C/D	AAS 17-626	Robert Pritchett	10:30 - 10:50	Low-Thrust Transfer Design Based on Collocation Techniques: Applications in the Restricted Three-Body Problem
05 Space Situational Awareness	Stevenson B	AAS 17-809	Manoranjan Majji	10:30 - 10:50	CONJUGATE UNSCENTED TRANSFORM BASED JOINT PROBABILITY DATA ASSOCIATION
06 Trajectory Design	Stevenson A	AAS 17-724	Christopher Spreen	10:30 - 10:50	AUTOMATED NODE PLACEMENT CAPABILITY FOR SPACECRAFT TRAJECTORY TARGETING USING HIGHER-ORDER STATE TRANSITION MATRICES
03 Attitude Control I	Cascade A	AAS 17-691	Colin Monk	10:50 - 11:10	Time Optimal Control of a Double Integrator Spacecraft Model With Feedback Dynamics
04 Low-Thrust Trajectory Design	Stevenson C/D	~~AAS 17-729~~	~~Dandan Zheng~~	~~10:50 - 11:10~~	~~SHAPE-BASED TRAJECTORY DESIGN OF LOW THRUST TO L1 HALO ORBIT OF EARTH-MOON SYSTEM~~
05 Space Situational Awareness	Stevenson B	AAS 17-830	Ryan Coder	10:50 - 11:10	Modern Differential Photometry Using Small Telescopes
06 Trajectory Design	Stevenson A	AAS 17-675	Mark Karpenko	10:50 - 11:10	SCALING AND BALANCING FOR FASTER TRAJECTORY OPTIMIZATION
03 Attitude Control I	Cascade A	AAS 17-730	John Alcorn	11:10 - 11:30	Fully-Coupled Dynamical Jitter Modeling of Variable-Speed Control Moment Gyroscopes
04 Low-Thrust Trajectory Design	Stevenson C/D	AAS 17-740	Roberto Furfaro	11:10 - 11:30	Waypoint-based ZEM/ZEV Feedback Guidance: Applications to Low-thrust Interplanetary Transfer and Orbit Raising
05 Space Situational Awareness	Stevenson B	AAS 17-737	Liam Healy	11:10 - 11:30	Estimation of untracked geosynchronous population from short-arc angles-only observations
06 Trajectory Design	Stevenson A	AAS 17-842	Nitin Arora	11:10 - 11:30	Space and Time Continuous Algorithm for Fast Trajectory Optimization
04 Low-Thrust Trajectory Design	Stevenson C/D	AAS 17-757	Bindu Jagannatha	11:30 - 11:50	Exploration of Low-thrust Trajectories to Earth-Moon Halo Orbits

05 Space Situational Awareness	Stevenson B	AAS 17-792	Carolin Frueh	11:30 - 11:50	Fusing Survey and Follow-up for SSA Sensor Tasking
06 Trajectory Design	Stevenson A	AAS 17-828	RENYONG ZHANG	11:30 - 11:50	Orbit Design Method Research on Transfer to the Retrograde GEO Orbit by Lunar Gravity Assist for Spacecraft

04 Low-Thrust Trajectory Design	Stevenson C/D	AAS 17-748	Lorenzo Casalino	11:50 - 12:10	Optimal Power Partitioning for Electric Thrusters
05 Space Situational Awareness	Stevenson B	AAS 17-600	Daniel Oltrogge	11:50 - 12:10	Application of New Debris Risk Evolution And Dissipation (DREAD) Tool to Characterize Post-Fragmentation Risk
06 Trajectory Design	Stevenson A	AAS 17-790	Pradipto Ghosh	11:50 - 12:10	Approximate-optimal Feedback Guidance For Soft Lunar Landing Using Gaussian Process Regression

07 Advances in Spacecraft Design	Stevenson B	AAS 17-734	Josep Virgili-Llop	13:40 - 14:00	LABORATORY EXPERIMENTS ON THE CAPTURE OF A TUMBLING OBJECT BY A SPACECRAFT-MANIPULATOR SYSTEM USING A CONVEX-PROGRAMMING-BASED GUIDANCE
08 Attitude Control II	Cascade A	AAS 17-615	Minh Phan	13:40 - 14:00	Model Predictive Control and Model Predictive Q-Learning for Structural Vibration Control
09 Collision Avoidance	Stevenson C/D	AAS 17-556	Darrel Conway	13:40 - 14:00	A Monte-Carlo Study of Conjunction Analysis Using Paramat
10 Planetary Exploration	Stevenson A	AAS 17-608	Sonia Hernandez	13:40 - 14:00	Families of Io-Europa-Ganymede Triple Cyclers

07 Advances in Spacecraft Design	Stevenson B	AAS 17-747	JoAnna Fulton	14:00 - 14:20	Dynamic Modeling of Folded Deployable Space Structures With Flexible Hinges
08 Attitude Control II	Cascade A	AAS 17-670	Wenxiang Zhou	14:00 - 14:20	ZERO LOCATIONS IN DISCRETE-TIME NON-MINIMUM PHASE SYSTEMS AS A FUNCTION OF SAMPLE RATE
09 Collision Avoidance	Stevenson C/D	AAS 17-559	Matthew Hejduk	14:00 - 14:20	Conjunction Assessment Screening Volume Sizing and Event Filtering in light of Natural Conjunction Event Development Behaviors
10 Planetary Exploration	Stevenson A	AAS 17-699	Jeff Parker	14:00 - 14:20	Mission Design for the Emirates Mars Mission

07 Advances in Spacecraft Design	Stevenson B	AAS 17-797	Vishwa Shah	14:20 - 14:40	Cis-Lunar Mission Design for Small-Sats
08 Attitude Control II	Cascade A	AAS 17-774	Harleigh Marsh	14:20 - 14:40	Minimum-Power Attitude Steering
09 Collision Avoidance	Stevenson C/D	AAS 17-567	Doyle Hall	14:20 - 14:40	Remediating Non-Positive Definite State Covariainces for Collision Probability Estimation
10 Planetary Exploration	Stevenson A	AAS 17-728	Alec Mudek	14:20 - 14:40	A Catalog of Gravity-Assist Trajectories to Uranus for Launch Dates from 2023 to 2073
07 Advances in Spacecraft Design	Stevenson B	AAS 17-618	Jordan Maxwell	14:40 - 15:00	Applicability of the Multi-Sphere Method to Flexible One-Dimensional Conducting Structures
08 Attitude Control II	Cascade A	AAS 17-775	Alen Golpashin	14:40 - 15:00	Stochastic Attitude Control of Spacecraft under Thrust Uncertainty
09 Collision Avoidance	Stevenson C/D	AAS 17-582	William Wiesel	14:40 - 15:00	Stochastic Dynamics of and Collision Prediction for Low Altitude Earth Satellites
10 Planetary Exploration	Stevenson A	AAS 17-651	James Moore	14:40 - 15:00	A Tool for Identifying Key Gravity-Assist Trajectories from Broad Search Results
07 Advances in Spacecraft Design	Stevenson B	AAS 17-636	Yu Nakajima	15:00 - 15:20	Stabilization Methodology of Tethered Space Tug Using Electrical Propulsion System
08 Attitude Control II	Cascade A	AAS 17-806	Puneet Singla	15:00 - 15:20	A Sparse Collocation Approach for Optimal Feedback Control for Spacecraft Attitude Maneuvers
09 Collision Avoidance	Stevenson C/D	AAS 17-590	Kwangwon Lee	15:00 - 15:20	Optimal collision avoidance maneuvers for spacecraft proximity operations via discrete-time Hamilton-Jacobi theory
10 Planetary Exploration	Stevenson A	AAS 17-777	Brenton Ho	15:00 - 15:20	LOW-COST OPPORTUNITY FOR MULTIPLE TRANS-NEPTUNIAN OBJECT RENDEZVOUS AND CAPTURE - “CERBERUS”

BREAK 15:20 - 15:50

07 Advances in Spacecraft Design	Stevenson B	~~AAS 17-638~~	~~Xuan Jin~~	~~15:50 - 16:10~~	~~RESEARCH ON DYNAMIC CHARACTERISTICS AND CONTROL SCHEME OF LOX/KEROSENE SPACE PROPULSION SYSTEM FOR ORBIT CONTROL~~
08 Attitude Control II	Cascade A	AAS 17-816	Kaushik Basu	15:50 - 16:10	Time-Optimal Reorientation using Neural Network and Particle Swarm Formulation
09 Collision Avoidance	Stevenson C/D	AAS 17-614	Russell Carpenter	15:50 - 16:10	Relevance of the American Statistical Society's Warning on p-Values for Conjunction Assessment
10 Planetary Exploration	Stevenson A	AAS 17-804	Braxton Brakefield	15:50 - 16:10	Enceladus Sample Return Mission
07 Advances in Spacecraft Design	Stevenson B	AAS 17-706	Dario Modenini	16:10 - 16:30	OPTIMAL BLADE PITCH PROFILE FOR AN AUTOROTATIVE ENTRY VEHICLE
08 Attitude Control II	Cascade A	AAS 17-819	Ozan Tekinalp	16:10 - 16:30	EFFECTS OF ROTOR GEOMERY ON THE PERFORMANCE OF VIBRATING MASS CONTROL MOMENT GYRPOSCOPES
09 Collision Avoidance	Stevenson C/D	AAS 17-650	Barbara Braun	16:10 - 16:30	The Evolution of Secondary Object Position in 18SCS Conjunction Data Messages
10 Planetary Exploration	Stevenson A	AAS 17-696	Michel Loucks	16:10 - 16:30	Practical Methodologies for Low Delta-V Penalty, On-Time Departures to Arbitrary Interplanetary Destinations from a Medium-Inclination Low-Earth Orbit Depot
07 Advances in Spacecraft Design	Stevenson B	AAS 17-722	George Zhu	16:30 - 16:50	Parametric Study of Electron Collection Efficiency of Curved Electrodynamic Tethers
09 Collision Avoidance	Stevenson C/D	AAS 17-703	Marc Balducci	16:30 - 16:50	Maneuver Optimization and Collision Probability Estimation Using Separated Representations
10 Planetary Exploration	Stevenson A	AAS 17-847	Min Qu	16:30 - 16:50	Optimizing Parking Orbits for Roundtrip Mars Missions
07 Advances in Spacecraft Design	Stevenson B	AAS 17-725	Tingting Sui	16:50 - 17:10	design of obstacle avoiding in high tracking accuracy for spatial manipulator
09 Collision Avoidance	Stevenson C/D	AAS 17-782	Jorge Nascimento	16:50 - 17:10	REDUCING THE RISK OF SPACE DEBRIS COLLISIONS USING CONDITIONS FOR PERFORMANCE SIMULTANEOUS OPERATIONS IN MINIMUM TIME.
10 Planetary Exploration	Stevenson A	AAS 17-708	Eiji Shibata	16:50 - 17:10	Robust Miniature Probes for Expanded Atmospheric Planetary Exploration

07 Advances in Spacecraft Design	Stevenson B	AAS 17-726	George Zhu	17:10 - 17:30	CubeSat Deorbit Mission Using an Electrodynamic Tether
10 Planetary Exploration	Stevenson A	AAS 17-849	Kamesh Subbarao	17:10 - 17:30	PATH PLANNING AND CONTROL USING STATE DEPENDENT NAVIGATION FUNCTIONS FOR PLANETARY ROVERS
07 Advances in Spacecraft Design	Stevenson B	AAS 17-824	Go Ono	17:30 - 17:50	Stability Analysis of Generalized Sail Dynamics Model

CONFERENCE ATTENDEE PLANNING TOOL: WEDNESDAY

Wednesday, August 23, 2017

Session	Room	Doc. #	Presenter		Title
11 Attitude Estimation	Cascade A	AAS 17-845	Sung-Woo Kim	8:00 - 8:20	Attitude Estimation and Control of Spacecraft in Formation Flying Using Relative Measurement on Earth Magnetic Field and SDRE-Based Neuro-Fuzzy Controller
12 Orbital Dynamics	Stevenson A	AAS 17-572	Francisco Crespo	8:00 - 8:20	CRITICAL INCLINATIONS FOR THE ROTO-ORBITAL DYNAMICS OF A RIGID BODY AROUND A SPHERE
13 Small Body Exploration	Stevenson C/D	AAS 17-662	Brian Kaplinger	8:00 - 8:20	Selected Trajectory Options to 2016 HO3
14 Special Session: Outer Planet Exploration	Stevenson B	AAS 17-633	Jennie Johannesen	8:00 - 8:20	Initial JOI and PRM Plans for Juno
11 Attitude Estimation	Cascade A	AAS 17-673	Hélio Kuga	8:20 - 8:40	SPACECRAFT ATTITUDE ESTIMATION USING UNSCENTED KALMAN FILTERS, REGULARIZED PARTICLE FILTER AND EXTENDED H INFINITY FILTER
12 Orbital Dynamics	Stevenson A	AAS 17-579	Weston Faber	8:20 - 8:40	Application of Multi-Hypothesis Sequential Monte Carlo for Breakup Analysis
13 Small Body Exploration	Stevenson C/D	AAS 17-731	Brian Gunter	8:20 - 8:40	Orbit Design for a Phobos-Deimos Cycler Mission
14 Special Session: Outer Planet Exploration	Stevenson B	AAS 17-573	Thomas Pavlak	8:20 - 8:40	Juno Trajectory Redesign Following PRM Cancellation

11 Attitude Estimation	Cascade A	AAS 17-554	Erik Hogan	8:40 - 9:00	Treatment of Measurement Variance for Star Tracker-Based Attitude Estimation
12 Orbital Dynamics	Stevenson A	AAS 17-613	Javier Roa	8:40 - 9:00	A new concept of stability in orbit propagation, useful for quantifying numerical errors
13 Small Body Exploration	Stevenson C/D	AAS 17-640	Alena Probst	8:40 - 9:00	Optimization Process of Target Selection for Multiple Asteroid Encounters in the Main Belt
14 Special Session: Outer Planet Exploration	Stevenson B	AAS 17-564	Thomas Pavlak	8:40 - 9:00	Maneuver Operations During Juno's Approach, Orbit Insertion, and Early Orbit Phase
11 Attitude Estimation	Cascade A	AAS 17-591	Julie Halverson	9:00 - 9:20	Tuning the Solar Dynamics Observatory Onboard Kalman Filter
12 Orbital Dynamics	Stevenson A	AAS 17-659	Ashley Biria	9:00 - 9:20	Analytical State Propagation of Oblate Spheroidal Equinoctial Orbital Elements for Vinti Theory
13 Small Body Exploration	Stevenson C/D	AAS 17-698	Pablo Machuca	9:00 - 9:20	Robust Optimization of Descent Trajectories on Irregular-Shaped Bodies in the Presence of Uncertainty
14 Special Session: Outer Planet Exploration	Stevenson B	AAS 17-595	Shadan Ardalan	9:00 - 9:20	Juno Orbit Determination Experience During First Year At Jupiter
11 Attitude Estimation	Cascade A	AAS 17-637	Halil Ersin Soken	9:20 - 9:40	ADVANCED ATTITUDE DETERMINATION ALGORITHM FOR ARASE: PRELIMINARY MISSION EXPERIENCE
12 Orbital Dynamics	Stevenson A	AAS 17-581	Richard Linares	9:20 - 9:40	A methodology for reduced order modeling and calibration of the upper atmosphere
13 Small Body Exploration	Stevenson C/D	AAS 17-721	Benjamin Villac	9:20 - 9:40	EVALUATION OF A RAPID TRANSFER DESIGN APPROACH FOR SMALL BODY APPLICATIONS
14 Special Session: Outer Planet Exploration	Stevenson B	AAS 17-714	Arnaud Boutonnet	9:20 - 9:40	JUICE: When Navigation DeltaV Cost is Reduced via Tour Redesign

BREAK 9:40 - 10:10

11 Attitude Estimation	Cascade A	AAS 17-723	Divya Bhatia	10:10 - 10:30	SPACECRAFT HIGH ACCURACY ATTITUDE ESTIMATION:PERFORMANCE COMPARISON OF QUATERNION BASED EKF, UF AND PF
12 Orbital Dynamics	Stevenson A	AAS 17-628	Alan Jenkin	10:10 - 10:30	Orbital Lifetime and Collision Risk Reduction for Tundra Disposal Orbits
13 Small Body Exploration	Stevenson C/D	AAS 17-584	Kristen Tetreault	10:10 - 10:30	Investigation of transfers to stable spacecraft orbits in a CR3BP model of a binary asteroid system
14 Special Session: Outer Planet Exploration	Stevenson B	AAS 17-596	Sean Wagner	10:10 - 10:30	Cassini Maneuver Experience Through the Final Targeted Titan Flyby and the Grand Finale

11 Attitude Estimation	Cascade A	AAS 17-767	Dario Spiller	10:30 - 10:50	Inverse Dynamics Particle Swarm Optimization Applied to Bolza Problems
12 Orbital Dynamics	Stevenson A	AAS 17-553	William Wiesel	10:30 - 10:50	A KAM Tori Algorithm for Earth Satellite Orbits
13 Small Body Exploration	Stevenson C/D	AAS 17-762	Diogo Sanchez	10:30 - 10:50	On the use of Mean Motion Resonances to explore the Haumea System
14 Special Session: Outer Planet Exploration	Stevenson B	AAS 17-625	Kevin Criddle	10:30 - 10:50	OPTICAL NAVIGATION THROUGH CASSINI'S SOLSTICE MISSION

12 Orbital Dynamics	Stevenson A	AAS 17-756	Dayung Koh	10:50 - 11:10	Cell Mapping Orbit Search for Mission Design at Ocean Worlds Using Parallel Computing

12 Orbital Dynamics	Stevenson A	AAS 17-827	John Junkins	11:10 - 11:30	Accelerated Picard-Chebyshev Integration with Error Feedback and Adaptive Segmentation

15 Earth Orbiters	Stevenson A	AAS 17-692	Aaron Brown	13:40 - 14:00	Constrained Burn Optimization for the International Space Station
16 Orbit Determination	Cascade A	AAS 17-750	Todd Ely	13:40 - 14:00	Batch Sequential Estimation with Non-Uniform Measurements and Non-Stationary Noise
17 Small Body Modeling	Stevenson C/D	AAS 17-557	James Miller	13:40 - 14:00	A Comparison of Gravity Models used for Navigation Near Small Bodies
18 Special Session: Constrained Global Trajectory Optimization	Stevenson B	AAS 17-598	Arnold Englander	13:40 - 14:00	Walking the Filament of Feasibility: Global Optimization of Highly-Constrained, Multi-Modal Interplanetary Trajectories Using a Novel Stochastic Search Technique

15 Earth Orbiters	Stevenson A	AAS 17-818	DAVID MORANTE	14:00 - 14:20	Multiobjective Trajectory Optimization during Orbit Raising with Combined Chemical-Electric Propulsion
16 Orbit Determination	Cascade A	AAS 17-755	Mark Psiaki	14:00 - 14:20	GAUSSIAN MIXTURE KALMAN FILTER FOR ORBIT DETERMINATION USING ANGLES-ONLY DATA

17 Small Body Modeling	Stevenson C/D	AAS 17-619	Benjamin Bercovici	14:00 - 14:20	Autonomous Shape estimation and navigation about small bodies using Lidar observations
18 Special Session: Constrained Global Trajectory Optimization	Stevenson B	AAS 17-605	Kyle Hughes	14:00 - 14:20	GRAVITY-ASSIST TRAJECTORIES TO THE ICE GIANTS: AN AUTOMATED METHOD TO CATALOG MASS- OR TIME-OPTIMAL SOLUTIONS
15 Earth Orbiters	Stevenson A	AAS 17-635	Sung-Hoon Mok	14:20 - 14:40	Impulsive Orbit Control for Multi-Target Acquisition
16 Orbit Determination	Cascade A	AAS 17-793	Ethan Burnett	14:20 - 14:40	Interpolation on the Unit Sphere in Laplace's Method
17 Small Body Modeling	Stevenson C/D	AAS 17-743	Patrick Wittick	14:20 - 14:40	Mascon Models for Small Body Gravity Fields
18 Special Session: Constrained Global Trajectory Optimization	Stevenson B	AAS 17-654	Matthew Vavrina	14:20 - 14:40	Global, Multi-objective Trajectory Optimization with Parametric Spreading
15 Earth Orbiters	Stevenson A	AAS 17-563	Erik Hogan	14:40 - 15:00	The SSL-100: ADCS & GNC for the Next Generation of Low-Cost, Agile LEO Spacecraft
16 Orbit Determination	Cascade A	AAS 17-794	Andrew Sinclair	14:40 - 15:00	Optimal Linear Orbit Determination
17 Small Body Modeling	Stevenson C/D	AAS 17-763	Jay McMahon	14:40 - 15:00	Improved Gravity Model Performance by using Mixed Fidelity Shape Models for Irregularly Shaped Small Bodies
18 Special Session: Constrained Global Trajectory Optimization	Stevenson B	AAS 17-715	Yuichi Tsuda	14:40 - 15:00	Stochastic Event-Robust Deoptimization Technique for Low Thrust Trajectory Design
15 Earth Orbiters	Stevenson A	AAS 17-778	Theodore H Sweetser	15:00 - 15:20	CloudSat at 11—Now What?
16 Orbit Determination	Cascade A	AAS 17-810	Matt Gualdoni	15:00 - 15:20	AN IMPROVED REPRESENTATION OF MEASUREMENT INFORMATION CONTENT VIA THE DISTRIBUTION OF THE KULLBACK-LEIBLER DIVERGENCE
17 Small Body Modeling	Stevenson C/D	AAS 17-768	Flaviane Venditti	15:00 - 15:20	Modelling asteroids to assist in orbiting and landing missions
18 Special Session: Constrained Global Trajectory Optimization	Stevenson B	AAS 17-785	Ryne Beeson	15:00 - 15:20	Automated Solution of Low Energy Trajectories

BREAK 15:20 - 15:50

15 Earth Orbiters	Stevenson A	AAS 17-779	Theodore H Sweetser	15:50 - 16:10	The Design of the Reference Orbit for NISAR, the NASA-ISRO Synthetic Aperature Radar mission
16 Orbit Determination	Cascade A	AAS 17-815	Christine Schmid	15:50 - 16:10	Minimum Divergence Filtering Using A Polynomial Chaos Expansion
17 Small Body Modeling	Stevenson C/D	AAS 17-658	Stefaan Van wal	15:50 - 16:10	Parallelized small-body lander/hopper simulations with distributed contact and procedural noise
18 Special Session: Constrained Global Trajectory Optimization	Stevenson B	AAS 17-788	Etienne Pellegrini	15:50 - 16:10	Applications of the Multiple-Shooting Differential Dynamic Programming Algorithm with Path and Terminal Constraints
15 Earth Orbiters	Stevenson A	AAS 17-783	Donald Chu	16:10 - 16:30	The GOES In-Situ Geomagnetism Experiment Reimagined
16 Orbit Determination	Cascade A	AAS 17-624	Brad Sease	16:10 - 16:30	Preliminary Analysis of Ground-Based Orbit Determination Accuracy for the Wide Field Infrared Survey Telescope (WFIRST)
17 Small Body Modeling	Stevenson C/D	AAS 17-781	Dante Bolatti	16:10 - 16:30	Practical Galerkin Variational Integrators for Orbital Dynamics About Asteroids
18 Special Session: Constrained Global Trajectory Optimization	Stevenson B	AAS 17-814	Damon Landau	16:10 - 16:30	Fast and Reliable Approximations for Interplanetary Low-Thrust Transfers
15 Earth Orbiters	Stevenson A	AAS 17-796	Kazuaki Ikemoto	16:30 - 16:50	High Altitude Sun-Synchronous Orbits as Solutions of the Circular Restricted Sun-Earth-Moon-Satellite 4-Body Problem
16 Orbit Determination	Cascade A	AAS 17-668	Zhang Zhongkai	16:30 - 16:50	Research and Demonstration of △DOR Tracking by Sparse Calibration
17 Small Body Modeling	Stevenson C/D	AAS 17-823	Shota Kikuchi	16:30 - 16:50	Stability Analysis of Coupled Orbit-Attitude Dynamics around Asteroids Using Finite-Time Lyapunov Exponents
18 Special Session: Constrained Global Trajectory Optimization	Stevenson B	AAS 17-833	Takehiro Koyanagi	16:30 - 16:50	Synthesis of highly inclined and short period solar polar orbit with electric propulsion

15 Earth Orbiters	Steven-son A	AAS 17-713	Florian Wöske	16:50 - 17:10	MODELING OF THERMAL HEATING AND THERMAL RADIATION PRESSURE DUE TO SUN AND ALBEDO WITH APPLICATION TO GRACE ORBIT AND ACCELEROMETER DATA
16 Orbit Determination	Cascade A	AAS 17-647	Krysta Lemm	16:50 - 17:10	COMPARING DOUBLE DIFERENCE GLOBAL NAVIGATION SATELLITE SYSTEMS AT MID LATITUDE
17 Small Body Modeling	Steven-son C/D	AAS 17-825	Ann Dietrich	16:50 - 17:10	Filter Robustness of Flash Lidar Based Navigation Around Small Bodies
18 Special Session: Constrained Global Trajectory Optimization	Steven-son B	AAS 17-837	David Ottesen	16:50 - 17:10	Space Trajectory Optimization using Embedded Boundary Value Problems
17 Small Body Modeling	Steven-son C/D	AAS 17-720	Shankar Kulumani	17:10 - 17:30	Geometric Control for Autonomous Landing on Asteroids
18 Special Session: Constrained Global Trajectory Optimization	Steven-son B	AAS 17-701	Jason Reiter	17:10 - 17:30	Low Thrust Trajectory Optimization Applications to Debris Removal Mission Design

Conference Attendee Planning Tool: Thursday

Thursday, August 24, 2017

Session	Room	Doc. #	Presenter		Title
19 Constellations and Formations	Stevenson C/D	AAS 17-760	Trevor Williams	8:00 - 8:20	Results of the Apogee-Raising Campaign of the Magnetospheric Multiscale Mission
20 Low-Energy Mission Design	Stevenson B	AAS 17-784	Vishwa Shah	8:00 - 8:20	RAPID APPROXIMATION OF INVARIANT MANIFOLDS USING MACHINE LEARNING
21 Relative Motion	Stevenson A	AAS 17-641	Giovanni Franzini	8:00 - 8:20	Relative Motion Equations in the Local-Vertical Local-Horizon Frame for Rendezvous in Lunar Orbits
22 Spacecraft GNC I	Cascade A	AAS 17-576	Drew Jones	8:00 - 8:20	Orbit Determination Covariance Analyses for the Parker Solar Probe Mission
19 Constellations and Formations	Stevenson C/D	AAS 17-661	Osama Mostafa Abdelaziz ALI	8:20 - 8:40	MAINTENANCE OF ORBITAL ELEMENTS OF SATELLITES CONSTELLATIONS IN TUNDRA ORBIT
20 Low-Energy Mission Design	Stevenson B	AAS 17-746	Gaurav Vaibhav	8:20 - 8:40	Trajectory Optimization to the Halo Orbit in Full Force Model using Evolutionary Technique
21 Relative Motion	Stevenson A	AAS 17-688	Bradley Kuiack	8:20 - 8:40	Orbital Element-Based Relative Motion Guidance on J2-Perturbed Eccentric Orbits
22 Spacecraft GNC I	Cascade A	AAS 17-580	Mitra Farahmand	8:20 - 8:40	MAGNETOSPHERIC MULTISCALE MISSION NAVIGATION PERFORMANCE DURING APOGEE-RAISING AND BEYOND
19 Constellations and Formations	Stevenson C/D	AAS 17-607	Sonia Hernandez	8:40 - 9:00	Satellite Constellation Orbit Design to Enable a Space-Based Radio Interferometer
20 Low-Energy Mission Design	Stevenson B	AAS 17-597	Andrew Cox	8:40 - 9:00	Dynamical Structures in a Combined Low-Thrust Multi-Body Environment
21 Relative Motion	Stevenson A	AAS 17-704	Sittiporn Channumsin	8:40 - 9:00	Distributed spacecraft path planning and collision avoidance via reciprocal velocity obstacle approach
22 Spacecraft GNC I	Cascade A	AAS 17-599	Nicholas Bradley	8:40 - 9:00	Optical-based Kinematic Positioning for Deep-Space Navigation

19 Constellations and Formations	Stevenson C/D	AAS 17-761	Giovanni Minelli	9:00 - 9:20	Autonomous Operations of Large-Scale Satellite Constellations and Ground Station Networks
20 Low-Energy Mission Design	Stevenson B	AAS 17-695	Ricardo Restrepo	9:00 - 9:20	Patched Periodic Orbits: A Systematic Strategy for Low Energy Transfer Design
~~21 Relative Motion~~	~~Stevenson A~~	~~AAS 17-736~~	~~Roberto Furfaro~~	~~9:00 - 9:20~~	~~Multiple Sliding Surface Guidance in SE(3) for Autonomous Rendezvous and Docking~~
22 Spacecraft GNC I	Cascade A	AAS 17-660	Adonis Pimienta-Penalver	9:00 - 9:20	Assessing Orbit Determination for a Lunar CubeSat Mission
19 Constellations and Formations	Stevenson C/D	AAS 17-565	Chia-Chun Chao	9:20 - 9:40	Deployment and Control Algorithms for Wheel Cluster Formation Satellites
20 Low-Energy Mission Design	Stevenson B	AAS 17-697	Rodney Anderson	9:20 - 9:40	Computing Libration Point Hyperbolic Invariant Sets Using Isolating Blocks
~~21 Relative Motion~~	~~Stevenson A~~	~~AAS 17-738~~	~~XIAOQING GAO~~	~~9:20 - 9:40~~	~~CONTROL STRATEGIES FOR CONSTRAINED HOVERING ORBITS USING CONTINUOUS CONSTANT LOW-THRUSTS~~
22 Spacecraft GNC I	Cascade A	AAS 17-672	James Miller	9:20 - 9:40	Mathematics used for Deep Space Navigation
BREAK 9:40 - 10:10					
19 Constellations and Formations	Stevenson C/D	AAS 17-601	Stuart Gegenheimer	10:10 - 10:30	Long-Term Stability of Common-Inclination Satellite Clusters
20 Low-Energy Mission Design	Stevenson B	AAS 17-759	Gregory Lantoine	10:10 - 10:30	Efficient NRHO to DRO transfers in cislunar space
21 Relative Motion	Stevenson A	AAS 17-739	Roberto Furfaro	10:10 - 10:30	Waypoint-Optimized Closed-Loop Guidance for Spacecraft Rendezvous in Relative Motion
22 Spacecraft GNC I	Cascade A	AAS 17-684	Stoian Borissov	10:10 - 10:30	Pulsar Navigation: Defining an Upper Bound for Distance From Reference

19 Constellations and Formations	Stevenson C/D	AAS 17-813	Katherine Mott	10:30 - 10:50	Heterogeneous constellation design methodology applied to a Mars-orbiting communications and positioning constellation
20 Low-Energy Mission Design	Stevenson B	AAS 17-653	Natasha Bosanac	10:30 - 10:50	Trajectory Design and Station-Keeping Analysis for the Wide Field Infrared Survey Telescope (WFIRST) Mission
21 Relative Motion	Stevenson A	AAS 17-758	Eric Butcher	10:30 - 10:50	A New Time-Explicit J2-Perturbed Nonlinear Relative Orbit Model with Perturbation Solutions
22 Spacecraft GNC I	Cascade A	AAS 17-667	Zhang Zhongkai	10:30 - 10:50	Fringe Fitting for DOR Tones in geodetic VLBI
20 Low-Energy Mission Design	Stevenson B	AAS 17-587	Florian Renk	10:50 - 11:10	Disposal Investigations for ESA's Sun-Earth Libration Point Orbiters
21 Relative Motion	Stevenson A	AAS 17-791	Andrew Sinclair	10:50 - 11:10	Approximate Closed Form Solutions of Spacecraft Relative Motion via Abel and Riccati Equations
22 Spacecraft GNC I	Cascade A	AAS 17-690	Benjamin Margolis	10:50 - 11:10	Comparative Study of Tracking Controllers Applied to Martian Aerocapture
20 Low-Energy Mission Design	Stevenson B	AAS 17-687	Anthony Genova	11:10 - 11:30	From GTO to Ballistic Lunar Capture using an Interior Lagrange Point Transfer
22 Spacecraft GNC I	Cascade A	AAS 17-669	Zixuan Xiong	11:10 - 11:30	Station-keeping of Libration Point orbits with Sequential Action Control technique
20 Low-Energy Mission Design	Stevenson B	AAS 17-593	Stijn De Smet	11:30 - 11:50	Dynamics and Stability of Sun-Driven Transfers from LEO to GEO
20 Low-Energy Mission Design	Stevenson B	AAS 17-711	Narcis Miguel Banos	11:50 - 12:10	Solar Sailing at the L4/L5 Libration Points

23 Proximity Operations	Stevenson A	~~AAS 17-716~~	~~Baichun Gong~~	~~13:40 - 14:00~~	~~Range-Only Relative Orbit Estimation for Close-in Proximity Operations~~
24 Spacecraft GNC II	Cascade A	AAS 17-800	John Christian	13:40 - 14:00	Perspective Projection of Ellipses and Ellipsoids with Applications to Spacecraft Navigation
25 Spaceflight Mechanics	Stevenson C/D	AAS 17-552	Jinjun Shan	13:40 - 14:00	Atmospheric Density Estimation with Limited Orbit Tracking Data
26 Special Session: Human Missions Beyond Earth Orbit	Stevenson B	AAS 17-652	Ryan Woolley	13:40 - 14:00	Low-Thrust Trajectory Maps (Bacon Plots) to Support a Human Mars Surface Expedition
23 Proximity Operations	Stevenson A	AAS 17-665	Yinrui Rao	14:00 - 14:20	HOVERING ORBIT CONTROL BASED ON CONTINUOUS THRUST
24 Spacecraft GNC II	Cascade A	AAS 17-555	Juan Arrieta	14:00 - 14:20	A Methodology for Optimizing the Orbital Location of Prime and Backup Maneuvers
25 Spaceflight Mechanics	Stevenson C/D	AAS 17-610	Shyam Bhaskaran	14:00 - 14:20	Deflection Assessment for a Gravity Tractor Spacecraft
26 Special Session: Human Missions Beyond Earth Orbit	Stevenson B	AAS 17-826	Diane Davis	14:00 - 14:20	Stationkeeping and Transfer Trajectory Design for Spacecraft in Cislunar Space
23 Proximity Operations	Stevenson A	AAS 17-574	Naomi Murakami	14:20 - 14:40	Navigation System and Trajectory Analysis for Active Debris Removal Mission
24 Spacecraft GNC II	Cascade A	AAS 17-676	Travis Lippman	14:20 - 14:40	AUTONOMOUS PLANNING OF CONSTRAINED SPACECRAFT REORIENTATION MANEUVERS
25 Spaceflight Mechanics	Stevenson C/D	AAS 17-611	Dong-Huei Tseng	14:20 - 14:40	Converting to Physical Coordinates With or Without a Full Set of Sensors by Eigen-Decomposition of Identified State-Space Models
26 Special Session: Human Missions Beyond Earth Orbit	Stevenson B	AAS 17-577	Drew Jones	14:20 - 14:40	Low Excess Speed Triple Cyclers of Venus, Earth, and Mars

23 Proximity Operations	Stevenson A	AAS 17-733	Jing Pei	14:40 - 15:00	Preliminary GNC Design for the On-orbit Autonomous Assembly of NanoSatellite Demonstration Mission
24 Spacecraft GNC II	Cascade A	AAS 17-589	Demyan Lantukh	14:40 - 15:00	Enhanced Q-Law Lyapunov Control for Low-Thrust Transfer and Rendezvous Design
25 Spaceflight Mechanics	Stevenson C/D	AAS 17-612	Dong-Huei Tseng	14:40 - 15:00	Mass, Stiffness, and Damping Matrices From State-Space Models in Physical Coordinates By Eigen-Decomposition of a Special Matrix
26 Special Session: Human Missions Beyond Earth Orbit	Stevenson B	AAS 17-630	Brian Kaplinger	14:40 - 15:00	Single-Cycler Trajectories for Mars Exploration
23 Proximity Operations	Stevenson A	AAS 17-753	Daniel Groesbeck	15:00 - 15:20	Simulated Formation Control Maneuvers for the RANGE CubeSat Mission
24 Spacecraft GNC II	Cascade A	AAS 17-811	Kevin Bokelmann	15:00 - 15:20	Optimization of Impulsive Transfer Trajectories to Europa Capture using Primer Vector Theory
25 Spaceflight Mechanics	Stevenson C/D	AAS 17-663	Zhang Zhongkai	15:00 - 15:20	Study of Lunar Librations by Chang'E-3 Lunar lander VLBI Observations
26 Special Session: Human Missions Beyond Earth Orbit	Stevenson B	AAS 17-648	Paul Witsberger	15:00 - 15:20	Hyperbolic Abort Options for Human Missions to Mars

BREAK 15:20 - 15:50

23 Proximity Operations	Stevenson A	AAS 17-787	Theodore Wahl	15:50 - 16:10	Autonomous Guidance Algorithms for Formation Reconfiguration Maneuvers
24 Spacecraft GNC II	Cascade A	AAS 17-771	James McCabe	15:50 - 16:10	Decentralized Fusion with Finite Set Statistics for Landing Navigation
25 Spaceflight Mechanics	Stevenson C/D	AAS 17-664	David Shteinman	15:50 - 16:10	USE OF ADVANCED STATISTICAL TECHNIQUES FOR MISSION ANALYSIS: CASE STUDY FROM A GOOGLE LUNAR X TEAM (SPACEIL)
26 Special Session: Human Missions Beyond Earth Orbit	Stevenson B	AAS 17-586	Florian Renk	15:50 - 16:10	Operational Aspects and Low Thrust Transfers for Human-Robotic Exploration Architectures in the Earth-Moon System and Beyond

23 Proximity Operations	Stevenson A	AAS 17-821	Davide Conte	16:10 - 16:30	Semi-analytical Methods for Computing Delta-V and Time Optimal Rendezvous Maneuvers in Cis-lunar Halo Orbits
24 Spacecraft GNC II	Cascade A	AAS 17-718	Francesco Castellini	16:10 - 16:30	Operational Experience and Assessment of the Implementation of the Maplet Technique for Rosetta's Optical Navigation
25 Spaceflight Mechanics	Stevenson C/D	AAS 17-666	Zixuan Xiong	16:10 - 16:30	The study of online learning Recognition Method of the Space Tumbling Non-cooperstive Target Based On Small Satellite Platform
26 Special Session: Human Missions Beyond Earth Orbit	Stevenson B	AAS 17-643	Christopher D'Souza	16:10 - 16:30	Navigation Design and Analysis for the Orion Exploration Mission 2
~~23 Proximity Operations~~	~~Stevenson A~~	~~AAS 17-839~~	~~Joshua Sullivan~~	~~16:30 - 16:50~~	~~Angles-Only Navigation for Autonomous On-Orbit Servicing Applications~~
24 Spacecraft GNC II	Cascade A	AAS 17-831	Pavel Galchenko	16:30 - 16:50	Precision Formation Flying and Spacecraft Pointing Using Plasmonic Force Propulsion
25 Spaceflight Mechanics	Stevenson C/D	AAS 17-678	Zachary Folcik	16:30 - 16:50	TIMING COEFFICIENT AND SOLAR LUNAR PLANETARY EPHEMERIS FILES VALID OVER VERY LONG TIME INTERVALS AND THEIR APPLICATION IN NUMERICAL AND SEMIANALYTICAL ORBIT PROPAGATION
23 Proximity Operations	Stevenson A	AAS 17-841	Jill Davis	16:50 - 17:10	Development and Validation of a GNC Algorithm Using a Stereoscopic Imaging Sensor in Close Proximity Operations
24 Spacecraft GNC II	Cascade A	AAS 17-835	Donghun Lee	16:50 - 17:10	Orbit Transfer Trajectory Design Using Finite-Burn Maneuver Under Steering-angle Constraints
25 Spaceflight Mechanics	Stevenson C/D	AAS 17-683	Daniel Condurache	16:50 - 17:10	POISSON-DARBOUX PROBLEM'S EXTENDED IN DUAL LIE ALGEBRA

23 Proximity Operations	Stevenson A	AAS 17-848	Eric Prince	17:10 - 17:30	OPTIMAL FORMATION ESTABLISHMENT AND RECONFIGURATION USING METAHEURISTIC OPTIMIZATION METHODS
24 Spacecraft GNC II	Cascade A	AAS 17-707	Xian Li	17:10 - 17:30	LOW-THRUST GEO ORBIT TRANSFER GUIDANCE USING SEMI-ANALYTIC METHOD
25 Spaceflight Mechanics	Stevenson C/D	AAS 17-780	Ariadna Farres	17:10 - 17:30	Using Spherical Harmonics to Model Solar Radiation Pressure Accelerations

23 Proximity Operations	Stevenson A	AAS 17-799	John Christian	17:30 - 17:50	Geometric Camera Calibration Using Near-Field Images of the ISS Centerline Docking Plate
24 Spacecraft GNC II	Cascade A	AAS 17-742	Puneet Singla	17:30 - 17:50	CONJUGATE UNSCENTED TRANSFORMATION BASED APPROACH TO COMPUTE HIGHER ORDER STATE TRANSITION MATRIX FOR NONLINEAR DYNAMIC SYSTEMS: APPLICATIONS TO ESTIMATION AND CONTROL

AUTHOR INDEX

Author, Session #

Abraham, Bereket 15
Abukhalil, Sumayya 02
Akbulut, Burak 08
Alcorn, John 03
Aldrin, Buzz 26
Alfano, Salvatore 09
ALI, Osama Mostafa Abdelaziz 19
Ali, Rekesh 10
Allard, Cody 03
Anderson, Isabel 02
Anderson, Jessica 01
Anderson, Rodney 12 , 13 , 20
Arberkli, Ferhat 08
Ardalan, Shadan 14
Arora, Archit 26
Arora, Nitin 06
Arrieta, Juan 24
Asamura, Kazushi 11
Aurich, Joshua 02 , 07 , 18
Ayoubi, Mohammad 22
Azgın, Kıvanç 08
Aziz, Jonathan 04
Baker, John 26
Balducci, Marc 09
Bamann, Christoph 01
Bang, Hyochoong 15
Barbee, Brent 02
Baresi, Nicola 02
Basiri Azad, Seyed Mahdi 08
Basu, Kaushik 08
Beeson, Ryne 04 , 07 , 18 , 20
Beierle, Connor 23
Bellerose, Julie 14
Bercovici, Benjamin 17
Besser, Rebecca 09
Bhaskaran, Shyam 22 , 25
Bhat, Ramachandra 01 , 14
Bhatia, Divya 11
BHATTACHARJEE, SHAMBO 05
Biria, Ashley 12
Bishop, Andrew 10
Black, Jonathan 13 , 19
Bokelmann, Kevin 24
Bokinsky, Ann Catherine 13
Bolatti, Dante 17
Boone, Dylan 14
Bordi, John 14
Borissov, Stoian 22
Bosanac, Natasha 20
Boutonnet, Arnaud 14
Bradley, Nicholas 04
Bradley, Nicholas 14
Bradley, Nicholas 22
Bradstreet, Andrew 07
Brakefield, Braxton 10
Braun, Barbara 09
Bridges, Grayson 22
Broschart, Stephen 19 , 22
Brown, Aaron 15
Burke, Laura 01
Burnett, Ethan 16 , 21
Butcher, Eric 21
Butcher, Jeffrey 22
Capderou, Michel 01
Carbott, Gregory 16
Carpenter, Russell 09 , 11
Carrico, John 10
Carroll, Katherine 02
Casalino, Lorenzo 04 , 06
Castellini, Francesco 24
Cefola, Paul 25
Ceniceros, Angelica 01
Ceriotti, Matteo 21

Author， Session #

Chadha, Siddharth 02
Chai, Patrick 10
Channumsin, Sittiporn 21
Chao, Chia-Chun 19
Chen, Xiao 01
Chien, Steve 19
Cho, Dong-Hyun 03
Christian, John 23 , 24
Chu, Donald 15
Chung, Min-Kun 01
Chung, Min-Kun 06
Chung, Min-Kun 06 , 22
Cobb, Richard 23
Coder, Ryan 05
Comeyne, Gustave 15
Concha, Marco 15
Condurache, Daniel 25
Conte, Davide 02 , 18 , 23
Conway, Darrel 09
Costigan, Glen 10
Couto Oliveira, Geraldo Magela 01
Cox, Andrew 20
Crespo, Francisco 12
Criddle, Kevin 14
Curti, Fabio 11
D'Amico, Simone 23
D'Souza, Christopher 26
Davis, Diane 01 , 26
Davis, Jill 23
de Ruiter, Anton 17
De Smet, Stijn 20
Debevec, Ryan 02
DeHart, Russell 09
Deleflie, Florent 01
DeMars, Kyle 16 , 24
Dietrich, Ann 17
DiPrinzio, Marc 24
Drozd, Kristofer 02
Duncan, Matthew 09
Easton, Robert 20
Edelman, Peter 24
Eiler, Eric 05
Elalfy, Mohamed 02
Elgohary, Tarek 02
Elliot, Ian 13
Elliott, Jacob 02
Ellison, Donald 18
Ely, Todd 16
Englander, Arnold 18
Englander, Jacob 18
Eun, Youngho 09
Everett, Jason 18
Faber, Weston 05 , 12
Farahmand, Mitra 22
Farnocchia, Davide 14
Farres, Ariadna 20 , 25
Fellows, David 15
Feng, Dongzhu 25
Ferreira, Alessandra 01
Ferrer, Sebastian 12
Finlayson, Paul 04
Foerstner, Roger 13
Folcik, Zachary 25
Folta, David 20 , 25
Franzini, Giovanni 21
Frueh, Carolin 01
Frueh, Carolin 05
Fulton, JoAnna 07
Furfaro, Roberto 04 , 05 , 21
Gaebler, John 09
Galchenko, Pavel 23 , 24
GAO, XIAOQING 21
Gao, Yang 06
Garza, David 19
Gegenheimer, Stuart 19
Genova, Anthony 13 , 20 , 26
Ghosh, Pradipto 06

Author, Session #

Goff, Jonathan 10
Golpashin, Alen 08
Gong, Baichun 23
Gong, Qi 06 , 08
Gonzalez-Arribas, Daniel 13
Goodson, Troy 06 , 22
Goodyear, Andrew 02 , 18
Grebow, Daniel 04 , 06
Groesbeck, Daniel 23
Gualdoni, Matt 16
Guerman, Anna 01
Guit, William 09
Gunter, Brian 13 , 23
Guo, Jian 07
Guo, Jun 07
Hack, Kurt 01
Hahn, Yungsun 14
Hall, Doyle 09
Halverson, Julie 11
Han, Chao 04
Han, Chao 21
Han, Chao 23 , 24
han, songtao 16 , 22
Han, Songtao 25
Hanada, Toshiya 19
Hansen, Brian 05
Harman, Rick 11
Hart, Kenneth 23
Hasan, Syed 09
Hassan, Walid 01
Hatch, Sara 15
Haw, Robert 01
He, Guanwei 02 , 18
Heacock, Matthew 02 , 15
Healy, Liam 05
Hejduk, Matthew 09
Henning, Gregory 06
Hernandez, Sonia 10 , 14 , 19 , 26
Herron, Marrisa 09
Herzig, Sebastian 19
Hintz, Gerald 17
Hintz, Gerald R. 22
Ho, Brenton 10
Ho, Koki 04 , 08
Hogan, Erik 03 , 11 , 15
Hollister, Jacob 19 , 22
Homer, Michael 15
Honaker, Shelby 10
Howell, Kathleen 04 , 06 , 20 , 23 , 26
Hughes, Kyle 18
Hughes, Steven 04
Hur-Diaz, Sun 22
Hussain, Omar 10
Hussein, Islam 05 , 12
Hwang, Yoola 01
Ikemoto, Kazuaki 15
Innocenti, Mario 21
Ionasescu, Rodica 14
Jackman, Coralie 01
Jagannatha, Bindu 04
Jah, Moriba 05 , 09
Jenkin, Alan 12
Jesick, Mark 10 , 26
Jesus, Antonio Delson 09
Ji, Xiaoqiang 03
Jin, Xuan 07
Jinyue, Li 03
Johannesen, Jennie 14
Johnson, Lauren 09
Jones, Brandon 09 , 15
Jones, Drew 06 , 10 , 22 , 26
Junior, Allan 01
Junkins, John 12
Kaplinger, Brian 02 , 13 , 20 , 26
Karpenko, Mark 03 , 06 , 08 , 19 , 24
Kathuria, Yukti 02
Kato, Takahiro 15
Kaufman, James 24
Kawaguchi, Jun'ichiro 15 , 17 , 18

Author, Session #

Kent, John 05
Kikuchi, Shota 07 , 17
Kim, Hae-Dong 03
Kiran, B.S. 20
Kiran, Ujwal 02
Knittel, Jeremy 18
Koh, Dayung 12
Koyanagi, Takehiro 18
Kuga, Hélio 11
Kuiack, Bradley 21
Kulumani, Shankar 17
Laipert, Frank 14
Lanave, Giulia 04
Landau, Damon 18
Landau, Damon 26
Landgraf, Markus 26
Lantoine, Gregory 01 , 06 , 20
Lantukh, Demyan 24
Lau, Eunice 06 , 22
Lauer, Mathias 24
Lee, Byoung-Sun 01
Lee, Donghun 03 , 24
Lee, Julim 01
Lee, Kwangwon 09
Lee, Taewook 24
Lee, Taeyoung 17
Legg, Sara 02
Lemm, Krysta 16
Lemmens, Stijn 20
Li, Gangqiang 07
Li, Te 03
Li, Xian 24
Lin, Victor 19
Linares, Richard 04 , 05 , 12 , 21
Lippman, Travis 24
List, Meike 15
Little, Bryan 01
Lo, Martin 20
Longman, Richard 03 , 08 , 25
Longuski, James 01
Longuski, James 10
Longuski, James 10 , 26
Lorah, John 16
Loucks, Michel 10
Lovell, Alan 16 , 21
Lovera, Marco 04 , 21
Luo, Jianjun 04 , 22
Luo, Yufeng 02
Lyne, James Evans 10
Ma, Xiao 07
Machuca, Pablo 13
Majji, Manoranjan 05 , 08 , 24
Marandola, Elizabeth 02
Margolis, Benjamin 22
Marsh, Harleigh 08
Matney, Mark 05
Maxwell, Jordan 07
McCabe, James 24
McCarthy, Brian 26
McCarty, Steven 01
McGuire, Melissa 01
McMahon, Jay 17
McVey, John 12
Meginnis, Ashton 02
Mehta, Piyush 12
Melton, Robert 08 , 11
Mena, Steve 22
Merrill, Raymond 10
Miguel Banos, Narcis 20
Millance, James 26
Miller, James 17 , 22
Minelli, Giovanni 19
Mirzaei, Mehrdad 08
Mishra, Utkarsh 05
Modenini, Dario 07
Mok, Sung-Hoon 15
Monk, Colin 03
Moore, James 10
MORANTE, DAVID 13 , 15

Author, Session #

Moretto, Mark 02
Mortari, Daniele 22
Mott, Katherine 19
Mottinger, Neil 06 , 22
Mudek, Alec 10 , 26
Munoz, Josue 10
Murakami, Naomi 07 , 23
Murcia, Jhonathan 01
Myers, Jessica 16
Nakajima, Yu 07
Nakamura, Yosuke 11
Namachchivaya, N. Sri 08
Nascimento, Jorge 09
Nayyar, Mollik 02
Nazari, Morad 21
Negi, Kuldeep 20
Newman, James 19
Nicholas, Austin 01
Nutter, Nicole 10
ocampo, cesar 01
Ogundele, Ayansola 21
Oltrogge, Daniel 05
Ono, Go 07
Ottenstein, Neil 19
Ottesen, David 18
Owen, William 14
Pachura, Daniel 09
Paik, Ghanghoon 02 , 18
Palmer, Eric 19
Pardo, Ramon 24
Park, Chandeok 09
Park, Ryan 04
Parker, Jeff 10
Parker, Jeff 20
Parrish, Nathan 04 , 10
Patel, Nikunj 02
Pavlak, Thomas 06 , 14
Pei, Jing 23
Pelaez, Jesus 12
Pellegrini, Etienne 18
Pernicka, Henry 23 , 24
Persinger, Randy 06
Petit, Alexis 01
Petropoulos, Anastassios 04 , 06
Phan, Minh 08 , 25
Phillips, Sean 18 , 26
Pimienta-Penalver, Adonis 22
Pinon, Elfego 01
Poland, Devin 11
Ponnapalli, Kaushik 07
Post, Kevin 26
Potter, Robert 01
Potter, Robert 26
Pouplin, Jennifer 02
Prado, Antonio Fernando Bertachini 01 , 13
Prince, Eric 23
Pritchett, Robert 02 , 04
Probst, Alena 13
Proulx, Ronald 06
Psiaki, Mark 16
Qu, Min 01 , 10
Quillen, Paul 10
Radice, Gianmarco 21
Ranieri, Chris 24
Rao, Yinrui 23
Reid, Robert 17
Reis Silva, William 11
Reiter, Jason 02 , 05 , 18
Ren, Yuan 25
Renk, Florian 20 , 26
Restrepo, Ricardo 06 , 20
Rhodes, Andrew 23
Rich, Adam 09
Ricker, George 06
Rievers, Benny 15
Roa, Javier 04 , 12
Rocchi, Amedeo 14
Rocco, Evandro 17

Author, Session #

Rödelsperger, Max 26
Rolley, Robert 02
Romano, Marcello 07
Roscoe, Christopher 05 , 12
Ross, Isaac M. 06 , 19
Ross, Shane 13
Roth, Duane 14
Ruggiero, Roberto 21
Russell, Ryan 06 , 12 , 17 , 18 , 20 , 24
Sabitbek, Bolys 13
Saikia, Sarag 10 , 26
Sampat, Jigisha 02
Sanchez, Diogo 01 , 13
Sanjurjo-Rivo, Manuel 13 , 15
Santos, Denilson Paulo Souza dos 01
Schadegg, Maximilian 01
Schaub, Hanspeter 03 , 07
Scheeres, Daniel 04 , 17 , 20
Schmid, Christine 16
Schoenmaekers, Johannes 14
Schumacher, Paul 05 , 12
Sease, Brad 16
Seubert, Jill 16
Shah, Vishwa 02
Shah, Vishwa 04 , 07
Shah, Vishwa 18
Shah, Vishwa 20
Shan, Jinjun 25
Shaw, Matthew 02 , 18
Shen, Chi-bing 07
Shen, Decai 01
Shen, Haijun 01
Sheng, Chao 03
Shibata, Eiji 02 , 10
Shin-ichiro, Sakai 11
Short, Cody 06
Shteinman, David 25
Silva Neto, José 01
Sinclair, Andrew 16 , 21
Singla, Puneet 05 , 08 , 24
Sinha, S. C. 21
Small, Jeffrey 18
Smith, David 01
Smith, Liam 01
Soken, Halil Ersin 11
SOLER ARNEDO, MANUEL 13 , 15
Spencer, David 23
Spiller, Dario 11
Spreen, Christopher 06
Stamper, Katherine 10
Stanbridge, Dale 01
Strange, Nathan 01 , 06
Stuart, Jeffrey 19
Stuart, Kenneth 09
Stumpf, Paul 14
Subbarao, Kamesh 10
Sui, Tingting 07
Sullivan, Joshua 23
Sun, Chong 01
Sweetser, Theodore H 15
Tadikonda, Sivakumara 15
Takahashi, Yu 14
Takashima, Takeshi 11
Tarzi, Zahi 14
Taylor, Brier 10
Tekinalp, Ozan 08
Tetreault, Kristen 13
Thawesee, Jasmine 02
Thomas, Casey 15
Thomasson, Delphine 01
Thompson, Paul 06 , 14 , 22
Thompson, Roger 05
Ting, Ian 25
Topputo, Francesco 04 , 21
Tortora, Paolo 07
Tseng, Dong-Huei 25
Tsuda, Yuichi 07 , 17 , 18
Ulrich, Steve 21
Urrutxua, Hodei 12

Author, Session #

Vaibhav, Gaurav 20
Valerino, Powtawche 06 , 14 , 22
Vallado, David 05
Van wal, Stefaan 17
Vane, Deborah 15
Vantournhout, Klaas 24
Vaquero, Mar 14
Vavrina, Matthew 01 , 04 , 18
Veloso Garcia, Roberta 11
Venditti, Flaviane 17
Venigalla, Chandrakanth 02
Villac, Benjamin 13
Virgili-Llop, Josep 07
Vlasak, William 22
Vutukuri, Srianish 26
Wagner, Sean 14
Wahl, Theodore 23
Wang, Dongxia 01
Webster, Cassandra 16 , 20 , 25
Wen, Changxuan 01
Wenbin, Wang 04
Whitley, Ryan 01
Wiesel, William 09 , 12
Wilkins, Matthew 05 , 12
Williams, Bobby 01
Williams, Jessica 01
Williams, Kenneth 01
Williams, Trevor 19
Wilson, James 12
Winter, Othon 01
Witkowski, Mona 15
Witsberger, Paul 02 , 26
Wittick, Patrick 17
Wong, Mau C. 14
Woo, Byoungsam 11 , 15
Woo, Byoungsam (Andy) 03
Woodburn, James 06
Woollands, Robyn 12
Woolley, Ryan 01 , 26
Wöske, Florian 15
Wright, Victoria 22
Wu, Xianyu 07
Xiong, Zixuan 22 , 25
Yamamoto, Toru 07 , 23
Yamanaka, Koji 07
Yu, Hang 01 , 25
Yuan, Jianping 01
Yucelen, Tansel 21
Zagaris, Costantinos 07
Zaidi, Waqar 05 , 12
Zanardi, Maria 11
Zanetti, Renato 26
Zannoni, Marco 07
Zappulla, Richard 07
Zhang, Jingrui 03
Zhang, Ran 04 , 23
Zhang, Ran 24
ZHANG, RENYONG 04 , 06
Zhang, Tianyi 03
zhao, hengwang 01
Zheng, Dandan 04 , 22
Zhongkai, Zhang 16 , 22 , 25
Zhou, Wenxiang 08
Zhu, George 07
Zhu, Jianzhong 03
Zizzi, Andrew 01

CHAIR INDEX

Anderson, Rodney 05
Arora, Nitin 10
Arrieta, Juan 03
Aziz, Jonathan 18
Bowes, Angela 12
Casotto, Stefano 16
Darling, Jacob 23
Davis, Diane 20
DeMars, Kyle 08
DSouza, Christopher 24
Englander, Jacob 18
Frueh, Carolin 09
Furfaro, Roberto 17
Gunter, Brian 07
Majji, Manoranjan 01
McMahon, Jay 13
Merrill, Raymond 26
Roscoe, Christopher 15
Russell, Ryan 11
Scheeres, Daniel 02
Sims, Jon 04
Sinclair, Andrew 25
Thompson, Paul 14
Wagner, Sean 22
Wilkins, Matthew 19
Wilson, Roby 06
Zanetti, Renato 21