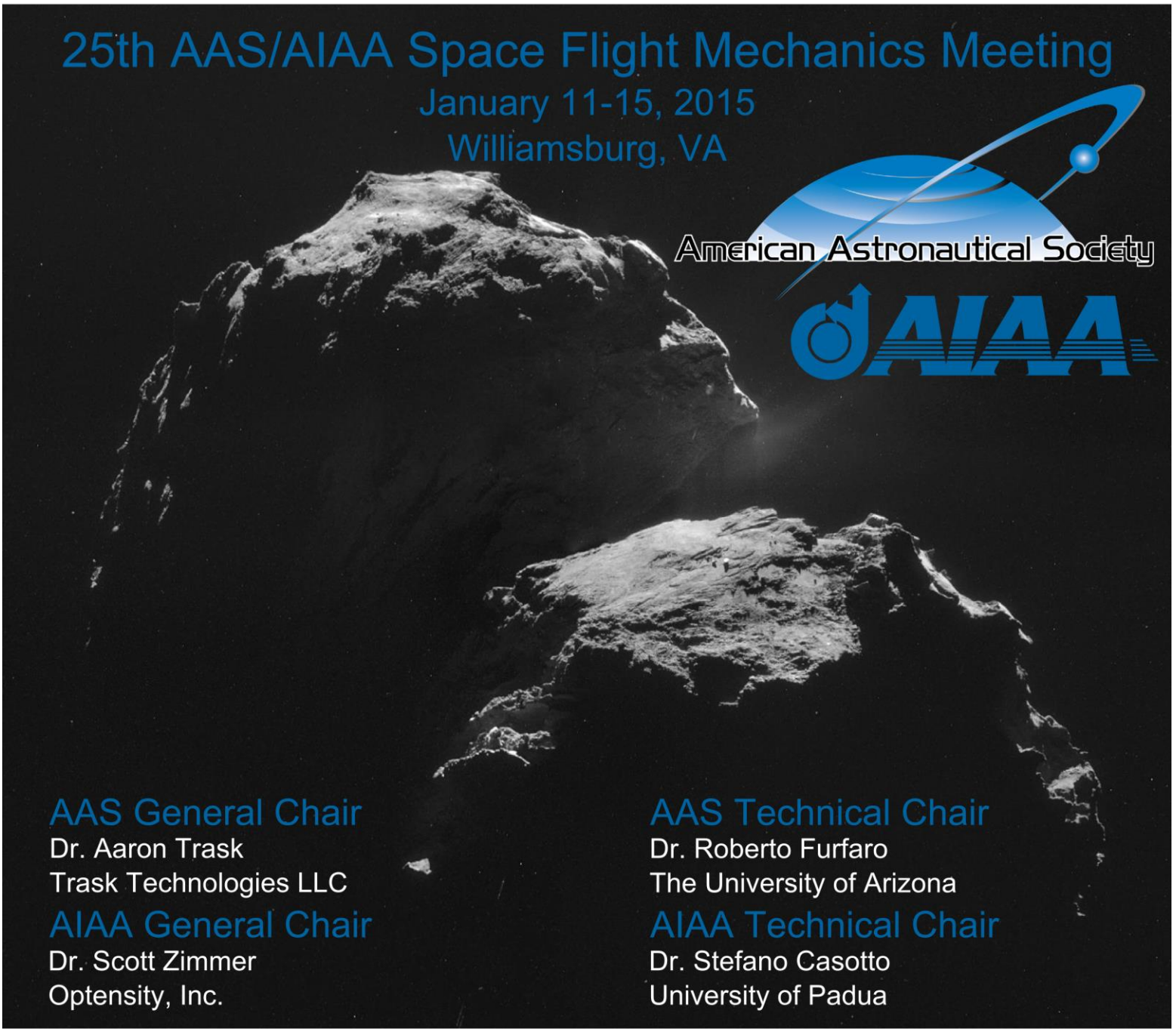
25th AAS/AIAA Space Flight Mechanics Meeting

January 11-15, 2015

Williamsburg, VA



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Cover image: This mosaic comprises four individual NAVCAM images taken from 31.8 km from the center of Comet 67P/Churyumov-Gerasimenko on 4 November 2014. The image resolution is 2.7 m/pixel and thus each original 1024 x 1024 pixel frame measured 2.8 km across. The mosaic has been slightly rotated and cropped, and measures roughly 4.6 x 3.8 km.

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20TH AAS/AIAA SPACE FLIGHT MECHANICS MEETING
CONFERENCE INFORMATION

REGISTRATION

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

In order to encourage early registration, we have implemented the following conference registration rate structure: **Register by 21 Dec 2014 and save $75!**

Category	Early Registration (through 21 Dec 2014)	Registration (after 21 Dec 2014)
Full - AAS or AIAA Member	$465	$540
Full - Non-member	$565	$640
Retired	$125	$150
Student	$125	$150

The receptions are included for all registrants.

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

- Sunday Jan. 11 3:00 PM - 6:00 PM
- Monday Jan. 12 8:00 AM - 2:00 PM
- Tuesday Jan. 13 8:00 AM - 2:00 PM
- Wednesday Jan. 14 8:00 AM - 2:00 PM
- Thursday Jan. 15 8:00 AM - 10:00 AM

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

SCHEDULE OF EVENTS

Sunday January 11, 2015

Session	Room	Paper No.	Presenter	Title
Early Bird Reception 18:30-21:00 in Virginia Room AB				

Monday January 12, 2015 - Morning

Session	Room	Paper No.	Presenter	Title
Monday Speakers' Breakfast 7:00am in Virginia Room DE				
8:00				
03	Virginia Room B	AAS 15-289	Xianyu Wang	Bifurcation of equilibrium points in the potential field of irregular-shaped bodies
04	Virginia Room C	AAS 15-240	Emma Kerr	An Accurate General Perturbations Method for Spacecraft Lifetime Analysis
02	Virginia Room A	AAS 15-213	Wei Wang	Necessary and Sufficient Conditions for Optimal Single Impulse Maneuver Ensuring Virtual-Chief Spacecraft Periodic Relative Motion
01	Piedmont Room B	AAS 15-231	Ryan Coder	improved models for radiometric attitude ESTIMATION OF AGILE SPACE OBJECTS
8:20				
03	Virginia Room B	AAS 15-297	James Miller	Weak Stability Boundary Trajectory Design
04	Virginia Room C	AAS 15-244	Jill Seubert	Utilization of the Deep Space Atomic Clock for Europa Gravitational Tide Recovery
02	Virginia Room A	AAS 15-245	WANG XUEYAO	Simulation and Engineering Analysis of Manned Short Rendezvous Mission Transferred at Special Points
01	Piedmont Room B	AAS 15-233	Ken Chan	Formulation of Collision Probability with Time-Dependent Probability Density Functions
8:40				
03	Virginia Room B	AAS 15-320	Alessandro Dei Tos	Automated trajectory refinement of three-body orbits in the real solar system model
04	Virginia Room C	AAS 15-294	Hao Peng	Numerical energy analysis of the motion in the ELLIPTIC RESTRICTED THREE-BODY PROBLEM
02	Virginia Room A	AAS 15-247	Yu Qi	Similar Analysis for Ground-based Astrodynamical Experiment of Space Relative Maneuver
01	Piedmont Room B	AAS 15-234	Ken Chan	Hovering Collision Probability
9:00				
03	Virginia Room B	AAS 15-342	Edward Belbruno	Earth-Mars Transfer with Ballistic Capture
04	Virginia Room C	AAS 15-295	Martin Lara	Efficient computation of short-period analytical corrections due to third-body effects
02	Virginia Room A	AAS 15-266	Youngkwang Kim	a hybrid algorithm based on duality for linear fuel-optimal impulsive trajectory
01	Piedmont Room B	AAS 15-243	W. Todd Cerven	Bounding Collision Probability Updates
9:20				
03	Virginia Room B	AAS 15-311	Jeffrey Parker	Low-Energy Transfers to Distant Retrograde Orbits
04	Virginia Room C	AAS 15-385	Christopher McCullough	Numerical Accuracy of Satellite Orbit Propagation and Gravity Field Determination for GRACE and Future Geodetic Missions
02	Virginia Room A	AAS 15-324	Leizheng Shu	Precise Relative Navigation for SJ-9 Mission using Reduced-dynamic Technique
01	Piedmont Room B	AAS 15-261	Islam Hussein	The Probabilistic Admissible Region with Additional Constraints
Morning Break 9:40-10:00				

Session	Room	Paper No.	Presenter	Title
10:00				
03	Virginia Room B	AAS 15-322	Francesco Topputo	Approximation of Invariant Manifolds by Cubic Convolution Interpolation
04	Virginia Room C	AAS 15-286	Stefania Soldini	Solar radiation pressure end-of-life disposal for Libration- point orbits in the elliptic restricted three-body problem
02	Virginia Room A	AAS 15-334	Costantinos Zagaris	Survey of Spacecraft Rendezvous and Proximity Guidance Algorithms for On-board Implementation
01	Piedmont Room B	AAS 15-262	Islam Hussein	On Mutual Information Criteria for Observation-to-Observation Association
10:20				
03	Virginia Room B	AAS 15-282	Jin Haeng Choi	Design of Optimal Trajectory for Earth-L1-Moon Transfer
04	Virginia Room C	AAS 15-241	Chia-Chun Chao	Helium Discrepancy in NRLMSISE-2000 Density Model detected via CHAMP/GRACE data and Decaying Spheres
02	Virginia Room A	AAS 15-460	Atri Dutta	A Greedy Random Adaptive Search Procedure for Multi-Rendezvous Mission Planning
01	Piedmont Room B	AAS 15-348	Zahi Tarzi	An Updated Process for Automated Deepspace Collision Assessment
10:40				
03	Virginia Room B	AAS 15-287	Hao Peng	low-energy transfers to an earth-moon multi-REVOLUTION ELLIPTIC HALO ORBIT
04	Virginia Room C	AAS 15-407	Alexander Foster	Analytical Model of Van Allen Proton Radiation Flux For Low-Thrust Trajectory Optimization Solvers
11:00				
03	Virginia Room B	AAS 15-302	Collin Bezrouk	Ballistic Capture into Distant Retrograde Orbits
04	Virginia Room C	AAS 15-267	Yun Zhang	Effects of orbital ellipticity on dynamic evolution of asteroid impact ejecta
11:20				
03	Virginia Room B	AAS 15-265	Natasha Bosanac	A natural autonomous force added in the restricted problem and explored via stability analysis and discrete variational mechanics Estimation For Non-Resolved Space Objects
11:40				
03	Virginia Room B	AAS 15-442	Mariusz Grøtte	Solar Sail Equilibria Points in the Circular Restricted Three Body Problem Of Rigid Spacecraft Over An Asteroid
AAS/AIAA Joint Technical Committee Lunch 12:00-13:30 in Virginia Room DE				

Monday January 12, 2015 - Afternoon

Session	Room	Paper No.	Presenter	Title
13:30				
08	Virginia Room C	AAS 15-283	Kouhei Yamaguchi	Study on the required electric sail properties for kinetic impactor to deflect near-earth asteroids
05	Piedmont Room B	AAS 15-232	Angela Bowes	LDSD POST2 Simulation and SFDT-1 Pre-flight Launch Operations Analyses
06	Virginia Room A	AAS 15-277	Xiaoyu Liu	Distributed Cooperative Attitude Tracking Control for Multiple Spacecraft
07	Virginia Room B	AAS 15-201	Mark Jesick	Mars Double-Flyby Free Returns
13:50				
08	Virginia Room C	AAS 15-299	Marilena Di Carlo	optimized low thrust mission to the atira asteroids
05	Piedmont Room B	AAS 15-218	Joseph White	SFDT-1 Camera Pointing and Sun-Exposure POST2 Analysis and Flight Performance
06	Virginia Room A	AAS 15-362	Keith LeGrand	Space-Based Relative Multitarget Tracking
07	Virginia Room B	AAS 15-255	Craig Kluever	Designing Transfers to Geostationary Orbit Using Combined Chemical-Electric Propulsion
14:10				
08	Virginia Room C	AAS 15-333	Sung Wook Paek	rapid prototyping of asteroid deflection campaigns with spatially and temporally distributed phases
05	Piedmont Room B	AAS 15-224	Prasad Kutty	Supersonic Flight Dynamics Test One: Trajectory, Atmosphere, and Aerodynamics Reconstruction
06	Virginia Room A	AAS 15-401	Eric Butcher	Decentralized Relative Position and Attitude Consensus Control of a Spacecraft Formation with Communication Delay
07	Virginia Room B	AAS 15-221	Timothy Craychee	The Reboot of the International Sun/Earth Explorer 3: The Orbit Determination and Trajectory Design Option Analysis
14:30				
08	Virginia Room C	AAS 15-337	Yoshihide Sugimoto	Design and Operation of a Micro-Spacecraft Asteroid Flyby Mission: PROCYON
05	Piedmont Room B	AAS 15-219	Soumyo Dutta	supersonic flight dynamics test 1 - post-flight assessment of simulation performance
06	Virginia Room A	AAS 15-422	Lorraine Weis	Propagation of Chip-scale Spacecraft Swarms with Uncertainties Using the Kustaanheimo-Stiefel Transformation
07	Virginia Room B	AAS 15-456	Anthony Genova	Trajectory Design from GTO to Near-Equatorial Lunar Orbit for the Dark Ages Radio Explorer (DARE) Spacecraft
14:50				
08	Virginia Room C	AAS 15-462	Nathan Strange	Redirection of Asteroids on to Earth-Mars Cyclers
05	Piedmont Room B	AAS 15-290	Kai Jin	Rapid Generation of Reentry Landing Footprint Using Robust Adaptive Pseudospectral Method
06	Virginia Room A	AAS 15-452	Xu Zengwen	Collision Avoidance for Electromagnetic Spacecraft Formation Flying with Consensus Algorithms
07	Virginia Room B	AAS 15-416	Sainath Vijayan	Low-Thrust Orbit-Raising Using Non-Singular Orbital Elements and Proximity Quotient Approach
Afternoon Break 15:10-15:30				

15:30				
08	Virginia Room C	AAS 15-310	Gao Tang	Study on the Low-Thrust Trajectory Optimization of Asteroid Sample Return with Multiple Revolution and Moon Gravity Assists
05	Piedmont Room B	AAS 15-291	Kai Jin	The Generation of Reentry Landing Footprint with Robustness
06	Virginia Room A	AAS 15-441	Tse-Huai Wu	spacecraft attitude formation stabilization using lines-of-sight without angular velocity measurements
07	Virginia Room B	AAS 15-428	Jeremy Knittel	Aero-Gravity Assist Mission Design
15:50				
08	Virginia Room C	AAS 15-225	Hongwei Yang	Low-Cost Transfer between Asteroids with Distant Orbits Using Multiple Gravity-Assists
05	Piedmont Room B	AAS 15-340	Wanhong Hao	Software Doppler Tracking of Chinese Chang'E-3 Lunar Explorer in the Power Descent Phase
06	Virginia Room A	AAS 15-402	Ozan Tekinalp	state dependent riccati equation control of spinning three-craft coulomb formations
07	Virginia Room B	AAS 15-464	Hongru Chen	Phasing Problem for Sun-Earth Halo Orbit to Lunar Swingby Transfers
16:10				
08	Virginia Room C	AAS 15-336	Chong Sun	Continuous Low-thrusting Trajectory Design for Earth-crossing Asteroid Deflection
06	Virginia Room A	AAS 15-367	Kristin Nichols	Characterizing the Optical Performance of a Space-based Stellar Occultation System Using Aperture Formation Design
07	Virginia Room B	AAS 15-306	Lei Lan	Mercury sun-synchronous orbiter with a solar sail
16:30				
08	Virginia Room C	AAS 15-346	Kenta Oshima	Application of the Jumping Mechanism of Trojan Asteroids to the Design of a Tour Trajectory through the Collinear and Triangular Lagrange Points
06	Virginia Room A	AAS 15-379	Jeffery King	Rapid Collection of Large Areas for Imaging Spacecraft
07	Virginia Room B	AAS 15-223	Rafael Lugo	High Altitude Venus Operations Concept (HAVOC) Trajectory Design and Analysis
AAS CAS Sub-Committee Meeting 17:30-18:30 in Virginia Room A				
AAS TAS Sub-Committee Meeting 17:30-18:30 in Virginia Room B				
AAS WAS Sub-Committee Meeting 17:30-18:30 in Virginia Room C				

Tuesday January 13, 2015 - Morning

Session	Room	Paper No.	Presenter	Title
Tuesday Speakers' Breakfast 7:00am in Virginia Room F				
8:00				
10	Virginia Room A	AAS 15-341	Francesco Vicario	Bilinear System Identification by Minimal-Order State Observers
11	Virginia Room B	AAS 15-397	Matthew Vavrina	Coupled Low-thrust Trajectory and Systems Optimization Via Mulit-Objective Hybrid Optimal Control
09	Piedmont Room B	AAS 15-258	James Woodburn	Generation of Initial Orbit Error Covariance
12	Virginia Room C	AAS 15-204	Paul Anderson	Methodology for Characterizing High-Risk Orbital Debris in the Geosynchronous Orbit Regime
8:20				
10	Virginia Room A	AAS 15-211	Renato Zanetti	Observability Analysis and Filter Design for the Orion Earth-Moon Attitude Filter
11	Virginia Room B	AAS 15-227	Jacob Englander	Multi-Objective Hybrid Optimal Control for Multiple-Flyby Low-Thrust Mission Design
09	Piedmont Room B	AAS 15-268	Charlie Bellows	Updating Track Data from Partial Serendipitous Satellite Streaks
12	Virginia Room C	AAS 15-205	Paul Anderson	Conjunction Challenges of Low-Thrust Geosynchronous Debris Removal Maneuvers
8:40				
10	Virginia Room A	AAS 15-254	Daniele Mortari	Discrete and Continuous Time Adaptive Angular Velocity Estimators
11	Virginia Room B	AAS 15-273	Chen Zhang	Earth-to-halo low-thrust minimum fuel optimization with optimized launch conditions
09	Piedmont Room B	AAS 15-329	Andris Jaunzemis	Space Object Data Association using a Minimum-Fuel Metric
12	Virginia Room C	AAS 15-236	Daniel Casanova	Analysis of the evolution of space debris through a synthetic population
9:00				
10	Virginia Room A	AAS 15-380	Jeffery King	Estimation of Optimal Control Benefits Using the Agilitoid Concept
11	Virginia Room B	AAS 15-278	Ryne Beeson	An Automatic Medium to High Fidelity Low-Thrust Global Trajectory Toolchain; EMTG-GMAT
09	Piedmont Room B	AAS 15-361	James McCabe	Integrated Detection and Tracking for Multiple Space Objects
12	Virginia Room C	AAS 15-264	Antonella Albuja	Short Period Variations in Angular Velocity and Obliquity of Inactive Satellites Due to the YORP Effect
9:20				
10	Virginia Room A	AAS 15-344	Stephen O'Keefe	Gyro Accuracy and Failure Sensitivity of Underdetermined Coarse Sun Heading Estimation
11	Virginia Room B	AAS 15-281	Ran Zhang	Low-Thrust Orbit Transfer Optimization Using Unscented Kalman Filter Parameter Estimation
09	Piedmont Room B	AAS 15-368	Stefano Casotto	Gaussian Initial Orbit Determination in Universal Variables
12	Virginia Room C	AAS 15-293	Francesca Letizia	2D continuity equation method for space debris cloud collision analysis
Morning Break 9:40-10:00				

10:00				
10	Virginia Room A	AAS 15-319	Fu-Yuen Hsiao	Coarse Sun Acquisition only with Sun Sensors for Micro Satellites
11	Virginia Room B	AAS 15-323	Hao Zeng	low thrust minimum fuel optimization to libration point orbits using variable specific impulse engine
09	Piedmont Room B	AAS 15-413	Brandon Jones	A Labelled Multi-Bernoulli Filter for Space Object Tracking
12	Virginia Room C	AAS 15-335	Clemence le fevre	Integration of coupled orbit and attitude dynamics and impact on orbital evolution of space debris
10:20				
10	Virginia Room A	AAS 15-392	Stephen O'Keefe	On-Orbit Coarse Sun Sensor Calibration Sensitivity to Sensor and Model Error
11	Virginia Room B	AAS 15-434	Kathryn Graham	Mesh Refinement for Low-Thrust Trajectory Optimization of Earth-Orbit Transfers
09	Piedmont Room B	AAS 15-418	Kyle DeMars	Collaborative Multi-Sensor Tracking and Data Fusion
12	Virginia Room C	AAS 15-345	Liam Healy	Density of the built orbital environment from an object catalog
10:40				
10	Virginia Room A	AAS 15-425	Donald Chu	GOES-R magnetometer accuracy
11	Virginia Room B	AAS 15-431	Suwat Sreesawet	low-thrust orbit-raising trajectories considering eclipse constraints
09	Piedmont Room B	AAS 15-423	Richard Linares	applications of generalized Gaussian cubature for nonlinear filtering
12	Virginia Room C	AAS 15-260	Eleonora Botta	on the modelling and simulation of tether-nets for space debris capture
11:00				
10	Virginia Room B	AAS 15-438	Kathryn Graham	Low-Thrust Trajectory Optimization of Earth-Orbit Transfers with Eclipsing Constraints
11	Piedmont Room B	AAS 15-355	Davide Amato	Mitigation of trajectory propagation error in interplanetary trajectories
09	Virginia Room C	AAS 15-403	Carolin Frueh	Effects of thermal re-radiation using on orbit and attitude of high area-to-mass ratio objects using different models: yorp and yarkowski
11:20				
11	Piedmont Room B	AAS 15-359	Tarek Elgohary	An RBF-Collocation Algorithm for Orbit Propagation
AAS Technical Committee Lunch 12:00-13:30 in Virginia Room F				

Tuesday January 13, 2015 - Afternoon

Session	Room	Paper No.	Presenter	Title
13:30				
14	Virginia Room A	AAS 15-465	Michele Gaudreault	Technical Research Area Identification Working Group Process
16	Virginia Room C	AAS 15-389	Thomas Pavlak	Quantifying Mapping Orbit Performance in the Vicinity of Primitive Bodies
13	Piedmont Room B	AAS 15-394	Vivek Vittaldev	Collision Probability Using Multidirectional Gaussian Mixture Models
15	Virginia Room B	AAS 15-237	Jason Reiter	Optimization of Many-Revolution, Electric-Propulsion Trajectories with Engine Shutoff Constraints
13:50				
14	Virginia Room A	AAS 15-332	Aubrey Poore	Propagation of Uncertainty in Support of SSA Missions
16	Virginia Room C	AAS 15-296	eric jurado	Philae landing site selection and descent trajectory design
13	Piedmont Room B	AAS 15-366	Daniele Mortari	Fast Selection of Debris Subset for Conjunction Analysis using k-vector
15	Virginia Room B	AAS 15-246	Sujin Choi	A study on trajectory optimization of Korean lunar orbiter using pattern search method
14:10				
14	Virginia Room A	AAS 15-349	Robert Morris	satellite breakup processing
16	Virginia Room C	AAS 15-424	Simon Tardivel	accurate deployment of landers to dynamically challenging asteroids
13	Piedmont Room B	AAS 15-404	Carolin Frueh	probability of detection, clutter and measurement accuracy modeling for an optical ground based sensor in space situational awareness observations
15	Virginia Room B	AAS 15-372	Cesar Ocampo	a crewed mars exploration architecture using flyby and return trajectories
14:30				
14	Virginia Room A	AAS 15-374	Elfego Pinon	Analysis of Resident Space Object Tracking Data Using Hierarchical Mixtures of Experts
16	Virginia Room C	AAS 15-445	Ryan Russell	Heliotropic orbits at asteroids: zonal gravity perturbations and application at bennu
13	Piedmont Room B	AAS 15-409	Brad Sease	GEODETICA: A General Software Platform for Processing Continuous Space-Based Imagery
15	Virginia Room B	AAS 15-393	Mauro Massari	Massively Parallel Optimization of Target Sequences for Multiple-Rendezvous Low-Thrust Missions on gpus
14:50				
14	Virginia Room A	AAS 15-420	Kyle DeMars	Tracking of the Landsat 2 Rocket Body Primary Breakup
16	Virginia Room C	AAS 15-330	Loic Chappaz	Orbital Perturbation Analysis near Small Body Binary Systems
13	Piedmont Room B	AAS 15-410	Brad Sease	Multi-Stereo Resident Space Object Discrimination and Ranging
15	Virginia Room B	AAS 15-298	Jonathan Herman	High-Speed, High-Fidelity Low-Thrust Trajectory Optimization through Parallel Computing & Collocation Methods
Afternoon Break 15:10-15:30				

15:30				
14	Virginia Room A	AAS 15-449	Moriba Jah	astrodynamics collaborative environment: a step toward data sharing and collaboration via the air force research laboratory
16	Virginia Room C	AAS 15-430	Gaurav Misra	asteroid landing guidance design in the framework of coupled orbit-attitude spacecraft dynamics
13	Piedmont Room B	AAS 15-412	Brad Sease	polar and spherical image transformations for star localization and rso discrimination
15	Virginia Room B	AAS 15-216	Yuri Ulybyshev	trajectory optimization using discrete sets of pseudoimpulses: a review of advantages and difficulties
15:50				
16	Virginia Room C	AAS 15-466	Justin Atchison	asteroid flyby gravimetry via target tracking
13	Piedmont Room B	AAS 15-455	Ajay Verma	sensor resource management for sub-orbital multi-target tracking and discrimination
15	Virginia Room B	AAS 15-370	Juan Luis Gonzalo	low-thrust trajectory optimization in dromo variables
16:10				
16	Virginia Room C	AAS 15-363	Corwin Olson	Spin State Estimation of Tumbling Small Bodies
13	Piedmont Room B	AAS 15-360	Brian Hansen	Visualizing the Dissipation of High-Risk Regions in Breakup Debris Clouds
15	Virginia Room B	AAS 15-354	David Spencer	Vertical Takeoff Vertical Landing Spacecraft Trajectory Optimization via Direct Collocation and Nonlinear Programming
16:30				
16	Virginia Room C	AAS 15-427	Kiichiro DeLuca	Divergence Characteristic of the Exterior Spherical Harmonic Gravity Potential
13	Piedmont Room B	AAS 15-391	Camilla Colombo	Density of debris fragments through Differential Algebra and Averaged Dynamics
15	Virginia Room B	AAS 15-364	Juan Luis Gonzalo	Optimal Low-Thrust-Based Rendezvous Maneuvers
Brower Award Ceremony and Lecture 18:00-19:00 in Virginia Room D				
Reception 19:00-21:00 in Virginia Room EF				

Wednesday January 14, 2015 - Morning

Session	Room	Paper No.	Presenter	Title
Tuesday Speakers' Breakfast 7:00am in Virginia Room F				
8:00				
20	Virginia Room C	AAS 15-217	Rajnish Sharma	galerkin approximations for solving the finite-time hjb and hji equations used for feedback control in space trajectory and applications
24	Piedmont Room B	AAS 15-212	Arlen Kam	LADEE flight dynamics: overview of mission design and operations
19	Virginia Room B	AAS 15-238	Daniel Casanova	station-keeping for lattice-preserving flower constellations
18	Virginia Room A	AAS 15-269	Jianjun Luo	study on angles-only relative navigation integrated with guidance based on observability analyzing
8:20				
20	Virginia Room C	AAS 15-249	Justin Atchison	robust high-fidelity gravity-assist trajectory generation using forward/backward multiple shooting
24	Piedmont Room B	AAS 15-396	Laura Plice	trade studies in LADEE trajectory design
19	Virginia Room B	AAS 15-303	Sanghyun Lee	design of constellations for earth observation with inter-satellite links
18	Virginia Room A	AAS 15-307	Uros Kalabic	station-keeping and momentum-management on halo orbits around l2: linear-quadratic feedback and model predictive control approaches
8:40				
20	Virginia Room C	AAS 15-271	Hongli Zhang	a modified upe method to design two-impulse earth-moon transfers in a four-body model
24	Piedmont Room B	AAS 15-419	Craig Nickel	LADEE flight dynamics system overview
19	Virginia Room B	AAS 15-308	yao wei	a novel optimization algorithm for constellation using 'superior and inferior' principle
18	Virginia Room A	AAS 15-356	Jules Simo	performance evaluation of artificial neural network-based shaping algorithm for planetary pinpoint guidance
9:00				
20	Virginia Room C	AAS 15-274	Donald Ellison	Numerical Computation of a Continuous-Thrust State Transition Matrix Incorporating Accurate Hardware and Ephemeris Models
24	Piedmont Room B	AAS 15-230	Lisa Policastri	Pre-launch orbit determination design and analysis for the LADEE mission
19	Virginia Room B	AAS 15-357	Yury Razoumny	Method of Satellite Orbit and Constellation Design for Earth Discontinuous Coverage with Minimal Satellite Swath under the Given Constraint on the Maximum Revisit Time
18	Virginia Room A	AAS 15-358	Yanning Guo	New Waypoints Generation Method for Fuel-efficient Planetary Landing Guidance
9:20				
20	Virginia Room C	AAS 15-373	Robyn Woollands	Method of Particular Solutions and Kustaanheomi-Stiefel Regularized Picard Iteration for Solving Two-Point Boundary Value Problems
24	Piedmont Room B	AAS 15-270	Ken Galal	Attitude design for the LADEE mission
19	Virginia Room B	AAS 15-208	Xinwei Wang	Attitude maneuver strategy of agile earth observing satellite constellation
18	Virginia Room A	AAS 15-458	Feng Yang	Integrated Guidance and Control of Dual-Controlled Near-Space Rendezvous Spacecraft Based-on HOSM
Morning Break 9:40-10:00				

10:00				
20	Virginia Room C	AAS 15-309	Jianjun Luo	A Novel Method Based on Displaced Orbit for Solving Non-planar Orbit Maneuver Problem
24	Piedmont Room B	AAS 15-381	James Woodburn	Generation of Simulated Tracking Data for LADEE Operational Readiness Testing
19	Virginia Room B	AAS 15-338	Zhigang Wu	Optimal Control of Martian Constellations of Artificial Frozen Orbiters and Artificial Sun-Synchronous Orbiters using Continuous Low-thrust propulsion
18	Virginia Room A	AAS 15-222	Chengchao Bai	Lunar Landing Trajectory and Abort Trajectory Integrated Optimization Design
10:20				
20	Virginia Room C	AAS 15-406	Carolin Frueh	modified encke corrector step method for semi-coupled orbit-attitude propagation
24	Piedmont Room B	AAS 15-400	Michel Loucks	the LADEE trajectory as flown
18	Virginia Room A	AAS 15-317	Dengwei Gao	spacecraft safe trajectory integrated guidance and control using artificial potential field and sliding mode control based on hamilton-jacobi inequality
10:40				
20	Virginia Room C	AAS 15-440	Austin Probe	radially adaptive evaluation of the spherical harmonic gravity series for numerical orbital propagation
24	Piedmont Room B	AAS 15-257	Lisa Policastri	orbit determination and acquisition for LADEE and LLCD mission operations
18	Virginia Room A	AAS 15-450	Ryan Caracciolo	a survey of spaceflight dynamics and control architectures based on electromagnetic effects
11:00				
20	Virginia Room C	AAS 15-417	Brent Macomber	Automated Tuning Parameter Selection for Orbit Propagation with Modified Chebyshev Picard Iteration
24	Piedmont Room B	AAS 15-453	Alisa Hawkins	LADEE Maneuver Planning and Performance
18	Virginia Room A	AAS 15-447	Wenlong Li	Adaptive reactionless control of a space snake-arm robot for pre/postcapture of an uncooperative target
11:20				
18	Virginia Room A	AAS 15-292	Hao Sun	A Novel Differential Geometric Nonlinear Control Approach for Spacecraft Attitude Control Propagation
AIAA Technical Committee Lunch 12:00-13:30 in Piedmont Room A				

Wednesday January 14, 2015 - Afternoon

Session	Room	Paper No.	Presenter	Title
13:30				
21	Piedmont Room B	AAS 15-275	Guanyang Luo	Lifetime Simulation of Attitude Changing CubeSat
23	Virginia Room B	AAS 15-202	Drew Jones	Using Onboard Telemetry for MAVEN Orbit Determination
17	Virginia Room C	AAS 15-315	Vladimir Martinusi	Analytic Solution for The Relative Motion of Satellites in Near-Circular Low-Earth Orbits
22	Virginia Room A	AAS 15-386	Jason Laing	Operational Challenges in TDRS Post Maneuver Orbit Determination
13:50				
21	Piedmont Room B	AAS 15-284	yanyan li	Dynamics of Deorbiting of Low Earth Orbit Nano-satellites by Solar Sail
23	Virginia Room B	AAS 15-228	Russell Carpenter	Cauchy Drag Estimation For Low Earth Orbiters
17	Virginia Room C	AAS 15-331	Andrew Sinclair	Decalibration of Linearized Solutions for Satellite Relative Motion
22	Virginia Room A	AAS 15-259	Daniele Mortari	Position Estimation using Image Derivative
14:10				
21	Piedmont Room B	AAS 15-300	Jing Yuan	The Design of NPU-PhoneSat: A Foldable Picosatellite using Smart Phone Technology
23	Virginia Room B	AAS 15-276	Craig McLaughlin	Precision Orbit Derived Atmospheric Density: An Update
17	Virginia Room C	AAS 15-339	Hui Yan	State Transition Matrix for Relative Motion Including General Gravitational Perturbations
22	Virginia Room A	AAS 15-248	Stoian Borissov	Pose Estimation using GEO Satellites Identification
14:30				
21	Piedmont Room B	AAS 15-353	David Folta	LunarCube Transfer Trajectory Options
23	Virginia Room B	AAS 15-451	Evan Kaufman	Nonlinear Observability Measure for Relative Orbit Determination with Angles-Only Measurements
17	Virginia Room C	AAS 15-390	Andrew Sinclair	Initial Relative-Orbit Determination using Second-Order Dynamics and Line-of-Sight Measurements
22	Virginia Room A	AAS 15-220	Sonia Hernandez	Energy Conserved Planar Spacecraft Motion with Constant Thrust Acceleration
14:50				
21	Piedmont Room B	AAS 15-382	Blake Rogers	An Interplanetary Microsatellite Mission Concept to Test the Solar Influence of Nuclear Decay Rates (SINDR)
23	Virginia Room B	AAS 15-365	Christopher Binz	Centroid dynamics for group object tracking
17	Virginia Room C	AAS 15-437	Alex Perez	Relative Satellite Motion Solutions using Curvilinear Coordinate Frames
22	Virginia Room A	AAS 15-301	Benjamin Morrell	Autonomous Operation of Multiple Free-Flying Robots on the International Space Station
Afternoon Break 15:10-15:30				
15:30				
21	Piedmont Room B	AAS 15-463	Arthur Kar Leung Lin	SIGMA CubeSat ADCS Hardware Selection toward data sharing and collaboration via the air force research laboratory
23	Virginia Room B	AAS 15-376	Emmanuel Delande	multi-object filtering for space situational awareness
17	Virginia Room C	AAS 15-444	Ashish Jagat	control of spacecraft relative motion using angles-only navigation
22	Virginia Room A	AAS 15-321	Vladimir Martinusi	closed-from solution to the attitude kinematics equation for an arbitrary angular velocity

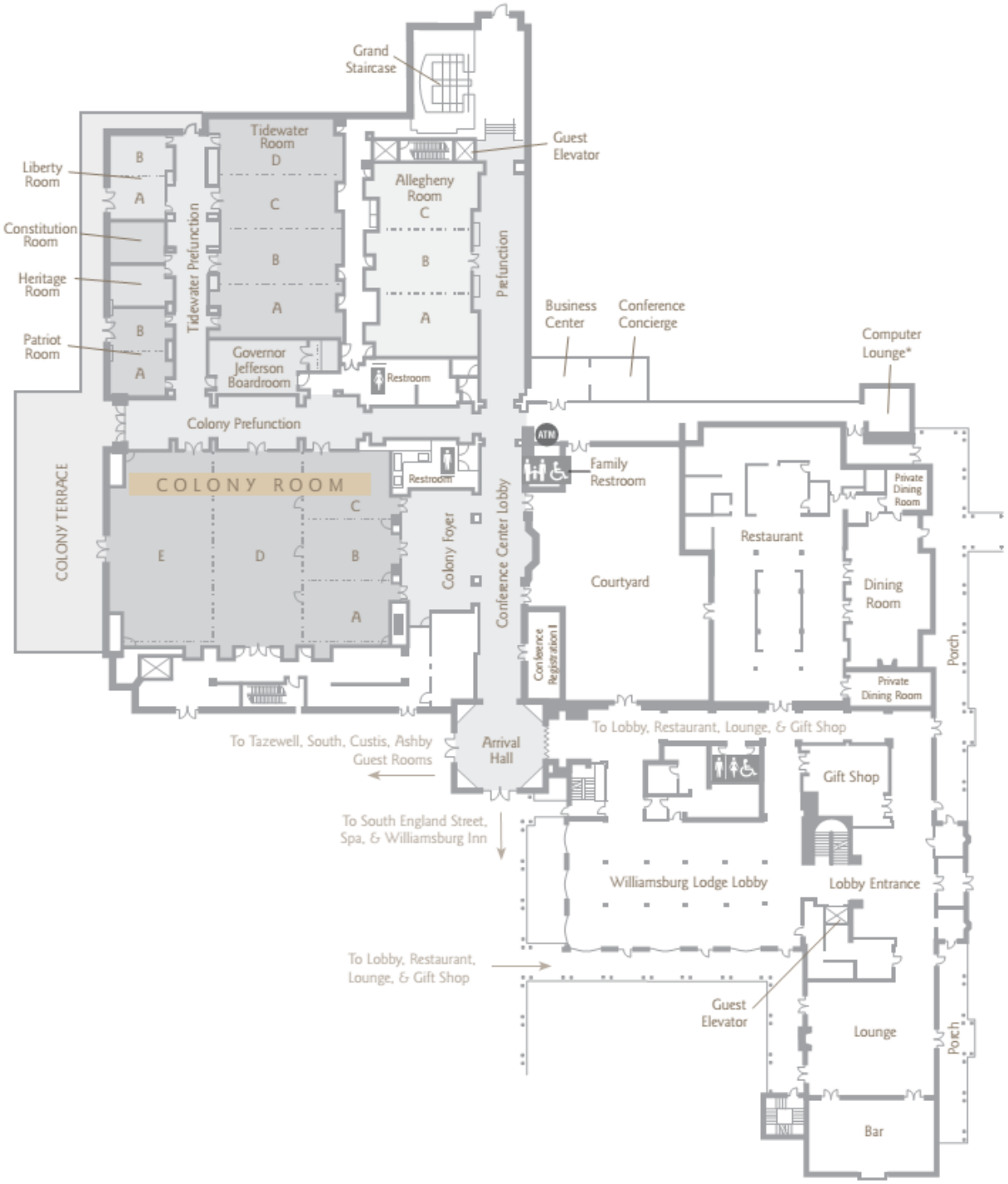
15:50				
23	Virginia Room B	AAS 15-318	Deok Jin Lee	atmospheric re-entry prediction of uncontrolled space objects using multiple hypothesis based distributed sensor fusion approach
17	Virginia Room C	AAS 15-446	Brett Newman	hybrid linear-nonlinear initial orbit determination with single iteration refinement for relative motion
22	Virginia Room A	AAS 15-347	Jacob Darling	rigid body attitude uncertainty propagation using the gauss-bingham distribution
16:10				
23	Virginia Room B	AAS 15-384	Todd Ely	One-Way Radiometric Navigation with the Deep Space Atomic Clock
17	Virginia Room C	AAS 15-210	Javier Roa	Regularized formulations in relative motion
22	Virginia Room A	AAS 15-383	Trevor Bennett	Touchless Electrostatic Detumbling while Tugging Large GEO Debris
16:30				
17	Virginia Room C	AAS 15-272	Javier Roa	Error propagation in relative motion
22	Virginia Room A	AAS 15-352	Andrew Sinclair	Angles-Only Initial Relative-Orbit Determination via Maneuver Maneuvers

Thursday January 15, 2015 - Morning

Session	Room	Paper No.	Presenter	Title
Thursday Speakers' Breakfast 7:00am in Piedmont Room A				
8:00				
26	Virginia Room A	AAS 15-350	Hodei Urrutxua	A Singularity-free DROMO-based Regularized Method for the Propagation of Roto-Translationally Coupled Asteroids
28	Virginia Room C	AAS 15-304	Dayu Zhang	Nonlinear optimal control of flexible spacecraft tracking a non-cooperative target
27	Virginia Room B	AAS 15-251	Daniel Lubey	Robust Tracking and Dynamics Estimation with the Automated Optimal Control Based Estimator
25	Piedmont Room B	AAS 15-326	Francesco Topputo	Advances in Ballistic Capture Orbits Computation with Applications
8:20				
26	Virginia Room A	AAS 15-215	Sung-Woo Kim	Spacecraft Attitude Control using Neuro-Fuzzy Controller Trained by State-Dependent Riccati Equation Controller
28	Virginia Room C	AAS 15-375	George Zhu	Tethered Satellite Deployment and Retrieval by Fractional Order Tension Control
27	Virginia Room B	AAS 15-252	Daniel Lubey	Estimating Object-Dependent Natural Orbital Dynamics with Optimal Control Policies: A Validation Study
25	Piedmont Room B	AAS 15-214	Xiangyuan Zeng	Study on resonant orbits around elongated celestial bodies
8:40				
26	Virginia Room A	AAS 15-242	S. Lauren McNair	Characterization of Self-Excited, Asymmetric, Spinning Rigid-Body motion as an Oblate Epicycloid
28	Virginia Room C	AAS 15-378	Ozan Tekinalp	Architectures for vibrating mass attitude control actuators
27	Virginia Room B	AAS 15-253	Timothy Murphy	Particle and matched filtering using admissible regions
25	Piedmont Room B	AAS 15-435	Aaron J. Rosengren	Dynamical Instabilities in Medium Earth Orbits: Chaos Induced by Overlapping Lunar Resonances
9:00				
26	Virginia Room A	AAS 15-279	Yao Zhang	Dynamic characteristic analysis of a moment control unit with vibration isolation capability and its application
28	Virginia Room C	AAS 15-388	Ozan Tekinalp	Attitude Control of an Earth Orbiting Solar Sail Satellite to Progressively Change the Selected Orbital Element
27	Virginia Room B	AAS 15-432	Evan Kaufman	Minimum Uncertainty JPDA Filter and Coalescence Avoidance Performance Evaluations
25	Piedmont Room B	AAS 15-395	Camilla Colombo	Long-term evolution of highly-elliptical orbits: luni-solar perturbation effects for stability or re-entry
9:20				
26	Virginia Room A	AAS 15-288	Mark Karpenko	Experimental Implementation of Riemann-Stieltjes Optimal Control for Agile CMG Maneuvering
28	Virginia Room C	AAS 15-371	George Zhu	Dynamics and Control of Electrodynamic Tether for Space Debris Removal
27	Virginia Room B	AAS 15-398	Brett Newman	Quadratic hexa-dimensional solution for relative orbit determination - revisited
25	Piedmont Room B	AAS 15-206	Juan Félix San-Juan	On solving a generalization of the Kepler Equation
Morning Break 9:40-10:00				

10:00				
26	Virginia Room A	AAS 15-327	Christopher Petersen	Hybrid Switching Attitude Control of Underactuated Spacecraft Subject to Solar Radiation Pressure
28	Virginia Room C	AAS 15-312	Zixi Guo	An inner structural vibration isolation method for control moment gyroscope considering manufacturing and the assembling errors
27	Virginia Room B	AAS 15-448	Vivek Vittaldev	Uncertainty Propagation using Polynomial Chaos and Gaussian Mixture Models
25	Piedmont Room B	AAS 15-239	Eva Tresaco	Frozen orbits computation for a Mercury solar sail
10:20				
26	Virginia Room A	AAS 15-250	Daniel Lubey	An Instantaneous Quadratic Power Optimal Attitude-Tracking Control Policy for N-CMG Systems
27	Virginia Room B	AAS 15-433	Samuel Haberberger	Fault-Tolerant Dead Reckoning Navigation in a Distributed Network
25	Piedmont Room B	AAS 15-209	Javier Roa	Orbit propagation in Minkowskian Geometry
10:40				
26	Virginia Room A	AAS 15-343	Joshua Chabot	Spherical Magnetic Dipole Actuator for Spacecraft Attitude Control
27	Virginia Room B	AAS 15-405	Mohammad Abdelrahman	New algorithm for attitude and orbit determination using magnetic field measurements
25	Piedmont Room B	AAS 15-351	Hodei Urrutxua	Test Problems for Evaluating the Performance of Numerical Orbit Propagators
11:00				
26	Virginia Room A	AAS 15-411	Kaushik Basu	Survey of Optimal Rigid-Body Attitude Maneuvers
27	Virginia Room B	AAS 15-313	Gongyou Wu	Determine geo satellite statues with long term TLE data
25	Piedmont Room B	AAS 15-207	Juan Félix San-Juan	Hybrid Perturbation methods. Modelling the J2 effect through the Kepler problem
11:20				
26	Virginia Room A	AAS 15-429	Te Li	Robustification of Iterative Learning Control Produced by Multiple Zero Order Holds Each Time Step
27	Virginia Room B	AAS 15-415	Tsutomu Ichikawa	The estimation of angular position for a spacecraft using the tracking station

WILLIAMSBURG LODGE CONFERENCE CENTER MAIN LEVEL



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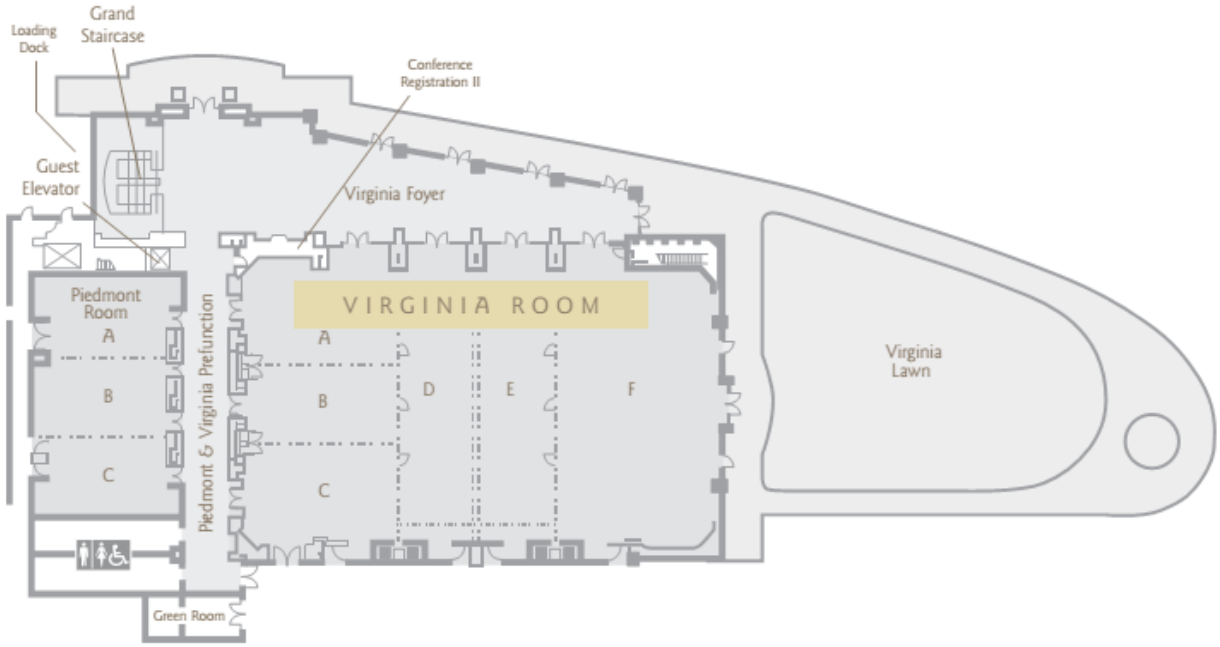

SPECIAL EVENTS

EARLY BIRD RECEPTION

Sunday, 11 January 6:30 – 9:00pm
Location: Virginia Room AB

AWARD CEREMONY, DIRK BROUWER AWARD LECTURE, AND RECEPTION

Tuesday, 13 January 6-7pm (ceremony and lecture)
7-9pm (reception)
Location: Virginia Room D (ceremony and lecture)
Virginia Room EF (reception)

DIRK BROUWER AWARD HONOREE

Srinivas Rao Vadali is a Professor of Aerospace Engineering at Texas A&M University. He has more than 30 years of academic teaching and research experience. He has made significant contributions in the areas of satellite attitude control and orbital mechanics. His current research interests are focused on spacecraft relative motion and formation flying. He is a co-author of the book Spacecraft Formation Flying: Dynamics, Control and Navigation. He has served as an Associate Editor of the AIAA Journal of Guidance, Control, and Dynamics and is currently an Associate Editor of the International Journal of Aerospace Engineering. He is a Fellow of the AAS and an AIAA Associate Fellow.

Conference Location

WILLIAMSBURG LODGE ACCOMMODATIONS

The conference is located at the Williamsburg Lodge in Williamsburg, VA.

Williamsburg Lodge
310 South England Street
Williamsburg, VA 23185
(888) 965-7254

http://www.colonialwilliamsburg.com/stay/williamsburg-lodge

Rates

The conference rate for the hotel is $83 plus applicable taxes. Although, the deadline to book rooms at this rate has passed, the hotel ***may*** choose to honor this rate. Please request the AAS/AIAA Space Flight Mechanics Meeting rate which is booking ID 25418.

Check-In and Checkout

- Check-in: 4:00 PM
  Check-out: 11:00 AM

Parking

- Free parking is available for all hotel guests.

High-Speed Internet Access

- Public Areas: Free Wireless
- Guest Rooms: Free Wireless

Transportation Info

AIRPORT SHUTTLE SERVICES

These shuttle companies may offer a discount for AIAA/AAS conference attendees.

Richmond International Airport

Groome Transportation Shuttle Service: $110 (for 1-3 passengers), rates subject to change. Advance reservation required by phone (1-804-222-7222 or 1-800-552-7911) or email: reservations@groometrans.com. If reserving by email, make a reservation at least several days before your flight.

Tidewater Coach Shuttle Service: $90 per person; $60 each if multiple riders, rates subject to change. Advance reservation required.

Newport News/Williamsburg International Airport

Tidewater Coach Shuttle Service: $45 per person; $30 per person if multiple riders, rates subject to change. Advance reservation required.

Norfolk International Airport

James River Transportation Shuttle Service: $120 (for 1-3 passengers), rates may vary. Advance reservation required. Phone: 1-866-823-4626, or book online.

Tidewater Coach Shuttle: $120 per person; $60 each if multiple riders, rates subject to change. Advance reservation required.

Directions

Newport News/Williamsburg International Airport

Approximately 25 minutes
Exit onto I-64 W toward Williamsburg/Richmond
Take exit 242A to merge onto VA-199 W toward Williamsburg/Jamestown
Turn right onto Colonial National Historic Pkwy
Turn right toward Newport Ave
Turn left onto Newport Ave
Turn left onto S England St/Newport Ave
Destination will be on the left

Richmond International Airport

Approximately 50 minutes
Exit onto I-64 E toward Norfolk/VA Beach
Take exit 238 to merge onto VA-143 E toward US-60/Camp Peary/Williamsburg/Colonial
Turn right onto VA-132 S
Turn left onto Visitor Center Dr
Slight right onto Colonial National Historic Pkwy
Turn right toward Newport Ave
Take the 1st right onto Newport Ave
Turn left onto S England St/Newport Ave
Destination will be on the left

Norfolk International Airport

Approximately 50 minutes
Exit onto I-64 W toward Richmond
Take exit 242A to merge onto VA-199 W toward Williamsburg/Jamestown
Turn right onto Colonial National Historic Pkwy
Turn right toward Newport Ave
Turn left onto Newport Ave
Turn left onto S England St/Newport Ave
Destination will be on the left

Reagan National Airport

Approximately 2 hours and 20 minutes
Exit onto GW Parkway N toward I-395
Take I-395 S toward Richmond
Merge onto I-95 S toward Richmond
Take exit 84A on the left to merge onto I-295 S toward Rocky Mt NC
Take exit 28A to merge onto I-64 E toward Norfolk/VA Beach
Take exit 238 to merge onto VA-143 E toward US-60/Camp Peary/Williamsburg/Colonial
Turn right onto VA-132 S
Turn left onto Visitor Center Dr
Slight right onto Colonial National Historic Pkwy
Turn right toward Newport Ave
Take the 1st right onto Newport Ave
Turn left onto S England St/Newport Ave
Destination will be on the left

DULLES INTERNATIONAL AIRPORT

Approximately 2 hours and 30 minutes
Exit onto Dulles Access Rd
Follow signs for Sully Rd/ VA-28 S and merge onto VA-28 S/Sully Rd
Turn left onto I-66 E
Take exit 55A for Fairfax County Pkwy VA 286 S toward Springfield/
Take the Ox Road/Virginia 123 S exit and then turn left onto VA-123 S
Take I-95 S toward Richmond
Take exit 84A on the left to merge onto I-295 S toward Rocky Mt NC
Take exit 28A to merge onto I-64 E toward Norfolk/VA Beach
Take exit 238 to merge onto VA-143 E toward US-60/Camp Peary/Williamsburg/Colonial
Turn right onto VA-132 S
Turn left onto Visitor Center Dr
Slight right onto Colonial National Historic Pkwy
Turn right toward Newport Ave
Take the 1st right onto Newport Ave
Turn left onto S England St/Newport Ave
Destination will be on the left

BALTIMORE WASHINGTON INTERNATIONAL

Approximately 3 hours and 10 minutes
Exit the airport on I-195 W Take exit 2B for Maryland 295 S/Balt/Wash Pkwy
Take the exit onto I-495 S / I-95 S toward Richmond
Take exit 84A on the left to merge onto I-295 S toward Rocky Mt NC
Take exit 28A to merge onto I-64 E toward Norfolk/VA Beach
Take exit 238 to merge onto VA-143 E toward US-60/Camp Peary/Williamsburg/Colonial
Turn right onto VA-132 S
Turn left onto Visitor Center Dr
Slight right onto Colonial National Historic Pkwy
Turn right toward Newport Ave
Take the 1st right onto Newport Ave
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Destination will be on the left

Explore Williamsburg

RESTAURANTS, MUSEUMS, SHOPPING, AND ACTIVITIES

Colonial Williamsburg has a variety of offerings for visitors. The Colonial Williamsburg website maintains a website that details activities, museums, restaurants and shopping options in the Williamsburg area.
http://www.colonialwilliamsburg.com/do/

Additional Information

SPEAKER ORIENTATION

On the day of their sessions authors making presentations meet with their session chairs at the Speaker's Breakfast at 7:00 am each morning. Please refer to the schedule for the location on the appropriate day. A continental breakfast will be served. **Speaker attendance is mandatory.**

VOLUNTEERS

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

PRESENTATIONS

Each presentation is limited to 15 minutes. An additional five minutes is allotted between presentations for audience participation and transition. Session chairs shall maintain the posted schedule to allow attendees the option of joining a parallel session. Each room is equipped with a microphone, a laser pointer, an electrical outlet, and a video projector that can be driven by a computer. Presenters shall coordinate with their Session Chairs regarding the computing equipment, software, and media requirements for the session; however, *each presenter is ultimately responsible for having the necessary computer and software available to drive the presentation*. Microsoft PowerPoint and PDF are the most common formats.

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

PREPRINTED MANUSCRIPTS

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

CONFERENCE PROCEEDINGS

All registrants will receive a CD of the proceedings mailed to them after the conference (extra copies are available to order for **$55** during the conference). However, the hardbound volume of *Advances in the Astronautical Sciences* covering this conference will be available to attendees at a reduced pre-publication cost, if ordered at the registration desk. After the conference, the hardbound proceedings will more than double in price, although authors will still receive a special 50% discount even if they delay their order until after the conference. Cost of Proceedings:

- Hardbound Domestic Copy Conference Rate **$290**
- Hardbound International Copy Conference Rate **$380**

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

Journal of Guidance, Control and Dynamics
http://arc.aiaa.org/loi/jgcd

Journal of Spacecraft and Rockets
http://arc.aiaa.org/loi/jsr

Journal of the Astronautical Sciences
http://www.astronautical.org/journal

COMMITTEE MEETINGS

Committee seating is limited to committee members and invited guests. Committee meetings will be held according to the following schedule:

Joint AAS/AIAA Technical Committees, Monday, Noon – 1:30 pm Virginia Room DE.
AAS Space Flight Mechanics Technical Committee, Tuesday, Noon – 1:30 pm Virginia Room F.
AIAA Astrodynamics Technical Committee, Wednesday, Noon – 1:30 pm Piedmont Room A.

SUBCOMMITTEE MEETINGS

Conference Administration Subcommittee - Monday, Virginia Room A 5:30-6:30pm
Technical Administration Subcommittee - Monday, Virginia Room B 5:30-6:30pm
Website Administration Subcommittee - Monday, Virginia Room C 5:30-6:30pm

SESSION 1: SPACE SITUATIONAL AWARENESS I

Session Chair: Moriba Jah, Air Force Research Laboratory

8:00 AAS 15-231 Improved models for radiometric attitude estimation of agile space objects
Ryan Coder, Georgia Institute of Technology; Richard Linares, Los Alamos National Lab; Marcus Holzinger, Georgia Institute of Technology

Several innovations are introduced to ameliorate error in space object attitude estimation. A radiometric measurement noise model is developed to define the observation uncertainty in terms of optical, environmental, and sensor parameters. This reduces biases in the space objects' posterior state distributions. Additionally, a correlated angular rate dynamics model is adopted to decouple the effects of inertia and body torques for agile space objects. This novel dynamics model requires the adoption of marginalized particle filters to preserve computational tractability. The software framework is outlined, and simulated results are presented to demonstrate resultant reductions in agile space object attitude estimation error.

8:20 AAS 15-233 Formulation of Collision Probability with Time-Dependent Probability Density Functions
Ken Chan, Chan Aerospace Consultants

Some recent papers have dealt with the determination of collision probability using the concept of integrating the flux of time-dependent probability density functions (pdfs) over time. This approach is permissible for the relatively simple case of time-independent pdfs and relative motion which does not lead to self-intersection of the integration cylindrical tube wherein both conjuncting bodies are spherical. However, it is not even valid for time-independent pdfs and self-intersecting integration volumes. It is definitely not consistent with the basic tenets of probability theory for the case of time-dependent pdfs. Several illustrative examples are provided.

8:40 AAS 15-234 Hovering Collision Probability
Ken Chan, Chan Aerospace Consultants

This paper concerns an orbiting (secondary) object hovering in the close vicinity of another (primary) object, whether deliberately or accidentally. It is assumed that measurements are made of the secondary object either from the ground or from the primary object at various times. During the periods between successive ground-tracking or inter-satellite ranging, the probability of collision is of grave concern. This paper deals with the computation of that probability. It involves the modeling of the growth of a time-dependent probability density function over a period of time and the effects of that growth on the collision probability.

9:00 AAS 15-243 Bounding Collision Probability Updates
W. Todd Cerven, The Aerospace Corporation

Over the last couple decades, the probability of collision (Pc) has been established as the dominant metric for evaluating satellite close approaches. However, the use of Pc by decision-

makers has been limited due at least partially to its non-intuitive often wild variations between catalog updates. It simply does not show the same consistency that relative miss geometry updates show relative to predicted uncertainties. This paper presents a method for predictively computing probabilities and confidence bounds on how the Pc will change with an update.

9:20 AAS 15-261 The Probabilistic Admissible Region with Additional Constraints
Islam Hussein, Applied Defense Solutions; Suman Chakravorty; Christopher Roscoe, Applied Defense Solutions; Paul Schumacher, Air Force Research Laboratory; Matthew Wilkins, Applied Defense Solutions

Based on known statistics of the measurement process, one can replace the constrained admissible region (CAR) with a probabilistic representation of the admissible region. This results in the probabilistic admissible region (PAR) that can be used for orbit initiation in Bayesian tracking and prioritization of tracks in a multiple hypothesis tracking framework. In this paper, we focus our attention on expanding the methodology to allow additional constraints, such as a constraint on perigee, to be modeled in the PAR.

9:40 Morning Break

10:00 AAS 15-262 On Mutual Information Criteria for Observation-to-Observation Association
Islam Hussein, Applied Defense Solutions; Christopher Roscoe, Applied Defense Solutions; Paul Schumacher, Air Force Research Laboratory; Matthew Wilkins, Applied Defense Solutions

In this paper we explore the use of mutual information for observation-to-observation data association. Specifically, we will explore a MC-based mutual information (MC-MI) index that we proposed in previous work but that has only been demonstrated on a linear-Gaussian non-SSA problem. This work will eventually lead to similar solutions for the observation-to-track and track-to-track association problems.

10:20 AAS 15-348 An Updated Process for Automated Deepspace Collision Assessment
Zahi Tarzi, Jet Propulsion Laboratory; David Berry, Jet Propulsion Laboratory; Ralph Roncoli

Current conjunction assessment activity is mainly focused on the Earth orbital environment. This paper will describe the Multimission Automated Deepspace Collision Avoidance Process (MADCAP) used at the Jet Propulsion Laboratory to perform conjunction assessment at Mars and the Moon. The process is controlled by an automated scheduler which initializes analysis based on a set timetable or the appearance of new ephemeris files. The process then generates and communicates reports which are used to facilitate collision avoidance decisions. Special considerations are discussed for the treatment of spacecraft with large uncertainties such as those with rapidly varying orbits or non-operational missions.

SESSION 2: RENDEZVOUS AND PROXIMITY OPERATIONS

Session Chair: Russell Carpenter, NASA Goddard Space Flight Center

8:00 AAS 15-213 Necessary and Sufficient Conditions for Optimal Single Impulse Maneuver Ensuring Virtual-Chief Spacecraft Periodic Relative Motion
Wei Wang

The optimal single impulse maneuver for virtual-chief spacecraft cluster flight is studied in this paper. Based on Gauss' variational equations, necessary and sufficient optimal conditions are provided for three cases: 1) Maneuver moment is fixed. 2) Maneuver moment is unfixed and spacecrafts maneuver separately. 3) Maneuver moment is unfixed and spacecrafts maneuver at the same time. After maneuvering, each spacecraft's semimajor axis comes to be identical, with minimum total fuel-consumption being the objective function. In each case, the exerted velocity impulse, total energy-consumption, and optimal semimajor axis are derived from the analytical point of view.

8:20 AAS 15-245 Simulation and Engineering Analysis of Manned Short Rendezvous Mission Transferred at Special Points
WANG XUEYAO; GONG shengping

With development of space exploration, manned short rendezvous technique will be widely used in the future. The purpose of this paper is to design of short rendezvous mission, including special orbit transfer strategy in remote guidance, initial phase difference, launch window, measurement conditions and so on. A simulation example of short rendezvous mission in full model is successfully achieved in this paper. For optimal fuel consumption, the initial phase difference between the target spacecraft and the tracking spacecraft should be within the proper range. The launch windows and measurement conditions of short rendezvous mission are also tested for the feasibility.

8:40 AAS 15-247 Similar Analysis for Ground-based Astrodynamical Experiment of Space Relative Maneuver
Yu Qi, School of astronautics Beihang University; Zhao Yushan, Beijing University of Aeronautics and Astronautics; Shi Peng, Beijing University of Aeronautics and Astronautics

In order to make out whether a spacecraft's ground-based experiment schedule reliable, the confident coefficient of experimental results is significant in proving the results reliable and credible. A similar function, based on similitude process and power analysis, is figured out to measure the similar degree for ground-based astrodynamical experimental results. With the benefits brought by similar function, it's convenient to tell whether the result of experiment reliable. Combining the similar analysis with Confidence Interval, the shortcomings of ground-based experiment system can be found out.

9:00 **AAS 15-266** **A hybrid algorithm based on duality for linear fuel-optimal impulsive trajectory**
Youngkwang Kim; Sang-Young Park, Yonsei University; Chandeok Park, Yonsei University

This paper addresses a time fixed, linear impulsive trajectory optimization problem for minimizing total characteristic velocity. To solve the optimization problem, a hybrid algorithm is developed here. With a NLP solver, the hybrid algorithm finds an approximate dual solution by applying the dual constraint on the primer vector's maximum magnitude at finite points. Based on the approximate solution, the hybrid algorithm completes the optimization process with a root-finding algorithm by solving the first-order necessary conditions of the primal problem. As an example, an impulsive rendezvous problem near circular reference orbit is solved with the hybrid algorithm.

9:20 **AAS 15-324** **Precise Relative Navigation for SJ-9 Mission using Reduced-dynamic Technique**
Leizheng Shu, Beihang University; Pei Chen; Chao Han, Beihang University

Shi Jian-9 Formation Flight Mission (SJ-9) was carried out in 2012 by China Academy of Space Technology (CAST) to develop and validate key technologies required for autonomous formation flying. This paper develops a real-time estimate algorithm to perform precision relative navigation for this mission. Double-difference GPS carrier phase and reduced-dynamic techniques are utilized to calculate the relative position and velocity. Actual flight data from SJ-9 is used to assess the algorithm performance. Results show that the relative position of the two satellites can be reconstructed with accuracies at the few millimeter to centimeter level.

9:40 **Morning Break**

10:00 **AAS 15-334** **Survey of Spacecraft Rendezvous and Proximity Guidance Algorithms for On-board Implementation**
Costantinos Zagaris; Morgan Baldwin, Air Force Research Laboratory; Christopher Jewison, Massachusetts Institute of Technology; Christopher Petersen, University of Michigan

Over the last several years the topic of autonomous spacecraft rendezvous and proximity operations (RPO) has been rapidly gaining interest. Several methods have been presented in literature that enable autonomous RPO trajectory planning. The purpose of this paper is to survey those methods and assess their suitability for on-board implementation. Factors such as optimality, algorithm convergence rate, convergence guarantees, complexity, and computational efficiency will be used to determine which algorithms are best suited for on-board implementation.

10:20 **AAS 15-460** **A Greedy Random Adaptive Search Procedure for Multi-Rendezvous Mission Planning**
Atri Dutta, Wichita State University

The paper considers the problem of optimizing a sequence of rendezvous of a spacecraft with multiple targets and proposes a new algorithm to solve the problem. The algorithm generates feasible solutions of the problem using a greedy randomized search procedure, and then performs local search about the constructed solution. The performance of the algorithm is

evaluated by considering different cases of complexity for each rendezvous problem. The first case considers C-W equations, the second case considers multi-revolution Lambert's problem, and the third case considers a Non-Linear Programming problem to determine a rendezvous maneuver.

SESSION 3: DYNAMICAL SYSTEMS & TRAJECTORY DESIGN

Session Chair: Kathleen Howell, Purdue University

8:00 **AAS 15-289** **Bifurcation of equilibrium points in the potential field of irregular-shaped bodies**
Xianyu Wang, School of Aerospace Engineering, Tsinghua University; Yu Jiang, School of Aerospace Engineering, Tsinghua University; Junfeng Li; Hexi Baoyin, Tsinghua University; Shengping Gong, Tsinghua University

The stability and topological structure of equilibrium points in the potential field of irregular-shaped minor bodies have been investigated with varied density and rotation period. The number and position of equilibrium points are calculated and illustrated by the contour plot of the gravitational effective potential field. Also the topological structure of the equilibrium points is investigated. The bifurcation occurs with the variation of density and rotation period of the minor bodies. The new equilibrium points will come into being and different equilibrium points will mix together and change their stability as well as topological structure.

8:20 **AAS 15-297** **Weak Stability Boundary Trajectory Design**
James Miller, Consultant

In this paper, a design methodology is described that relates to missions involving a trajectory from near Earth orbit to orbit about the Moon.

8:40 **AAS 15-320** **Automated trajectory refinement of three-body orbits in the real solar system model**
Diogene Alessandro Dei Tos, Politecnico di Milano; Francesco Topputo, Politecnico di Milano

In this paper, an automatic algorithm for the correction of orbits in the real solar system model is described. The differential equations governing the dynamics of a massless particle are written as perturbation of the RTBP in a nonuniformly rotating, pulsating frame by using a Lagrangian formalism. The refinement is carried out by means of a multiple shooting technique, and the problem is solved for a finite set of variables. Results are given for the dynamical substitutes of the collinear points of several gravitational systems. Periodic three-body orbits are continued to the real model through the proposed method.

9:00 **AAS 15-342** **Earth-Mars Transfer with Ballistic Capture**
Edward Belbruno, Innovative Orbital Design, Inc & Princeton University; Francesco Topputo, Politecnico di Milano

We construct a new type of transfer from the Earth to Mars, which ends in ballistic capture. This results in a substantial savings in capture DeltaV from that of a classical Hohmann transfer. This is accomplished by first becoming captured at Mars, far from the planet, and then from there, following a ballistic capture transfer to a desired altitude within a ballistic capture set of the Mars weak stability boundary. This transfer type is of interest for Mars missions due

to lower capture DeltaV values, mass fraction reduction and cost savings as applied to various launch vehicles.

9:20 AAS 15-311 Low-Energy Transfers to Distant Retrograde Orbits
Jeffrey Parker, University of Colorado; Collin Bezrouk, University of Colorado, Boulder

This paper presents an examination of low-energy transfers to Distant Retrograde Orbits (DROs) about the Moon. Large DROs become unstable with very little out-of-plane motion; smaller DROs become unstable with more out-of-plane motion. Many unstable DROs, big and small, may be targeted from Earth using very little fuel, if any. This paper examines the trade space of low-energy transfers to DROs using dynamical systems theory and evaluates their costs and benefits compared with conventional orbit transfers.

9:40 Morning Break

10:00 AAS 15-322 Approximation of Invariant Manifolds by Cubic Convolution Interpolation
Francesco Topputo, Politecnico di Milano; RenYong Zhang, Northwestern Polytechnical University

In this paper a two-step approach to approximate the invariant manifolds in the circular restricted three-body problem is presented. The method consists in a two-dimensional interpolation, followed by a nonlinear correction. A two-dimensional cubic convolution interpolation is implemented to reduce the computational effort. A nonlinear correction is applied to enforce the energy level of the approximated state. The manifolds are parameterized by using two scalars. Results show efficiency and moderate accuracy. The present method fits the needs of trajectory optimization algorithms, where a great number of manifold insertion points has to be evaluated online.

10:20 AAS 15-282 Design of Optimal Trajectory for Earth-L1-Moon Transfer
Jin Haeng Choi, Chonbuk National University; Tae Soo No, Chonbuk National University; Gyeong Eon Jeon; Deok Jin Lee, Kunsan National University; Dae-Won Chung

Design of transfer trajectory from the Earth to the Moon via Lagrange L1 point is often broken into two phases in the sense that Earth-to-L1 and L1-to-Moon transfer are considered separately. In this paper, we present a method of designing an optimal transfer trajectory from the Earth to the Moon via L1 Lagrange point in a “one-shot". As a way of enforcing a natural transit through L1 point, the Jacobi energy during the transfer is constrained to remain between L1 and L2 energy level. This paper will present and analyze the results of representative examples.

10:40 AAS 15-287 Low-energy transfers to an earth-moon multi-revolution elliptic halo orbit
Hao Peng, Beihang University; Shijie Xu, Beihang University

The Multi-revolution Elliptic Halo (ME-Halo) orbit is a kind of resonant periodic existing in the Elliptic Restricted Three-Body Problem (ERTBP). Patched Sun-Earth/Moon Circular Restricted Three-Body Problem (CRTBP) and Earth-Moon ERTBP model is adopted to

construct low-energy transfers to a specific ME-Halo orbit. The transfer is modeled by eight parameters. With only two parameters variable, different phases between the two systems and different orbit injection points on the target orbit are surveyed.

11:00 AAS 15-302 Ballistic Capture into Distant Retrograde Orbits

Collin Bezrouk, University of Colorado, Boulder; Jeffrey Parker, University of Colorado

This paper studies the trade space for ballistic trajectories that are captured by the Earth-Moon system and form distant retrograde orbits (DROs). An analysis is presented that illustrates how a stable DRO can be ballistically targeted from a variety of directions and energies. This investigation shows the boundaries for these trajectories in terms of energy and approach direction and identifies by options upon arrival and prior to DRO capture. These results provide a trade space for missions that intend to place a spacecraft into a stable or semi-stable DRO while using as little fuel as possible.

11:20 AAS 15-265 A natural autonomous force added in the restricted problem and explored via stability analysis and discrete variational mechanics

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

With improved observational capabilities, an increasing number of binary systems have been discovered both within the solar system and beyond. In this investigation, stability analysis is employed to examine the structure of selected families of periodic orbits near a large mass ratio binary in two dynamical models: the circular restricted three-body problem and an expanded model that incorporates an additional autonomous force. Discrete variational mechanics is employed to determine the natural parameters corresponding to a given reference orbit, facilitating exploration of the effect of an additional three-body interaction and the conditions for reproducibility in the natural gravitational environment.

11:40 AAS 15-442 Solar Sail Equilibria Points in the Circular Restricted Three Body Problem

Mariusz Grøtte, Georgia Institute of Technology; Marcus Holzinger, Georgia Institute of Technology

The Circular Restricted Three Body Problem is investigated together with the effects of solar and albedo radiation pressure acting on a solar sail spacecraft in a Sun-Asteroid system. The asteroid is treated as a Lambertian diffuse model. Due to the significant albedo effects experienced close to an asteroid with highly reflective surfaces, the solar sail dynamics differ from models investigated in previous work. It is found that albedo radiation effects shift the equilibrium points considerably as opposed to the model with SRP only, an important fact to address for potential missions to bright objects such as asteroids or comets.

SESSION 4: ORBITAL DYNAMICS AND ESTIMATION

Session Chair: Jill Seubert, Jet Propulsion Laboratory

8:00 AAS 15-240 An Accurate General Perturbations Method for Spacecraft Lifetime Analysis
Emma Kerr, University of Strathclyde; Malcolm Macdonald, University of Strathclyde

An analytical atmospheric density model, including solar activity effects, is developed and applied to a significantly enhanced analytical model for use in spacecraft orbit decay analysis and is shown to have a typical error of less than 5% when compared with historical data.

The developed method allows users to perform rapid Monte-Carlo analysis with thousands of permutations of the problem, such as varying launch date, initial orbit, spacecraft characteristics, and so forth, in fractions of a second, whilst a traditional numerical solution would require a much greater length of time to produce a lifetime prediction for one single permutation.

8:20 AAS 15-244 Utilization of the Deep Space Atomic Clock for Europa Gravitational Tide Recovery
Jill Seubert, NASA / Caltech JPL; Todd Ely, Jet Propulsion Laboratory

Estimation of Europa's gravitational tide can conclusively determine the existence of a subsurface liquid ocean. Unlike an orbiter, a Europa flyby mission suffers strong coupling between the gravity solution quality and tracking data quantity and quality. This work explores the coupling of Low Gain Antennas with the Deep Space Atomic Clock (DSAC) to provide abundant high accuracy uplink-only radiometric tracking data. DSAC's stability, expected to be less than 3e-15 at one day, provides long-term stability and accuracy on par with the Deep Space Network ground clocks, enabling one-way radiometric tracking data with accuracy equivalent

8:40 AAS 15-294 Numerical energy analysis of the motion in the elliptic restricted three-body problem
Hao Peng, Beihang University; Shijie Xu, Beihang University

The Elliptic Restricted Three-Body Problem (ERTBP) is a non-autonomous and periodic system. It is not conservative, so the motion of the third motion does not have an integral of motion like that in the circular situation. In some specific conditions the motion appears to be divergent. In this paper, the numerical method is used to study that in the planar ERTBP when the motion of the third body is unbounded by analyzing its energy.

9:00 AAS 15-295 Efficient computation of short-period analytical corrections due to third-body effects
Martin Lara; Rodolpho Moraes, UNIFESP; Diogo Sanchez, Instituto Nacional de Pesquisas Espaciais -- INPE; Antonio Fernando Prado

Efficient evaluation of short-period corrections is a key point in the semi-analytical integration

of the artificial satellite problem. This is particularly important when second-order corrections of the geopotential or third-body effects are taken into account. For the latter we show that the use of polar-nodal variables allows to cast the periodic corrections in a very simple form of straightforward evaluation which is valid for any eccentricity below one

9:20 AAS 15-385 Numerical Accuracy of Satellite Orbit Propagation and Gravity Field Determination for GRACE and Future Geodetic Missions

Christopher McCullough, University of Texas/Center for Space Research; Srinivas Bettadpur, University of Texas at Austin/Center for Space Research; Karl McDonald, The University of Texas at Austin

The orbit determination process, such as that used for the Gravity Recovery and Climate Experiment (GRACE), is highly dependent upon the comparison of measured observables with computed values, derived from mathematical models relating the satellites' numerically integrated state to the observable. Significant errors in the computed state corrupt this comparison and induce errors in the least squares estimate of the satellites' states, as well as the gravity field. Due to the high accuracy of the inter-satellite ranging measurements from GRACE, numerical computations must mitigate errors to maintain a similar level of accuracy.

9:40 Morning Break

10:00 AAS 15-286 Solar radiation pressure end-of-life disposal for Libration- point orbits in the elliptic restricted three-body problem

Stefania Soldini, University of Southampton; Camilla Colombo, Politecnico di Milano; Scott Walker, University of Southampton

This paper investigates the effect of Earth's eccentricity on an end-of-life propellant-free disposal strategy for Libration-point orbits. The spacecraft is initially disposed to the leaving trajectories from the reference Libration-point orbit, before a reflective sun-pointing surface is deployed to enhance the effect of solar radiation pressure. The consequent increase in energy prevents the spacecraft's return to Earth. An energetic approach is used to compute the required area for the Hill's curves closure at SL2. However, due to the non-autonomous nature of the ERTBPS, the energy is not a constant anymore.

10:20 AAS 15-241 Helium Discrepancy in NRLMSISE-2000 Density Model detected via CHAMP/GRACE data and Decaying Spheres

Chia-Chun Chao, The Aerospace Corporation

The authors performed an investigation of a helium discrepancy in the NRLMSISE-2000 density model (MSIS) with two parallel analyses. One analysis focused on processing data from the CHAMP/GRACE spacecraft, and the other analysis estimated the area-to-mass (A/m) ratio of ten decaying spheres with known diameter and mass. Results show that MSIS over-predicts temperature, which leads to density estimates that are about 30% too high for solar minimum of 2008. The estimated A/m values in the low altitude range are consistently lower by 15 to 26%, agreeing with findings by Thayer et. al. (2012).

10:40 AAS 15-407 Analytical Model of Van Allen Proton Radiation Flux For Low-Thrust Trajectory Optimization Solvers

Alexander Foster, Wichita State University; Atri Dutta, Wichita State University

Radiation damage is a concern for low-thrust orbit-raising of spacecraft to the Geostationary orbit because the spacecraft spends a lot of time in the Van Allen radiation belts. Considering that charged protons cause the majority of damage, this paper proposes to develop approximate analytical models of the flux of protons in the radiation belts, based on the recently released AP-9 data. The analytical functions can be used within optimization solvers for improving convergence characteristics and computational time. This paper will discuss the trade-offs between the benefits obtained and the error introduced by the approximate analytical models.

11:00 AAS 15-267 Effects of orbital ellipticity on dynamic evolution of asteroid impact ejecta

Yun Zhang, School of Aerospace Engineering, Tsinghua University; Hexi Baoyin, Tsinghua University; Junfeng Li

The behavior of the debris ejected from asteroids after collisional disruptions has significant implications for asteroid evolution, which will be influenced by the motion state of asteroid and solar gravity, especially for high-eccentricity orbit asteroids. For this reason, elliptic restricted three-body system is investigated to study the eccentric effects on the evolution of asteroid ejecta. The three-body dynamical environment is analyzed, which indicates that the behavior of ejecta will discriminatively vary with the true anomaly at impact position. As comparison, a series of impact simulations are conducted with various orbital eccentricities, which consist with the analyses.

SESSION 5: LAUNCH AND REENTRY OPERATIONS

Session Chair: Angela Bowes, NASA LaRC

13:30 AAS 15-232 LDSD POST2 Simulation and SFDT-1 Pre-flight Launch Operations Analyses

Angela Bowes, NASA LaRC; Jody Davis, NASA Langley Research Center; Soumyo Dutta, NASA Langley Research Center; Scott Striepe, NASA Langley; Mark Ivanov, Jet Propulsion Laboratory; Richard Powell, AMA; Joseph White, AMA, INC

The Low-Density Supersonic Decelerator (LDSD) Project's first Supersonic Flight Dynamics Test (SFDT-1) occurred June 28, 2014. POST2 was utilized to develop trajectory simulations characterizing all flight phases from drop to splashdown. These POST2 simulations were used to validate the targeting parameters developed for SFDT-1, predict performance/understand the sensitivity of the vehicle and nominal mission designs, and to support flight test operations with trajectory performance and splashdown location predictions for vehicle recovery. This paper provides an overview of the POST2 simulations developed for LDSD and presents the POST2 simulation flight dynamics support during SFDT-1.

13:50 AAS 15-218 SFDT-1 Camera Pointing and Sun-Exposure POST2 Analysis and Flight Performance

Joseph White, AMA, INC; Soumyo Dutta, NASA Langley Research Center; Scott Striepe, NASA Langley

The Supersonic Flight Dynamics Test (SFDT) vehicle was developed to advance and test technologies of NASA's Low Density Supersonic Decelerator (LDSD) Technology Demonstration Mission. The first flight test (SFDT-1) occurred on June 28, 2014. In order to optimize the usefulness of the camera data, analysis was performed to optimize parachute visibility in the camera field of view during deployment and inflation and to determine the probability of sun-exposure issues with the cameras given the vehicle heading and launch time. This paper documents this analysis, its results and their comparison with flight video of SFDT-1.

14:10 AAS 15-224 Supersonic Flight Dynamics Test One: Trajectory, Atmosphere, and Aerodynamics Reconstruction

Prasad Kutty; Chris Karlgaard, Analytical Mechanics Associates, Inc.; Eric M, Jet Propulsion Laboratory; Clara O'Farrell; Ginn Jason; Mark Schoenenberger, NASA Langley Research Center; Soumyo Dutta, NASA Langley Research Center

The Low Density Supersonic Decelerator (LDSD) project is a technology development program designed to advance aerodynamic decelerator technologies for landing high mass payloads on Mars. The Supersonic Flight Dynamics Tests (SFDT) are a series of flight tests within the LDSD campaign, performed to demonstrate these technologies at Mars relevant conditions. The first flight test was SFDT-1, completed on June 28, 2014 at the Pacific Missile Range Facility in Kauai, Hawaii. This paper describes the instrumentation, analysis techniques, and flight test data utilized to reconstruct the SFDT-1 vehicle trajectory, atmosphere, and aerodynamics. The reconstruction results are presented and explored.

14:30 AAS 15-219 Supersonic flight dynamics test 1 - post-flight assessment of simulation performance

Soumyo Dutta, NASA Langley Research Center; Angela Bowes, NASA LaRC; Scott Striepe, NASA Langley; Jody Davis, NASA Langley Research Center; Eric M, Jet Propulsion Laboratory; Mark Ivanov, Jet Propulsion Laboratory

NASA's Low Density Supersonic Decelerator (LDSD) project conducted its first Supersonic Flight Dynamics Test (SFDT-1) on June 28, 2014. A Program to Optimize Simulated Trajectories II (POST2) simulation was developed to predict the flight performance and Monte Carlo analysis was used to characterize the potential flight conditions experienced by the test vehicle. This paper compares the simulation predictions with the reconstructed trajectory of SFDT-1. Additionally, off-nominal conditions seen during flight are modeled in the simulation for post-flight analysis that could be beneficial for the pre-flight simulation and targeting of the two follow-on tests

14:50 AAS 15-290 Rapid Generation of Reentry Landing Footprint Using Robust Adaptive Pseudospectral Method

Kai Jin

A robust adaptive pseudo-spectral method is presented for the generations of reentry landing footprint. Rapid and accurate generation of the landing footprint of a reentry vehicle is the key capability required for onboard determination. To simultaneously improve computational efficiency and accuracy, a novel method is proposed. In this method, the accuracy of the footprint is improved either by increasing the degree of the polynomial within a mesh interval or by refining the mesh. The results show that this method can generate an accurate landing footprint with less calculation cost.

15:10 Afternoon Break

15:30 AAS 15-291 The Generation of Reentry Landing Footprint with Robustness

Kai Jin

In this paper, a novel method to obtain the footprint with robustness of entry vehicles is presented. Aiming at eliminating the deficiencies of traditional optimization method in robustness, a robust reentry guidance law is presented using the model predictive static programming. The presented guidance essentially shapes the trajectory of the vehicle by computing the necessary angle of attack and bank angle that the vehicle should execute. Then use an innovative performance index to generate the footprint. The simulations show that the method can generate an accurate landing footprint with reduced sensitivity to uncertainty for more robust performance.

15:50 AAS 15-340 Software Doppler Tracking of Chinese Chang'E-3 Lunar Explorer in the Power Descent Phase

Wanhong Hao, Beijing Institute of Tracking and Telecommunications Technology

This paper has given the demonstration result of the software Doppler tracking of Chinese Chang'E-3 Lunar Explorer in the power descent phase. A software Phase-Locked Loop has been designed and tested. Post analysis of the raw data has shown that extreme Doppler

dynamics has been introduced due to the jet braking in the power descent phase. During that time, all the downlink signal from the spacecraft has been recorded into the Delta-DOR open-loop recorder. The designed SPLL has successfully tracked the downlink carrier, and the corresponding Doppler residual is shown to be within 3mm/s.

SESSION 6: SPACECRAFT FORMATION FLIGHT

Session Chair: Eric Butcher, University of Arizona

13:30 AAS 15-277 Distributed Cooperative Attitude Tracking Control for Multiple Spacecraft
Xiaoyu Liu, Beihang University; Zhao Yushan, Beijing University of Aeronautics and Astronautics; Shi Peng, Beijing University of Aeronautics and Astronautics

A kind of distributed cooperative control method is proposed to handle the attitude tracking control problem of the multiple spacecraft in inertial space. Firstly, a distributed sliding mode estimator is designed to make every spacecraft get the state values of the non-cooperative target in finite time. Then two control methods which differ in whether the feedback control law utilizes angular velocity, are designed in consideration of the disparity between spacecraft in the ability to measure angular velocity. The two control methods constitute the control strategy of the whole distributed spacecraft system and global asymptotic stability results are gained.

13:50 AAS 15-362 Space-Based Relative Multitarget Tracking
Keith LeGrand, Missouri University of Science and Technology; Kyle DeMars, Missouri University of Science and Technology

As satellite proximity operations involving multiple neighbors, such as a nearby debris cloud or a cooperative swarm, become more common, satellite on-board relative navigation schemes must be augmented to be able to handle more than one target. Random finite set statistical approaches have shown promise as tractable methods to track single or multiple targets using measurement data which is subject to noise, misdetections, and false alarms. Different approximations to the full multi-target random finite set Bayes' filter are applied to the space-based tracking problem and their implementations and performances are discussed.

14:10 AAS 15-401 Decentralized Relative Position and Attitude Consensus Control of a Spacecraft Formation with Communication Delay
Eric Butcher, University of Arizona; Morad Nazari, New Mexico State University

The decentralized consensus control of a formation of rigid body spacecraft is studied in the framework of geometric mechanics while accounting for a constant communication time delay between spacecraft. The relative position and attitude dynamics are modeled in the framework of the Lie group SE(3) while the communication topology is modeled as a digraph. The consensus problem is converted into a local stabilization problem of the error dynamics associated with the Lie algebra se(3) in the form of an LTI delay differential equation with a single discrete delay.

14:30 AAS 15-422 Propagation of Chip-scale Spacecraft Swarms with Uncertainties Using the Kustaanheimo-Stiefel Transformation
Lorraine Weis, Cornell University; Mason Peck

Chip-scale spacecraft swarms trade the conventional highly reliable and well-characterized strategy of monolithic spacecraft for inexpensive, mass producible, and simple designs. Rather

than guarantee a behavior from a single spacecraft, we can instead ensure that the swarm in aggregate will fulfill the mission criteria. The KS transform provides a straightforward way to propagate a chipsat swarm as a whole, including its uncertainties, enabling quantitative evaluation of the swarm's dynamics.

14:50 AAS 15-452 Collision Avoidance for Electromagnetic Spacecraft Formation Flying with Consensus Algorithms

Xu Zengwen, Beijing University of Aeronautics and Astronautics; Shi Peng, Beijing University of Aeronautics and Astronautics; Zhao Yushan, Beijing University of Aeronautics and Astronautics

When the distance between electromagnetic spacecrafts is small, the far-filed model which could be used to calculate electromagnetic forces is no longer accurate. Collision avoidance of electromagnetic spacecraft formation flying in low earth circular orbit are discussed in this paper. Consensus algorithms of collision avoidance for spacecraft electromagnetic formation are derived according to the multi-agent control theory. Three examples of collision avoidance for electromagnetic spacecraft formation flying are provided to demonstrate the algorithms' performance. Simulation results show that the component spacecrafts do not collide with each other in the whole process of orbit transferring.

15:10 Afternoon Break

15:30 AAS 15-441 Spacecraft attitude formation stabilization using lines-of-sight without angular velocity measurements

Tse-Huai Wu, The George Washington University; Taeyoung Lee, George Washington University

Based on line-of-sight measurements between an arbitrary number of spacecraft in formation, velocity-free attitude formation control systems are developed. The proposed control systems are unique in the sense that spacecraft do not need to have possibly expensive, inertial measurement units, as attitude formation is directly controlled by lines-of-sight that can be measured by low-cost optical sensors. This paper generalizes the previous results of vision-based attitude formation control by making it velocity-free, thereby removing the need for gyros as well.

15:50 AAS 15-402 State dependent riccati equation control of spinning three-craft coulomb formations

Ozan Tekinalp, METU Aerospace Engineering Dept.; Mohammad Mehdi Gomroki, METU Aerospace Engineering Dept.

The relative position control of a collinear spinning three-spacecraft Coulomb formation with set charges is addressed. Such a formation is assumed to be in deep space without relevant gravitational forces present. The nonlinear control is realized through state dependent Riccati equation (SDRE) control method. The equations of motion of the formation are properly manipulated to obtain a suitable form for SDRE control. The state-dependent coefficient (SDC) form is then formulated to include the non-linearities in the relative dynamics. Simulations that shows the effectiveness of the method in reshaping the formation are presented.

16:10 AAS 15-367 Characterizing the Optical Performance of a Space-based Stellar Occultation System Using Aperture Formation Design
Kristin Nichols, Texas A&M University; David Hyland, Texas A&M University

This paper develops results supporting novel space-based stellar occultation systems which use shadow diffraction principles to resolve silhouettes of near-Earth asteroids. A formation of light-gathering telescopes are positioned at the Sun-Earth L2 in various orientations and orbits to determine the optimal configuration given a realistic asteroid-stellar environment. Parameters such as the number and size of telescopes in the formation, as well as formation geometry, are varied to find relationships relating these parameters to the system's optical performance. The most efficient formations are examined to determine how optical resolution is affected by system dynamics and

16:30 AAS 15-379 Rapid Collection of Large Areas for Imaging Spacecraft
Jeffery King, USNA; Mark Karpenko, Naval Postgraduate School

Minimum-time optimal control slew maneuvers have been flight-proven on operational systems such as the NASA Transition Region and Coronal Explorer (TRACE). Previous work has focused on minimum time spacecraft slews from one fixed attitude to another fixed attitude. These rest-to-rest maneuvers are not operationally relevant when using a scanning sensor. This paper addresses the time-optimal maneuvering problem where it is desired to maneuver without bringing the satellite to rest between imaging scans. Thus, the results of this paper are a generalization of the shortest-time maneuvering problem for arbitrary boundary conditions.

SESSION 7: TRAJECTORY DESIGN

Session Chair: Francesco Topputo, Politecnico di Milano

13:30 AAS 15-201 Mars Double-Flyby Free Returns
Mark Jesick, Jet Propulsion Laboratory

A subset of Earth-originating Mars double-flyby free returns is documented. The subset consists of those trajectories that fly by Mars, perform a half-revolution transfer with Mars, and return to the Earth. These ballistic trajectories exhibit low geocentric and Areocentric energy, and an extended stay time in Mars' vicinity. The mission is generally viable over four consecutive Mars synodic periods and unavailable for the next three, with the pattern repeating approximately every 15 years. Ballistic opportunities are documented over the remainder of the century, and trends in planetary encounter energy and flight time are presented.

13:50 AAS 15-255 Designing Transfers to Geostationary Orbit Using Combined Chemical-Electric Propulsion
Craig Kluever, University of Missouri

Despite recent increases in power available to electric propulsion systems, it is likely that a chemical stage will be required for transfer to geostationary-equatorial orbit (GEO) so that transfer time is acceptable. This paper presents a strategy for determining maximum-payload transfers from low-Earth orbit to GEO using combined chemical-electric propulsion. A series of optimization trials establishes the optimal starting orbits for the low-thrust transfer as a function of the total transfer time. Curve-fits of these solutions provide mission designers with a purely analytical method for determining optimal chemical-electric transfers to GEO.

14:10 AAS 15-221 The Reboot of the International Sun/Earth Explorer 3: The Orbit Determination and Trajectory Design Option Analysis
Timothy Craychee, Applied Defense Solutions; Craig Nickel, Applied Defense Solutions; Lisa Policastri, Applied Defense Solutions Inc.; Michel Loucks

In late spring 2014, a team of engineers investigated the feasibility of potentially recapturing the International Sun/Earth Explorer 3 (ISEE-3) also known as the Interstellar Cometary Explorer (ICE) spacecraft. This effort is known as the ISEE-3 Reboot Project. This paper reports on the flight dynamics team's efforts to accurately determine the ISEE-3 orbit and design trajectory options that were evaluated for the ISEE-3 spacecraft upon successful recapture.

14:30 AAS 15-456 Trajectory Design from GTO to Near-Equatorial Lunar Orbit for the Dark Ages Radio Explorer (DARE) Spacecraft
Anthony Genova

The trajectory design for the Dark Ages Radio Explorer (DARE) mission concept involves dropping the DARE spacecraft off in a generalized geosynchronous transfer orbit (GTO) as a secondary payload. From GTO, the spacecraft is then required to enter a near-equatorial lunar

orbit that is stable (i.e., no station-keeping maneuvers are required) and yields the required number of cumulative hours (1,000) for science measurements while in the lunar farside radio quiet cone over a span of three years. Preliminary and expected results of the corresponding trajectory design are presented herein.

14:50 AAS 15-416 Low-Thrust Orbit-Raising Using Non-Singular Orbital Elements and Proximity Quotient Approach
Sainath Vijayan, Wichita State University; Atri Dutta, Wichita State University

Recent years have shown a growing interest in the space industry in all-electric satellites. Mission designers analyzing the optimal deployment options for all-electric satellites need to consider three important metrics: transfer time, fuel expenditure and radiation damage. This paper proposes a proximity approach based guidance-scheme using modified equinoctial elements to determine a low-thrust trajectory that minimizes an arbitrary user-defined objective that could be a convex combination of transfer time, fuel expenditure and radiation damage. We present numerical examples and analyze the performance of the algorithm for different mission objectives.

15:10 Afternoon Break

15:30 AAS 15-428 Aero-Gravity Assist Mission Design
Jeremy Knittel, University of Maryland; Mark Lewis, Science and Technology Policy Institute; Kenneth Yu

A method for the design of spacecraft missions requiring the use of an aero-gravity assist maneuver is presented. Interplanetary paths are created by connecting lambert arcs based on maximum aero-gravity assist performance estimations. The atmospheric portion of the aero-gravity assist is designed using simulations of hypersonic flight. Genetic algorithms are used to design an aeroshell capable of delivering the needed aerodynamic performance to complete the maneuver, while optimizing for other figures of merit. The overall method is demonstrated with the step-by-step design of an interstellar probe mission.

15:50 AAS 15-464 Phasing Problem for Sun-Earth Halo Orbit to Lunar Swingby Transfers
Hongru Chen, Kyushu University; Yasuhiro Kawakatsu, JAXA / ISAS; Toshiya Hanada, Kyushu University

The current paper presents the required phasing ΔV to encounter the Moon for various lunar phases with respect to the halo orbit. The algorithm of solving the ΔV from the manifold to the Moon is explained. We can know whether going to the Moon is favorable comparing to other escape options and the trade-off between ΔV and the time to wait along the halo orbit.

16:10 AAS 15-306 Mercury sun-synchronous orbiter with a solar sail
Lei Lan, Laboratory of Aerospace and Dynamics, School of Aerospace, Tsinghua University

The exploration of the Mercury investigates not only the nature of the planet itself but also the evolution of the Solar system as well as the origin of life. Based on the predecessors' research, considering the illumination radiation pressure of the Sun, it takes the gravitational perturbation

of the Sun into consideration using averaged methods in this paper and prove the existence of Mercury sun-synchronous orbits with various orbit elements. Furthermore, orbiter can remain stable in a long time. Then, the fact that the influence by the strong, periodic and time-varying gravity is not ignorable has been proved.

16:30 AAS 15-223 High Altitude Venus Operations Concept (HAVOC) Trajectory Design and Analysis

Rafael Lugo, Analytical Mechanics Associates, Inc.; Thomas Ozoroski, Analytical Mechanics Associates, Inc.; John Van Norman, Analytical Mechanics Associates; Dale Arney, NASA Langley Research Center; Christopher Jones, NASA Langley Research Center; Carlie Zumwalt, NASA Langley Research Center

A trajectory design and analysis that describes aerocapture, entry, descent, and inflation of manned and unmanned High Altitude Venus Operation Concept (HAVOC) lighter-than-air missions is presented. Mission motivation, concept of operations, and notional vehicle designs are presented. The initial trajectory design space is analyzed and discussed before investigating specific trajectories that are deemed representative of feasible Venus missions. Design and analysis of the thermal protection system is also presented. The manned mission, with high entry mass, may require further research in atmospheric vehicle decelerator technology. The unmanned mission is determined to be feasible using current technology.

SESSION 8: ASTEROID AND COMETARY MISSIONS

Session Chair: Nathan Strange, Jet Propulsion Laboratory

13:30 AAS 15-283 Study on the required electric sail properties for kinetic impactor to deflect near-earth asteroids

Kouhei Yamaguchi, Research Institute for Sustainable Humanosphere, Kyoto University; Hiroshi Yamakawa, Research Institute for Sustainable Humanosphere, Kyoto University

The aim of this study is to investigate the realistic properties of the electric sail for asteroid deflection using a projectile's kinetic impact. Because the electric sail uses the solar wind plasma stream to produce its thrust, it enables a spacecraft to perform orbit transfer without consuming any reaction mass. It would be also attractive for accelerating a projectile to impact against an asteroid. In our work, we performed trajectory optimization of the electric sail by considering several properties like spacecraft total mass or launch capability to make this approach to become a feasible Earth protecting option.

13:50 AAS 15-299 Optimized low thrust mission to the atira asteroids

Marilena Di Carlo, University of Strathclyde; Natalia Ortiz Gomez, Southampton University; Juan Manuel Romero Martin, University of Strathclyde; Chiara Tardioli, Strathclyde University; Fabien Gachet, University of Tor Vergata; Kartik Kumar, Dinamica Srl; Massimiliano Vasile, University of Strathclyde

The aim of the proposed mission is to improve our knowledge of the Atira asteroids and to discover new inner-Earth asteroids. First, a trajectory model based on impulsive Lambert arcs is used in combination with a global deterministic algorithm, branch and heuristic prune. Secondly, the best solution is refined using AIDEA, an adaptive stochastic optimizer which combines Differential Evolution with Monotonic Basin Hopping algorithm. Finally, the refined solution is translated into a low thrust trajectory using a direct optimization method and a multiple shooting algorithm. A Montecarlo analysis of the observed asteroids with two optical cameras is also presented.

14:10 AAS 15-333 Rapid prototyping of asteroid deflection campaigns with spatially and temporally distributed phases

Sung Wook Paek, MIT; Olivier de Weck; Patricia Egger

This paper discusses a framework to design asteroid deflection campaigns consisting of multiple phases that are temporally or spatially distributed. A precursor mission prior to actual deflection can reduce uncertainties in asteroid properties in order to improve deflection accuracy and reduce impact probability. Also, spatially distributed, multiple impactors can increase the upper bound of achievable total deflection. An open-source Propagator for Asteroid Trajectories Tool (PAT2) is used to rapidly prototype and evaluate the resulting large tradespace of deflection campaigns for both exploration and mitigation purposes.

14:30 AAS 15-337 Design and Operation of a Micro-Spacecraft Asteroid Flyby Mission: PROCYON

Yoshihide Sugimoto, Japan Aerospace Exploration Agency; Stefano Campagnola, Japan Aerospace Exploration Agency; Chit Hong Yam, Japan Aerospace Exploration Agency; Chikako Hirose, Japan Aerospace Exploration Agency; Naoya Ozaki, The University of Tokyo; Bruno Sarli, The Graduate University for Advanced Studies; Hongru Chen, Kyushu University; Yosuke Kawabata, The University of Tokyo; Satoshi Ogura, The University of Tokyo; Kaito Ariu, The University of Tokyo; Ryu Funase, The University of Tokyo; Yasuhiro Kawakatsu, JAXA / ISAS

PROCYON (PRoximate Object Close flYby with Optical Navigation) is a 50kg-class micro-spacecraft developed by the University of Tokyo and the Japan Aerospace Exploration Agency (JAXA), to be launched in an Earth resonant trajectory at the end of 2014 as a secondary payload with Hayabusa 2 mission. The mission objective is to demonstrate low cost and applicability of a micro-spacecraft bus technology for deep space exploration and proximity flyby to asteroids performing optical navigation. This paper introduces the spacecraft and mission design for PROCYON, as well as, the operation strategy mainly for the deep-space cruising period.

14:50 AAS 15-462 Redirection of Asteroids on to Earth-Mars Cyclers

Nathan Strange, NASA / Caltech JPL; Damon Landau, NASA / JPL; James Longuski, Purdue

NASA is currently studying an Asteroid Redirect Mission (ARM) that would capture an entire 4-10 m asteroid or boulder form a larger asteroid and place it in orbit around the Moon using a Solar Electric Propulsion (SEP) vehicle. This asteroid redirection capability could also be used in future missions to redirect asteroids onto Earth-Mars cyclers where the asteroidal material could be used to provide water, propellant, structural material, and radiation shielding material. This last application is especially exciting as it may provide an economical solution to the problem of protecting astronauts from radiation on journeys to Mars.

15:10 Afternoon Break

15:30 AAS 15-310 Study on the Low-Thrust Trajectory Optimization of Asteroid Sample Return with Multiple Revolution and Moon Gravity Assists

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

For a low-thrust sample return mission from LEO(Low Earth Orbit) to NEA(Near-Earth Asteroid), many revolutions is required for the spacecraft to escape from the Earth and multiple moon gravity assists can be used to increase the escape speed to lower the mission cost. The trajectory is very difficult to optimize and a direct method is used and a shape-based trajectory is used as the initial guess. After escaping from earth, optimal control theory is used to maximize the mass collected and another moon gravity assist is used to capture the spacecraft.

15:50 AAS 15-225 Low-Cost Transfer between Asteroids with Distant Orbits Using Multiple Gravity-Assists

Hongwei Yang; Fanghua Jiang; Hexi Baoyin, Tsinghua University; Junfeng Li; Shengping Gong, Tsinghua University; Kun Zhai; Xiangyuan Zeng, Tsinghua University

Low-cost transfer trajectories are significant to explore asteroids with distant orbits in a multiple target mission. Methods for designing these trajectories optimally are proposed. The sequence of gravity-assists is evaluated by the Tisserand graph. Then, an optimization method combining the particle swarm optimization (PSO) and the indirect method is used to obtain the optimal low thrust trajectories. Conditions of resonant gravity-assists are incorporated in the PSO searching process to improve the efficiency. The Bang-Bang control problem in the indirect method is overcome by a smooth technique. Simulations are carried out for validating the proposed methods.

16:10 AAS 15-336 Continuous Low-thrusting Trajectory Design for Earth-crossing Asteroid Deflection

Chong Sun; Jianping Yuan

An analytical approach for continuous low thrusting trajectory design for earth crossing asteroid deflection is proposed in this paper. The performance measure is to minimize fuel consumption required to achieve target separation distance. The displacement of the asteroid at the minimum orbit interception distance from the earth's orbit is parameterized using proposed method. With Practical Swarm Optimization algorithm, optimization parameters can be found to satisfy astrodynamical constraints and optimize the transfer trajectory. The simulation results show that proposed method can provide a significant saving in computational time and maintain a good accuracy.

16:30 AAS 15-346 Application of the Jumping Mechanism of Trojan Asteroids to the Design of a Tour Trajectory through the Collinear and Triangular Lagrange Points

Kenta Oshima, Waseda University; Tomohiro Yanao, Waseda University

This study develops and optimizes a tour trajectory passing by the collinear (L1, L3) and triangular (L4, L5) Lagrange points in the Earth-Moon system. For the purposes of exploring L4 and L5 and reducing the transfer cost between them, we utilize a natural transfer trajectory of a Trojan asteroid between L4 and L5 through L3. We then connect this natural transfer trajectory with a halo orbit around L1 via a fuel-efficient trajectory utilizing lunar gravity assist. This fuel-efficient trajectory is globally optimized through a recently developed interior search algorithm and locally optimized through the Matlab function fmincon.

SESSION 9: ORBIT DETERMINATION I

Session Chair: John H. Seago, Analytical Graphics, Inc.

8:00 AAS 15-258 Generation of Initial Orbit Error Covariance
James Woodburn, AGI; Jens Ramrath, AGI

Significant research is being performed in the area of orbit error covariance propagation for cases of large uncertainty where linear methods break down. Often times, initial orbit error covariance matrices are selected to represent a desired initial uncertainty in position and/or velocity but lack correlation between the orbit states which are generated by orbit estimation processes. Resulting propagation of the orbit uncertainty then leads to unrealistically large growth rates. In this paper, we describe a methodology for generating initial orbit error covariance matrices including proper correlations which roughly satisfy arbitrary levels position and velocity uncertainty.

8:20 AAS 15-268 Updating Track Data from Partial Serendipitous Satellite Streaks
Charlie Bellows, Air Force Institute of Technology; Richard Cobb, Air Force Institute of Technology; Jonathan Black, Virginia Polytechnic Institute and State University

Reliable Space Situational Awareness (SSA) is a recognized requirement in the current environment of space operations. A shortage of available sensors and reliable data sources is a limiting factor for maintaining SSA. Current fiscal constraints prohibit drastically increasing the existing sensor inventory. This work examines the feasibility and utility of performing along-track and cross-track updates for space catalog objects using metric data obtained from streaks gathered by small astronomical telescopes. The focus of this work is on processing data from three possible categories: streaks that only enter, only exit, or cross completely through the astronomical image.

8:40 AAS 15-329 Space Object Data Association using a Minimum-Fuel Metric
Andris Jaunzemis, Georgia Institute of Technology; Midhun Mathew; Marcus Holzinger, Georgia Institute of Technology

Minimum-fuel distance metrics provide a natural tool with which to associate space object observation data. Trajectory optimization software is developed to solve deterministic minimum-fuel boundary value problems, implemented alongside the control distance metric for maneuver hypothesis testing. Simulated scenarios are constructed to test the algorithm, and the results are compared to real data gathered from the Wide Area Augmentation System (WAAS). The framework is tested to evaluate its limitations and potential applications in operational use. This technique is compared to other data association techniques, revealing the merits of the control distance metric in orbital mechanics applications.

9:00 AAS 15-361 Integrated Detection and Tracking for Multiple Space Objects
James McCabe, Missouri University of Science and Technology; Kyle DeMars, Missouri University of Science and Technology

Many obstacles exist for simultaneously tracking multiple space objects, including ambiguity in the numerousness and nature of the objects tracked as well as sensor injected uncertainty in the form of false returns, measurement noise, and probability of detection. Methods that employ the posterior intensity, the first order statistical moment of a random finite set, such as the probability hypothesis density (PHD) filter account for such things in the their formulation. This paper presents a Gaussian mixture approach to the PHD recursion to conduct the tracking of many space objects to evaluate its performance and applicability to the problem.

9:20 AAS Gaussian Initial Orbit Determination in Universal Variables
15-368 *Stefano Casotto, Universita' di Padova*

Gaussian IOD is based on the sector-to-triangle ratio, which incorporates the dynamical information associated with Keplerian motion. It has already been shown that this method leads to a system of six highly nonlinear equations in terms of Keplerian elements. Further research will be presented here that shows how the minimal set of five equations can be derived by adopting Stumpff's universal functions. Results obtained from the application of this new method will be shown and compared with the Gaussian method previously introduced and other non-Gaussian IOD procedures.

9:40 Morning Break

10:00 AAS A Labelled Multi-Bernoulli Filter for Space Object Tracking
15-413 *Brandon Jones, University of Colorado, Boulder; Ba-Ngu Vo, Department of Electrical and Computer Engineering, Curtin University*

To maintain custody of the increasing number of detectable objects in Earth orbit, tracking systems require robust methods of multi-target state estimation and prediction. One alternative to the classic multiple hypothesis and probabilistic data association methods uses a random finite set for representing the multi-target state. The general forms of such filters sacrifice knowledge of specific targets for the sake of tractability. This paper presents a labelled multi-Bernoulli filter for tracking space objects, which allows for the identification of individual targets. The benefits of the filter are then demonstrated for the tracking of objects near geosynchronous orbit.

10:20 AAS Collaborative Multi-Sensor Tracking and Data Fusion
15-418 *Kyle DeMars, Missouri University of Science and Technology; James McCabe, Missouri University of Science and Technology; Jacob Darling, Missouri University of Science and Technology*

Multi-sensor networks can alleviate the need for high-cost, high-accuracy, single-sensor tracking in favor of an abundance of lower-cost and lower-accuracy sensors to perform multi-sensor tracking. The use of a multi-sensor network gives rise to the need for a fusion step that combines the outputs of all sensor nodes into a single probabilistic state description. This paper investigates efficient methods for achieving multi-sensor data fusion in a collaborative network of disparate sensors. Simulation results are presented for the tracking of a low-Earth orbit object using both optical telescope and radar systems.

10:40 AAS 15-423 Applications of generalized Gaussian cubature for nonlinear filtering

Richard Linares, Los Alamos National Lab; John Crassidis, University at Buffalo, State University of New York

This paper discusses a novel method for nonlinear filtering based on Generalized Gaussian Cubature (GGC). This work develops a new point base nonlinear filter which is not based on one dimensional quadrature rules but rather uses multi-dimensional cubature rules for Gaussian distributions. The novel Generalized Gaussian Cubature Filter (GGCF) is not in general limited to odd order degree of accuracy but provides a wider range of order of accuracy. Finally, the GGCF is applied to benchmark problems in astrodynamics and compared against existing methods.

11:00 AAS 15-355 Mitigation of trajectory propagation error in interplanetary trajectories

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

Interplanetary trajectories are characterized by weak perturbations acting on long time scales which, however, rapidly grow in magnitude during planetary flybys. As a result, numerical error may be greatly amplified after a flyby, leading to gravitational scattering of the propagated body. In this work, we use a novel element-based formulation, named "Dromo", to reduce propagation error in trajectories involving at least one Earth flyby. Numerical experiments show that Dromo is able to reduce numerical error for a wide range of trajectories, and it can contain its amplification after a flyby.

11:20 AAS 15-359 An RBF-Collocation Algorithm for Orbit Propagation

Tarek Elgohary, Texas A&M University; John Junkins, Texas A&M University; Satya Atluri, University of California, Irvine

Several analytical and numerical methods exist to solve the classical/unperturbed two-body problem. For the perturbed two-body problem, orbit propagation relies solely on numerical methods mostly higher order adaptive Runge-Kutta methods. Recently, iterative methods have been introduced for orbit propagation based on the Chebyshev-Picard methods. In this work, Radial Basis Functions (RBFs) are used with collocation methods to introduce a fast, accurate integrator that can readily handle orbit propagation problems. The integrator is shown to be capable of taking large time steps while maintaining high accuracy which is very significant in long-term orbit propagation problems.

SESSION 10: ATTITUDE DETERMINATION AND SENSORS

Session Chair: Fu-Yuen Hsiao, Tamkang University

8:00 **AAS 15-341** **Bilinear System Identification by Minimal-Order State Observers**
Francesco Vicario, Columbia University

Bilinear systems can be viewed as a bridge between linear and nonlinear systems, providing a promising approach to handle nonlinear control problems such as satellite attitude control. Recent discrete-time bilinear model identification methods rely on Input-Output-to-State Relationships which can be derived via full-order bilinear state observers. This paper investigates the use of minimal-order state observers to overcome the computational limitations associated with IOSRs based on full-order observers. The advantages are shown to be very significant for a particular class of bilinear models.

8:20 **AAS 15-211** **Observability Analysis and Filter Design for the Orion Earth-Moon Attitude Filter**
Renato Zanetti, NASA JSC; Christopher D'Souza, NASA - Johnson Space Center

The Orion attitude navigation design is presented, together with justification of the choice of states in the filter and an analysis of the observability of its states while processing star tracker measurements. The analysis shows that when the gyro biases and scale factors drift at different rates and are modeled as first-order Gauss-Markov processes, the states are observable so long as the time constants are not the same for both sets of states. These results are used to finalize the design of the attitude estimation algorithm.

8:40 **AAS 15-254** **Discrete and Continuous Time Adaptive Angular Velocity Estimators**
Daniele Mortari, Texas A&M University; Maruthi Akella, The University of Texas at Austin

Two filtering techniques to estimate the angular velocity are presented for spacecraft with no gyros. Motivation arises from the possibility of estimating angular velocity using only star trackers data when the spacecraft is performing slew maneuvers, and/or to provide on-board Kalman filter implementations with good initial angular velocity estimates. Both discrete-time and continuous-time formulations are presented. No prior knowledge of the inertia tensor is required. The state estimates are guaranteed to be smooth functions of time and the convergence properties of the observer are established for all possible rotational motions subject to bounded angular rates.

9:00 **AAS 15-380** **Estimation of Optimal Control Benefits Using the Agilitoid Concept**
Jeffery King, USNA; Mark Karpenko, Naval Postgraduate School

The capability of space-based sensors to collect images is directly related to the agility of the sensor. Increasing the sensor agility can be accomplished using optimal control to design shortest-time maneuvers. Performance improvement is tied to the configuration of the satellite, e.g., mass properties, reaction wheel array geometry, etc. Therefore, it is difficult to predict

performance without extensive simulation. This paper presents a simple method to estimate the performance increase of system using optimal control maneuvering without the need to solve an optimal control problem. This approach is based on the concept of the agilitoid.

9:20 AAS 15-344 Gyro Accuracy and Failure Sensitivity of Underdetermined Coarse Sun Heading Estimation
Stephen O'Keefe, University of Colorado; Hanspeter Schaub, University of Colorado

Coarse sun sensors are commonly used to perform coarse attitude estimation. These sensors are attractive due to their relative inexpensiveness, small size, and minimal power consumption. While, traditionally, these sensors are used in large quantities to ensure redundant sensor coverage over the entire attitude sphere, this research examines underdetermined configurations where not enough sensors are available to uniquely determine the sun direction vector at any one time. The sensitivity of two coarse sun sensor based sun heading estimation schemes to rate gyroscope noise and CSS sensor failure is presented.

9:40 Morning Break

10:00 AAS 15-319 Coarse Sun Acquisition only with Sun Sensors for Micro Satellites
Fu-Yuen Hsiao, Tamkang University; Wei-Ting Chou, Tamkang University; Trendon Cato, Tamkang University; Carla Rebelo, Tamkang University

This paper discusses the algorithm of coarse sun acquisition only with sun sensors for micro satellites. Unlike a larger satellite, the power in a micro satellite is limited and an attitude estimator is usually not functioned at the launching stage. In this paper, an algorithm to perform blind search of sun is developed only with coarse sun sensors. We also consider the eclipse of the sun. A 6DOF model and Monte Carlo simulation method are employed to verify our algorithm. This algorithm will later be applied to the FormoSat 7 constellation, and can be used in any micro satellites.

10:20 AAS 15-392 On-Orbit Coarse Sun Sensor Calibration Sensitivity to Sensor and Model Error
Stephen O'Keefe, University of Colorado; Hanspeter Schaub, University of Colorado

The size and budgetary limitations of increasingly popular small satellites are a driving factor for making the most of inexpensive components and sensors. One such sensor is the coarse cosine-type sun sensor, which is often used, in combination with other sensors, to perform attitude determination. The sensitivity of a Modified Rodriguez Parameter attitude estimation filter, using coarse sun sensor and rate gyroscope measurements, to varying levels of sensor noise and model error is investigated in order to minimize the amount of ground-based support required and increase autonomy.

10:40 AAS 15-425 GOES-R Magnetometer Accuracy
Donald Chu

Magnetometers on the Geostationary Operational Environmental Satellites (GOES) are operational weather instruments rather than attitude sensors, and the challenges of calibrating them differ from those of low-earth research satellites. Accuracy requirements are tighter, and stray fields are more of a problem which leads to magnetometers being placed on long flexible

booms. Not only is there is attitude uncertainty, there is ambient field uncertainty. In spite of this, the GOES magnetometer system is predicted to provide “per axis” accuracy better than 1.7 nanoteslas and root mean square accuracy on the order of one nanotesla.

SESSION 11: LOW-THRUST TRAJECTORY DESIGN

Session Chair: Jeffrey Parker, University of Colorado at Boulder

8:00 AAS 15-397 Coupled Low-thrust Trajectory and Systems Optimization Via Mulit-Objective Hybrid Optimal Control

Matthew Vavrina, a.i. solutions; Jacob Englander, NASA Goddard Space Flight Center; Alexander Ghosh, University of Illinois at Urbana-Champaign

The optimization of low-thrust trajectories is tightly coupled with the spacecraft hardware. Trading trajectory characteristics with system parameters to identify viable solutions and determine mission sensitivities across discrete hardware configurations is labor intensive. Independent, local runs can sample the design space, but a global exploration that resolves the relationships between the system variables across multiple objectives is desired. In this development a multiobjective hybrid optimal control algorithm is formulated using a multiobjective genetic algorithm as an outer-loop systems optimizer around a global trajectory optimizer. The coupled problem is solved to generate Pareto-optimal solutions in a single execution.

8:20 AAS 15-227 Multi-Objective Hybrid Optimal Control for Multiple-Flyby Low-Thrust Mission Design

Jacob Englander, NASA Goddard Space Flight Center; Matthew Vavrina, a.i. solutions; Alexander Ghosh, University of Illinois at Urbana-Champaign

Preliminary design of low-thrust interplanetary missions is a highly complex process. The mission designer must choose discrete parameters such as the number of flybys, the bodies at which those flybys are performed, and in some cases the final destination. The customer who commissions a trajectory design is not usually interested in a point solution, but rather the exploration of the trade space of trajectories between several different objective functions. This can be a very expensive process. This work presents an automated approach by posing the mission design problem as a multi-objective hybrid optimal control problem.

8:40 AAS 15-273 Earth-to-halo low-thrust minimum fuel optimization with optimized launch conditions

Chen Zhang, beihang university; Francesco Topputo, Politecnico di Milano; Zhao Yushan, Beijing University of Aeronautics and Astronautics

Trajectory optimization with optimized launch conditions is studied under Earth-Moon restricted three-body model. The total fuel consumption is minimized, and base on the calculus of variation theory, the first-order necessary condition and analytic Jacobian are derived. These methods are applied to fuel-optimal Earth-Moon L1 transfer with hybrid propulsion system, the simulation reveals that this kind of method can afford various combination of time of flight and total mass consumption, which gives a greater flexibility to the mission designer.

9:00 AAS 15-278 An Automatic Medium to High Fidelity Low-Thrust Global Trajectory Toolchain; EMTG-GMAT

Ryne Beeson; Jacob Englander, NASA Goddard Space Flight Center; Steven Hughes; Maximilian Schadegg, NASA JPL

Optimizing low-thrust, multiple-flyby interplanetary trajectory problems with high-fidelity dynamical models requires significant computational resources. An approach demonstrated in this paper, is a multi-step process whereby a lower-fidelity solution is used as an initial guess for a higher-fidelity solver. The framework presented in this work uses two tools developed by NASA Goddard Space Flight Center: the Evolutionary Mission Trajectory Generator and the General Mission Analysis Tool. A discussion of the tool models as well as examples that highlight the toolchains ability to efficiently solve the difficult low-thrust global optimization problem nearly automatically are given.

9:20 AAS 15-281 Low-Thrust Orbit Transfer Optimization Using Unscented Kalman Filter Parameter Estimation

Ran Zhang, Beihang University; Chao Han, Beihang University; Jian Li

Unscented Kalman filter (UKF) parameter estimation algorithms are applied in solving two-point boundary value problems (TPBVP) for low-thrust orbit transfer scenarios. The algorithms are simple, efficient and robust to overcome the difficulties of guessing the initial values of the costate variables. Environmental constraints such as Earth oblateness and shadow effect are included in both minimum-time and fuel-saving cases. Several numerical simulations are presented to demonstrate the effectiveness of those proposed methods.

9:40 Morning Break

10:00 AAS 15-323 Low thrust minimum fuel optimization to libration point orbits using variable specific impulse engine

Hao Zeng, Beijing Institute of Technology; Jingrui Zhang; Rui Qi; Mingtao Li

Low-thrust minimum fuel-optimal transfer trajectories are studied in the Earth-Moon restricted three-body model with variable specific impulse engines. A hybrid technology, hp-adaptive pseudospectral method combined with sequential quadratic programming, is used to find an optimization solution which satisfies the constraints over the entire path. Meanwhile, the sensitivity of design variables is analyzed quantificationally and analytical gradients are incorporated to improve performance of the algorithm. Therefore, the research includes transfer trajectory from an Earth parking orbit to some sample libration point trajectories including L1 and L2 halo orbits whose invariant manifolds consider lunar flyby and modification.

10:20 AAS 15-434 Mesh Refinement for Low-Thrust Trajectory Optimization of Earth-Orbit Transfers

Kathryn Graham, University of Florida

The problem of determining a mesh refinement method for high-accuracy minimum-time Earth-orbit transfers using low-thrust propulsion is considered. The optimal control transfer problem is posed as a constrained nonlinear optimal control problem and is solved using a variable-order LGR quadrature orthogonal collocation method. A mesh refinement method is developed such that the structure of the low-thrust trajectory is taken into consideration. The

resulting mesh refinement method significantly reduces the number of collocation points and the CPU time compared to a traditional mesh refinement method.

10:40 AAS 15-431 Low-Thrust Orbit-Raising Trajectories Considering Eclipse Constraints
Suwat Sreesawet, Wichita State University; Atri Dutta, Wichita State University

Many revolution electric orbit-raising trajectories make numerous passages through the shadow of the Earth. The paper presents a new algorithm to determine the minimum-time trajectory of the spacecraft during orbit-raising. Standard two-body problem and cylindrical shadow model are assumed. The proposed methodology breaks the minimum-time orbit-raising problem into a series of optimization sub-problems, with each sub-problem attempting to maximize the proximity to the Geostationary orbit at the end of the time horizon. We present results for planar and non-planar orbit-raising scenarios and demonstrate the benefits of the algorithm.

11:00 AAS 15-438 Low-Thrust Trajectory Optimization of Earth-Orbit Transfers with Eclipsing Constraints
Kathryn Graham, University of Florida

The problem of determining high-accuracy minimum-time Earth-orbit transfers with eclipsing constraints using low-thrust propulsion is considered. The optimal control transfer problem is posed as a multi-phase constrained nonlinear optimal control problem and is solved using a variable-order LGR quadrature orthogonal collocation method. The shadow regions are determined assuming spherical celestial bodies. For the GTO to GEO transfer considered, the spacecraft travels through a shadow region 21 times leading to a multi-phase optimal control problem with 22 phases. The optimal trajectory contains 69 orbital revolutions and a flight time of 49 days.

SESSION 12: ORBITAL DEBRIS

Session Chair: Thomas Starchville, The Aerospace Corporation

8:00 **AAS 15-204** **Methodology for Characterizing High-Risk Orbital Debris in the Geosynchronous Orbit Regime**
Paul Anderson, University of Colorado Boulder; Hanspeter Schaub, University of Colorado

Methodology for identifying debris objects that pose the highest risk to operational satellites in the geostationary (GEO) ring is presented. Proximity and speed relative to GEO during near-miss events detected via a torus intersection metric are translated into a risk factor that is accumulated during propagation. This accumulated risk is used to identify objects that have the highest risk contributions, globally or in the vicinity of one of the gravitational wells. Results show that 60% of the total risk near the Western well is attributed to 10 derelicts alone, which has critical implications for active debris removal target selection.

8:20 **AAS 15-205** **Conjunction Challenges of Low-Thrust Geosynchronous Debris Removal Maneuvers**
Paul Anderson, University of Colorado Boulder; Hanspeter Schaub, University of Colorado

The challenges of using low-thrust engines for continuous thrust re-orbiting of geosynchronous (GEO) objects are investigated, with applications to end-of-life mitigation and active debris removal (ADR) technologies. In particular, the low maneuverability of low-thrust systems renders collision avoidance a challenging task. This study considers the number of conjunction events that a low-thrust system could encounter with the current GEO debris population during re-orbit to 300 km above GEO. Sensitivities to thrust level and initial longitude and inclination are evaluated, and a guidance strategy for collision avoidance is tested on a worst-case trajectory.

8:40 **AAS 15-236** **Analysis of the evolution of space debris through a synthetic population**
Daniel Casanova, Centro Universitario de la Defensa; Anne Lemaitre, University of Namur; Alexis Petit

Space debris are all man-made objects orbiting about the Earth which no longer serve a useful function. Space debris have increased substantially in the last decades and can be counted in millions. This paper deals with the idea of the creation of a synthetic population of space debris, which preserves as accurate as possible the characteristics of the real one. All the individuals of the synthetic population will be propagated by powerful numerical integrators, becoming into an excellent tool for global predictions or simulations, useful for the future ADR actions, and for the location of parking orbits.

9:00 **AAS 15-264** **Short Period Variations in Angular Velocity and Obliquity of Inactive Satellites Due to the YORP Effect**

Antonella Albuja, University of Colorado at Boulder; Daniel Scheeres, University of Colorado

The Yarkovsky–O'Keefe–Radzievskii–Paddack (YORP) effect is a proposed explanation for observed variations in the rotational period of inactive satellites. This paper analyzes the short period variations of the angular velocity and obliquity of a defunct satellite as a result of the YORP effect. These variations are used to find limits for the expected behavior of the rotational period of inactive satellites over short time frames. These bounds can be used to better compare simulation results to observed changes in rotational period.

9:20 **AAS 15-293** **2D continuity equation method for space debris cloud collision analysis**
Francesca Letizia, University of Southampton; Camilla Colombo, Politecnico di Milano; Hugh Lewis, University of Southampton

Small fragments are rarely included in the propagation of the debris population as their number is so large that the computational time would become prohibitive. However, they also can be dangerous to operational satellites, so it is interesting to study their contribution to the collision probability. This work proposes an analytical method to propagate fragment clouds, whose evolution under the effect of drag is studied on the space defined by the semi-major axis and eccentricity. This approach provides an analytical expression of the cloud density that can be translated into a quick assessment of the collision probability in several

9:40 **Morning Break**

10:00 **AAS 15-335** **Integration of coupled orbit and attitude dynamics and impact on orbital evolution of space debris**
CLEMENCE LE FEVRE, CNES; Vincent Morand, CNES

This paper addresses the integration of coupled orbit and attitude dynamics over the long term and analyses the impact of attitude motion on the orbital evolution of space debris. The computation of such 12-DOF motion becomes a challenging problem when talking about efficient numerical integration. The solution of integration with the Encke type correction algorithm is analyzed. Results of coupled trajectories for different space objects orbiting the Earth are presented, as well as sensitivity analysis to initial conditions and integration steps.

10:20 **AAS 15-345** **Density of the built orbital environment from an object catalog**
Liam Healy, Naval Research Laboratory; Christopher Binz, Naval Research Laboratory; Kevin Reich, Naval Research Laboratory

A density function in orbital element space provides a prior for a Bayesian computation of probability density. The orbital catalog can provide this initial density function. A histogram with wide bins is poorly resolved, and gives little information; one with narrow bins has either zero or one object in it, and also gives little information. Kernel density estimation methods have been developed and applied in a variety of fields and are presented here applied to orbital density estimation to resolve this conundrum. Clustering techniques and knowledge of orbital purpose to determine orbital neighborhoods are used to help refine these estimates.

10:40 AAS 15-260 On the modelling and simulation of tether-nets for space debris capture
Eleonora Botta, McGill University; Inna Sharf, Mcgill University; Arun Misra

A proposed method for containing the growth of space debris, which jeopardizes operation of spacecraft, is the active debris removal of massive derelict spacecraft and launcher upper stages by means of tether-nets. The behavior of such systems in space is not well-known: numerical simulation is needed to gain understanding of deployment and capture dynamics. In this paper, a lumped parameters approach for modelling the net, and different models of contact dynamics are combined. The ability of the tool developed to simulate multiple dynamic conditions is demonstrated, and linear and nonlinear models for the normal contact force are compared.

11:00 AAS 15-403 Effects of thermal re-radiation using on orbit and attitude of high area-to-mass ratio objects using different models: yorp and yarkowski
Carolin Frueh, Purdue University

High area-to-mass ratio (HAMR) objects are extremely sensitive to orbital and attitude perturbations. In geostationary orbits the main non-conservative source of perturbations is solar radiation pressure. Whereas the radiation pressure modeling, and self-shadowing effects have been studied in the past, the thermal re-radiation has been largely neglected so far. In the investigation of asteroids thermal attitude effects, YORP/YARKOWSKI, are a well investigated topic. The current paper investigates the thermal re-radiation effect on orbit and attitude of multi-layer insulation HAMR objects. The simplest possible model and more advances finite element models are compared.

SESSION 13: SPACE SITUATIONAL AWARENESS II

Session Chair: Carolin Frueh, Purdue University

13:30 AAS 15-394 Collision Probability Using Multidirectional Gaussian Mixture Models
Vivek Vittaldev, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin

The number of tracked space objects is trending upwards, raising the need for accurate and fast collision probability computations. Gaussian Mixture Models (GMMs) provide a compromise between accuracy and runtime by better approximating the true non-Gaussian distributions during conjunction. A conventional GMM splits along a single direction, limiting its use for transformations that are highly nonlinear in multiple directions. In this study, we propose the use of Multidirectional GMMs (MGMMs) to improve the collision probability accuracy in cases that are highly non-Gaussian. The method is formulated and examined using several test cases.

13:50 AAS 15-366 Fast Selection of Debris Subset for Conjunction Analysis using k-vector
Daniele Mortari, Texas A&M University; Roberto Furfaro, The University of Arizona

To perform a reliable conjunction analysis a time-consuming high accurate propagation capability is required. Due to the high number of detected and tracked debris this task becomes almost computationally prohibitive. This paper provides two k-vector based approaches to perform: a) management of debris database and b) quick selection of the smaller subset of debris that can be considered potential candidates for conjunction. This way just a smaller subset of debris will be considered for accurate conjunction analysis. This is done by extending the k-vector to modular arithmetic. Numerical tests are provided using SGP4 propagation model.

14:10 AAS 15-404 Probability of detection, clutter and measurement accuracy modeling for an optical ground based sensor in space situational awareness observations
Carolin Frueh, Purdue University

For the multi-object tracking in a Bayesian or multi hypothesis frameworks in space situational awareness (SSA), probabilistic expressions for the probability of detection of objects, as well as rates for clutter and the accuracy of the measurements are needed. These quantities depend on the observed objects (orbit, attitude) as well as reflection properties and geometries as well as the sensor mode and specifications. This paper derives the mathematical framework to assess these quantities for a given sensor setup.

14:30 AAS 15-409 GEODETICA: A General Software Platform for Processing Continuous Space-Based Imagery
Brad Sease, Virginia Polytechnic Institute and State University; Brien Flewelling, Air Force Research Laboratory

In this paper we describe a general tool for detection and tracking of objects in unresolved

space-based imagery. Through the use of Phase Congruency edge detection and a Bayesian, multi-hypothesis point tracking framework, this tool provides an automated data processing suite for ground- and space-based observers. Here we detail the internal operation of the algorithm, present some real and simulated verification scenarios, and discuss the limitations of the algorithm.

14:50 AAS 15-410 Multi-Stereo Resident Space Object Discrimination and Ranging

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

A method is proposed for using multi-view epipolar geometry to quickly discriminate and range resident space objects (RSOs) in the field of view of a multi-observer system. This method can be used to identify RSOs from a ground- or space-based optical system. The intersections of epipolar lines are then used to probabilistically associate objects of interest in a set of images from multiple observers. The association false-positive probability is quantifiable for multi-sensor configurations, and high certainties can be achieved. The objects of interest are then filtered by range to exclude non-Earth orbiting bodies.

15:10 Afternoon Break

15:30 AAS 15-412 Polar and spherical image transformations for star localization and RSO discrimination

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

Detection and discrimination of resident space objects is complicated by field rotation during the exposure. This produces ``streaked'' images, in which an object's size and shape is dependent on its location in the image. By resampling the original image about the axis of rotation, it is possible to remove the curvature from star streaks and produce an image wherein all star streaks have uniform appearances. Streak lengths in the resampled image correspond directly to the magnitude of the field rotation during the exposure. Further, resident space objects (RSOs) in the original image become clearly differentiated from the stellar background.

15:50 AAS 15-455 Sensor resource management for sub-orbital multi-target tracking and discrimination

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

This paper addresses a problem for efficient use of limited sensor resources for time constraint solution to support threat mitigation and threat situation assessment, arising from a cluster of unknown mix of threatening and non-threatening sub-orbital space objects. Sensor resources are allocated to track targets, identify and discriminate threat vs non-threat objects, and support a threat engagement needs by providing time-bound required quality of track estimation. The approach includes sensor task management prioritizing tasks based on situation awareness, information theory based sensor assignment maximizing expected information gain under the measurement constraints resulting from limited sensor capabilities.

16:10 AAS 15-360 Visualizing the Dissipation of High-Risk Regions in Breakup Debris Clouds

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

When satellite breakups are caused by hypervelocity impacts or explosions, it is important to assess and communicate the long-term environmental impact of the resulting debris clouds. Existing methods for visualizing long-term evolution of the debris environment tend to over-represent the persistence of dangerous risk regions. We present a new method that more accurately assesses and communicates the dissipation of these high-risk regions, highlighting the evolution of peak density as a function of altitude, inertial location, and time. Included is a discussion of how this method was enabled by efficient memory management techniques and particle binning algorithms.

16:30 AAS 15-391 Density of debris fragments through Differential Algebra and Averaged Dynamics

Camilla Colombo, Politecnico di Milano; Alexander Wittig, Politecnico di Milano; Francesca Letizia, University of Southampton; Roberto Armellin, University of Southampton

In this work Differential Algebra (DA) techniques are coupled with Semi-Analytical (SA) averaged dynamics to describe the density evolution of debris fragments and to assess the consequent collision probability. Given an initial probability density function, DA is used to propagate the probability density function to any given time by means of a high order polynomial expansion. The effect of orbit perturbations is described through averaged dynamics. We use the proposed DA+SA approach to represent the time evolution of a cloud of debris fragments in Medium Earth Orbit and to compute the collision probability over a target spacecraft.

SESSION 14: ASTRODYNAMICS INNOVATION AND DATA SHARING

Session Chair: Felix Hoots, The Aerospace Corporation

13:30 AAS 15-465 Technical Research Area Identification Working Group Process
Michele Gaudreault, HQ AFSPC/A2

13:50 AAS 15-332 Propagation of Uncertainty in Support of SSA Missions
Aubrey Poore, Numerica Corporation

The achievement of covariance/uncertainty realism is needed for several SSA mission areas and encompasses the quantification of uncertainty in sensor level processing, dynamics and space environment modeling, inverse problems such as statistical orbit determination, and the propagation of uncertainty. This presentation surveys some of the many methods being developed by the astrodynamics community for faithfully propagating uncertainty or covariances. To assist with a comparison of methods, we propose a set of metrics and an initial list of benchmark test cases. These are then demonstrated using the extended Kalman, the unscented Kalman, and the Gauss von Mises filters.

14:10 AAS 15-349 Satellite Breakup Processing
Felix Hoots, Aerospace Corporation; Robert Morris, Aerospace Corporation

The breakup of a satellite presents an immediate challenge to the Space Surveillance Network (SSN). Each new piece will generate an uncorrelated track (UCT) when it passes through a radar's coverage. These UCT's must be grouped together to form self consistent orbits. We apply a previously unpublished method first developed in the 1960's to recently released SSN tracking data to demonstrate the ability of an automated method to quickly process breakup UCT's. We also compare the results of breakup time determination using the classical backwards orbit prediction method to a recent method by Hoots using just

14:30 AAS 15-374 Analysis of Resident Space Object Tracking Data Using Hierarchical Mixtures of Experts
Elfego Pinon, Emergent Space Technologies, Inc.; Jessica Anderson, Emergent Space Technologies, Inc.

Sample SSN tracking data, recently made available through the AFSPC Astrodynamics Innovation Committee, presents a unique opportunity to test resident space object (RSO) tracking techniques and algorithms that have until now only been used to process simulated observation data. Emergent Space Technologies, Inc. has been involved in RSO tracking research through several SBIRs sponsored by Air Force Research Laboratory (AFRL) and has recently investigated the use of Hierarchical Mixtures of Experts (HMEs) to process simulated electro-optical measurements to determine an RSO's attitude profile. This paper describes the results of applying HMEs to the sample SSN tracking data.

14:50 AAS 15-420 Tracking of the Landsat 2 Rocket Body Primary Breakup
Kyle DeMars, Missouri University of Science and Technology; James McCabe, Missouri University of Science and Technology

The tracking of multiple space objects is a problem of vital importance in realistically predicting the forward behavior of space objects. Beyond the fact that there already exist a large number of space objects in orbit, new objects can be introduced through launches, separations, or fragmentation or delamination processes. This paper investigates the application of an approximate Bayesian multiple object tracking algorithm to data collected on the primary breakup event associated with the Landsat 2 rocket body. Results are presented for estimating the number of objects stemming from the event as well as localization estimates on each of the objects.

15:10 Afternoon Break

15:30 AAS 15-449 Astrodynamics collaborative environment: a step toward data sharing and collaboration via the air force research laboratory
Moriba Jah, Air Force Research Laboratory

As a result of the National Research Council's "Continuing Kepler's Quest" study, the Air Force Space Command (AFSPC) reinvigorated what is now called the Astrodynamics Innovation Committee (AIC). One of the activities of the AIC is to create and maintain an environment where the global astrodynamics community can have access to various data sets, algorithms, and tools called the Astrodynamics Collaborative Environment (ACE). The Air Force Research Laboratory has been explicitly invoked to create and maintain ACE for AFSPC. An actual data set has been provided to the community and its analyses are the subject of this session.

SESSION 15: TRAJECTORY OPTIMIZATION

Session Chair: Robert Melton, Pennsylvania State University

13:30 AAS 15-237 Optimization of Many-Revolution, Electric-Propulsion Trajectories with Engine Shutoff Constraints
Jason Reiter, The Pennsylvania State University; David Spencer, The Pennsylvania State University

Many-revolution, solar-electric-propulsion trajectories are difficult to computationally optimize. One of the most significant, unsolved problems with optimizing low-orbit trajectories using feedback control is eclipse constraints. Employing a new forward-looking feedback control technique, however, allows for an optimization of the trajectory including the effects of eclipses or any other arbitrary engine shutoff periods. The control law applies weightings to the optimal thrusting angles based on the spacecraft's relative instantaneous efficiency over one revolution, which includes the effect of the engine shutoffs. This method also facilitates simple exploration of the propellant versus time trade space in

13:50 AAS 15-246 A study on trajectory optimization of Korean lunar orbiter using pattern search method
Sujin Choi; Sang-Cher Lee, Korea Aerospace Research Institute; Hae-Dong Kim

This paper performed trajectory optimization research of lunar orbiter using Pattern Search method to minimize required ΔV regarding direct transfer trajectory. This method generates neighborhood points near initial condition of control variable and then searches if there is new point that can reduce objective function value. Although classical method requires gradient and acceleration of objective function, Pattern Search doesn't need to. Optimization results such as ΔV, TOF and numbers of function call by combinations of poll and search methods are plotted. As a result of simulation, 'MADSNp1' poll method could reduce required ΔV by changing TOF.

14:10 AAS 15-372 A Crewed Mars Exploration Architecture Using Flyby and Return Trajectories
Andrew Thomas, NASA JSC, Cesar Ocampo, Odyssey Space Research/NASA-JSC; Damon Landau, NASA / Caltech JPL

A sustainable human Mars exploration architecture is presented that uses Mars flybys and return trajectories. Several mission trajectory models are considered that differ in the number of transit habitats needed and the type of Earth-Mars flyby and return trajectories used. The existence and operation of the Space Launch System and the Orion Crew and Service modules is assumed. The capability for hyperbolic rendezvous and complex orbital operations at Mars is needed. Representative solutions and selected mission performance data are presented for missions in the 2020-2050 time frame.

14:30 AAS 15-393 Massively Parallel Optimization of Target Sequences for Multiple-Rendezvous Low-Thrust Missions on GPUs
Mauro Massari, Politecnico di Milano; Alexander Wittig, Politecnico di Milano

In this work a massively parallel method for identification of optimal sequences of targets in multiple-rendezvous low-thrust missions using GPU processors is presented. Given a list of possible targets, an exhaustive search of sequences compatible with mission requirements is performed. To estimate feasibility of each transfer, a heuristic model based on Lambert transfers is evaluated in parallel. The resulting sequences are ranked by user-specified criteria such as length or fuel consumption. The algorithm has been used to compute asteroid sequences for GTOC7. The efficiency of the method is further demonstrated by comparing it with traditional genetic optimization.

14:50 **AAS 15-298** **High-Speed, High-Fidelity Low-Thrust Trajectory Optimization through Parallel Computing & Collocation Methods**

Jonathan Herman, University of Colorado at Boulder; Jeffrey Parker, University of Colorado; Brandon Jones, University of Colorado, Boulder; George Born, University of Colorado at Boulder

This study develops a parallel implementation of a collocation-based low-thrust trajectory optimization method. It compares serial performance to parallel performance on both the Central Processing Unit (CPU) and the Graphical Processing Unit (GPU) for Gauss-Lobatto collocation schemes. The parallelized implementations significantly reduce the computation time to solve the optimization problem, enabling rapid design of very complex low-thrust trajectories.

15:10 **Afternoon Break**

15:30 **AAS 15-216** **Trajectory optimization using discrete sets of pseudoimpulses: a review of advantages and difficulties**

Yuri Ulybyshev, Rocket-Space Corp. ENERGIA

A review of methods for trajectory optimization using discrete sets of pseudoimpulses is presented. The methods are based on a near-uniform discrete approximation of a control space by a set of pseudoimpulses. Terminal conditions are presented as a linear matrix equation. A matrix inequality on the sum of the characteristic velocities for the pseudoimpulses is used to transform the problem into a large-scale linear programming form. A critical review of advantages and difficulties of the methods is described. For nonlinear problems, an iterative technique can be used. Examples for various spacecraft are presented.

15:50 **AAS 15-370** **Low-thrust trajectory optimization in Dromo variables**

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

The Dromo orbital propagator was recently introduced by Peláez et al., and has been under active development. It has proven to be an excellent propagation tool, both in terms of accuracy and computational cost. In this article, we explore its applicability to the solution of optimal control problem in low-thrust missions. To this end, an optimal control formulation based in Dromo and a direct transcription method is used to solve several LEO-GEO and escape from Earth problems; the obtained results clearly show the suitability of this orbital propagation for such purposes.

16:10 AAS 15-354 Vertical Takeoff Vertical Landing Spacecraft Trajectory Optimization via Direct Collocation and Nonlinear Programming

Michael Policelli, Space Exploration Technologies Corp. (SpaceX); David Spencer, The Pennsylvania State University

Optimal rocket-powered translational Vertical Takeoff Vertical Landing trajectories are analyzed. This vehicle would take off vertically under rocket propulsion, translate a specified horizontal distance, and vertically return softly to the surface. The trajectory optimization model developed was robust and able to handle a wide range of various spacecraft and mission parameters. Results were compared against the required propellant use and nominal time of flight determined via the ballistic-impulse burn-coast-burn analysis. For the finite model developed, the required propellant use and optimal flight times exceeded the ideal impulsive case by 5-30% for various spacecraft mission parameters.

16:30 AAS 15-364 Optimal Low-Thrust-Based Rendezvous Maneuvers

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

The minimum-time, low-constant-thrust, same circular orbit rendezvous problem is studied using a relative motion description of the system dynamics. The resulting Optimal Control Problem in the thrust orientation angle is formulated using both the Direct and Indirect method. An extensive set of test cases is numerically solved with the former, while perturbation techniques applied to the later allow to obtain several approximate solutions and provide a greater insight on the underlying physics. These results show that the structure of the solutions undergoes fundamental changes depending on the value of the non-dimensional thrust parameter.

SESSION 16: SMALL BODY PROXIMITY OPERATIONS

Session Chair: Laureano Cangahuala, Jet Propulsion Laboratory

13:30 AAS 15-389 Quantifying Mapping Orbit Performance in the Vicinity of Primitive Bodies
Thomas Pavlak, NASA / Caltech JPL; Stephen Broschart, NASA / Caltech JPL; Gregory Lantoine, NASA / Caltech JPL

Predicting and quantifying the capability of mapping orbits in the vicinity of primitive bodies is challenging given the complex orbit geometries that exist and the irregular shape of the bodies themselves. This paper employs various quantitative metrics to systematically characterize the performance and relative effectiveness of various types of mapping orbits including terminator, quasi-terminator, "hovering," and conic trajectories. Metrics of interest include surface area coverage, lighting conditions, and variety of viewing angles achieved. The metrics discussed in this investigation are intended to enable mission designers and project stakeholders to better characterize candidate mapping orbits during preliminary mission formulation activities.

13:50 AAS 15-296 Philae landing site selection and descent trajectory design
eric jurado, Centre National d'Etudes Spatiales; alejandro Blazquez, Centre National d'Etudes Spatiales; Thierry Martin, Centre National d'Etudes Spatiales; Elisabet Canalias, Centre National d'Etudes Spatiales; Thierry Ceolin; Romain Garmier; Jens Biele, DLR; laurent jorda, Laboratoire d'Astrophysique de Marseille; jean-baptiste vincent, Max Planck Institut für Sonnensystemforschung; julien laurent-varin, CNES/GRGS

The European mission Rosetta has reached its target comet Churyumov-Gerasimenko in August and it will deliver the Philae Lander on the comet nucleus surface in November 2014. This paper addresses the Flight Dynamics studies for the Philae Landing Site Selection. The selection process is very complex and relies heavily on science data products from the Orbiter instruments. Comet models have been generated and used to choose the nominal and backup landing sites on the 14th September 2014. This paper also reports on the actual landing, comparing the predicted design strategy with the reconstructed landing conditions

14:10 AAS 15-424 Accurate deployment of landers to dynamically challenging asteroids
Simon Tardivel, University of Colorado Boulder; Daniel Scheeres, University of Colorado

This paper investigates the ballistic deployment of landers to dynamically challenging asteroids, in the context of the current NASA Discovery mission proposal BASiX. Dynamically challenging asteroids are fast rotators, where the amended gravitational acceleration almost vanishes near the equator. In the studied architecture, a mothership flies by the asteroid at high altitude and releases the lander on a ballistic trajectory towards its target. Given fixed constraints and GNC capabilities, the landing time and spread can be reduced manyfold with fine adjustments of the lander's orbit parameters such as the radius of periapse, the inclination, or the argument of periapse.

14:30 AAS 15-445 Heliotropic orbits at asteroids: zonal gravity perturbations and application at bennu

Demyan Lantukh, The University of Texas at Austin; Ryan Russell, The University of Texas at Austin; Stephen Broschart, NASA / Caltech JPL

Analytical inclusion of high order zonal gravity harmonics and solar radiation pressure enables heliotropic orbits to be found at irregular primitive bodies like Bennu, the target of the OSIRIS-REx mission. Using a constrained, doubly-averaged disturbing potential in the Lagrange Planetary Equations yields inclined, long-lifetime, low-altitude science orbits. The existence of heliotropic orbits is shown to be robust to uncertainty in the gravity parameters of Bennu. Examples show how heliotropic orbits persist in the presence of other gravity perturbations as well.

14:50 AAS 15-330 Orbital Perturbation Analysis near Small Body Binary Systems

Loic Chappaz, Purdue University; Stephen Broschart, NASA / Caltech JPL; Gregory Lantoine, NASA / Caltech JPL; Kathleen Howell

Current estimates indicate that approximately sixteen percent of the known near-Earth asteroid population may be binaries. Within the context of exploring the dynamical behavior of a spacecraft near such systems, a first step in the analysis is an assessment of the perturbing effect that dominates the dynamics of the spacecraft. The relative strength of several perturbations, including the perturbation that arises from the existence of a binary system, rather than a single body system, is compared exploiting 'zonal maps'. Such a map is useful in determining the type of orbit that is practical to support a given mission scenario.

15:10 Afternoon Break

15:30 AAS 15-430 Asteroid Landing Guidance Design in the Framework of Coupled Orbit-Attitude Spacecraft Dynamics

Gaurav Misra, New Mexico State University; Amit Sanyal, New Mexico State University; Ehsan Samiei, New Mexico State University

This paper addresses the asteroid landing guidance and control problem for a rigid body spacecraft. The traditional approach for close proximity operations around small bodies considers the translational motion to be described a point mass while the attitude motion is considered to be decoupled from the translational motion. While, in this paper we consider a fully coupled spacecraft dynamics model for guidance and control design to ensure soft landing on a small body. A nonlinear continuous time feedback guidance scheme is implemented to guarantee that the spacecraft reaches the desired point on the asteroid surface in finite time.

15:50 AAS 15-466 Asteroid flyby gravimetry via target tracking

Justin Atchison, Johns Hopkins University Applied Physics Laboratory

We propose a technology for discerning the gravity fields and mass distribution of a solar system small body, without requiring dedicated orbiters or landers. Instead of a lander, a spacecraft releases a collection of small, simple probes during a flyby past an asteroid or comet. By tracking those probes from the host spacecraft, one can estimate the asteroids gravity field and infer its underlying composition and structure.

16:10 AAS Spin State Estimation of Tumbling Small Bodies
15-363 *Corwin Olson, UT Austin; Ryan Russell, The University of Texas at Austin; Shyam Bhaskaran, NASA / Caltech JPL*

It is expected that a non-trivial percentage of small bodies that future missions may visit are tumbling (in non-principal axis rotation). An EKF Simultaneous Localization and Mapping (SLAM) method is used to estimate the small body spin state with optical landmark measurements, as well as the spacecraft position, velocity, attitude, and surface landmark locations. An example scenario based on the Rosetta mission is used, with a tumbling small body. The SLAM method proves effective, with order of magnitude decreases in the spacecraft and small body spin state errors after less than a quarter of the comet characterization phase.

16:30 AAS Divergence Characteristic of the Exterior Spherical Harmonic Gravity Potential
15-427 *Kiichiro DeLuca, University of Colorado Boulder; Daniel Scheeres, University of Colorado*

In order to quantify the divergence characteristic of the classical exterior spherical harmonic expansion for the gravitational potential field modeling of non-spherical mass distributions, a simplified small body model consisting of just two point masses is introduced. Using the simplified model, tractable closed form solutions of the true, exterior spherical harmonic, and interior spherical harmonic gravity potentials are derived to investigate the divergence characteristic. Result from this investigation show that that some regions within the Brillouin sphere show asymptotic series behavior. A method for approximating the error of the exterior spherical harmonic potential is presented and demonstrated.

SESSION 24: FLIGHT MECHANICS ASPECTS OF THE LADEE MISSION

Session Chair: Lisa Policastri, SkySentry Stratospace Technologies

8:00 AAS 15-212 LADEE Flight Dynamics: Overview of Mission Design and Operations

Arlen Kam, WorldVu; Laura Plice; Ken Galal; Alisa Hawkins, Google/Skybox; Lisa Policastri, Applied Defense Solutions Inc.; Michel Loucks; John Carrico, Applied Defense Solutions; Craig Nickel, Applied Defense Solutions; Ryan Lebois, Applied Defense Solutions, Inc.; Ryan Sherman, Applied Defense Solutions

The Lunar Atmosphere and Dust Environment Explorer (LADEE) mission set out on September 6, 2013 to observe the lunar exosphere at low altitudes. The mission overview of LADEE Flight Dynamics addresses launch dispersions in the first use of the Minotaur V, science orbit maintenance for over five months, high precision past and predicted orbit estimation, the automated approach to calculating over 50000 attitude waypoints, and strong teamwork at an intense operational pace. The unique flight dynamics solutions for the near-circular, near-equatorial orbit in non-uniform lunar gravity resulted in a successful mission from both engineering and scientific standpoints.

8:20 AAS 15-396 Trade studies in LADEE trajectory design

Michel Loucks; Laura Plice; Daniel Cheke, Orbital Sciences Corporation; Cary Maunder, Orbital Sciences Corporation; Brian Reich, Orbital Sciences Corporation

The Lunar Atmosphere and Dust Environment Explorer (LADEE) mission design challenge was a “design to capabilities” approach in a tightly constrained trade space. Several trade studies defined feasible trajectory designs and launch opportunities. The first trade study selected the insertion orbit and identified usable combinations of transfer orbit plane and arrival nodes per launch block. The second trade study assessed each launch block by day with three-sigma launch energy dispersions against several parameters including delta-v budget, beta angle, and maximum shadow duration. Finally, in the third stage, detailed technical and operational considerations dictated the daily launch

8:40 AAS 15-419 LADEE Flight Dynamics System Overview

Craig Nickel, Applied Defense Solutions; John Carrico, Applied Defense Solutions; Lisa Policastri, Applied Defense Solutions Inc.; Ryan Lebois, Applied Defense Solutions, Inc.; Ryan Sherman, Applied Defense Solutions

This paper describes the design and implementation of the Flight Dynamics System (FDS) for the Lunar Atmospheric Dust Environment Explorer (LADEE). This paper also describes how the FDS was utilized by the mission operations team throughout all phases of the LADEE mission operations. Automation of many flight dynamics operations processes was essential to be able to reliably generate and delivery all necessary products keep up with LADEE’s mission operations pace. The FDS was utilized for all flight dynamics functions, including Orbit Determination, Maneuver Reconstruction, Trajectory Design, Maneuver Planning, Attitude Planning, and Products & Acquisition Data Generation.

9:00 AAS 15-230 Pre-launch orbit determination design and analysis for the LADEE mission
Lisa Policastri, Applied Defense Solutions Inc.; John Carrico, Applied Defense Solutions; Craig Nickel, Applied Defense Solutions

The Lunar Atmospheric Dust Environment Explorer (LADEE) successfully launched on September 7, 2013. The LADEE mission requirements relevant to orbit determination are listed. The orbit determination plan for each mission phase is described. Ground station assumptions, tracking schedule assumptions, timelines, goals, methods, and analysis results including gravity modeling approaches are discussed. The authors also present how testing with other operational spacecraft was used to verify the tracking plans and configurations prior to launch. Details are given on the analysis for the launch and early orbit phase as well as the nominal operations.

9:20 AAS 15-270 Attitude design for the LADEE mission
Ken Galal; Craig Nickel, Applied Defense Solutions; Ryan Sherman, Applied Defense Solutions

This paper summarizes attitude design and operations support provided to satisfy the numerous pointing requirements and constraints of the successfully completed LADEE mission. STK scripts used to automate the modeling of more than a dozen LADEE pointing profiles and a graphical tool used to design custom maneuver attitudes that satisfied communications and star tracker occultation constraints are described. Also, provided is an overview of how a set of rules and conventions and long-term constraint violation predictions were used to establish keep-out time-frames for particular attitude profiles in order to manage the complexity of this design challenge.

9:40 Morning Break

10:00 AAS 15-381 Generation of Simulated Tracking Data for LADEE Operational Readiness Testing
James Woodburn, AGI; Brandon Owens, SGT, Inc.; Lisa Policastri, Applied Defense Solutions Inc.

Operational Readiness Tests (ORTs) were an important part of the pre-launch preparation for the LADEE mission. The goal of the ORTs was to demonstrate that the Mission Operations System--including the operations team--was prepared to conduct the planned mission. Simulated tracking data to support the ORTs was constructed based on a trajectory that is deviated from the nominal mission trajectory through injection, maneuver and dynamical model errors. Additionally, tracking data anomalies including step changes in range and Doppler biases and increases in measurement white noise representative of typical ground station were included.

10:20 AAS 15-400 The LADEE Trajectory as Flown
Michel Loucks; Laura Plice; Daniel Cheke, Orbital Sciences Corporation; Cary Maunder, Orbital Sciences Corporation; Brian Reich, Orbital Sciences Corporation

The LADEE spacecraft launched on a Minotaur-V launch vehicle from Wallops Flight Facility on 7 Sep 2013 at 3:27 UTC as planned into a 6.4 day orbit. After three cis-lunar phasing

maneuvers, LADEE achieved Lunar orbit on 6 Oct. 2013, and entered a 232 x 247 km commissioning orbit on 13 Oct. 2013. LADEE performed many successful maneuvers to execute a baseline science plus an extended mission through April of 2014. Final maneuvers executed in early April led to a planned lunar impact on 18 Apr. 2014.

10:40 AAS 15-257 Orbit determination and acquisition for LADEE and LLCD mission operations

Lisa Policastri, Applied Defense Solutions Inc.; John Carrico, Applied Defense Solutions; Arlen Kam, WorldVu; Craig Nickel, Applied Defense Solutions; Ryan Lebois, Applied Defense Solutions, Inc.; Ryan Sherman, Applied Defense Solutions

This paper describes the orbit determination results for the Lunar Atmospheric Dust Environment Explorer (LADEE) from launch through the science operations. This paper also describes how the orbit determination and acquisition team supported the Lunar Laser Communications Demonstration (LLCD). Precise orbit determination was essential to all components in successful maneuver execution, properly correlated science collections, spacecraft situational awareness, and throughout the LLCD acquisition operations. We discuss the concurrent use of overlap analysis with the filter-smoother consistency test as quality-control methods.

11:00 AAS 15-453 LADEE Maneuver Planning and Performance

Alisa Hawkins, Google/Skybox; Arlen Kam, WorldVu; John Carrico, Applied Defense Solutions

The Lunar Atmosphere and Dust Environment Explorer (LADEE) launched on Sept 7, 2013 to investigate the tenuous atmosphere near the surface of the moon. It carried three science instruments and a lunar laser communications demonstration. Thirty one maneuvers were executed during the mission; each requiring careful planning and coordination across the LADEE Operations team at NASA Ames Research Center to plan, execute, and reconstruct. The paper will discuss maneuver planning and recovery workflows, maneuver timelines, and maneuver execution segments used for the LADEE mission. Also included will be a history of maneuver performance during the mission.

SESSION 18: SPACECRAFT GUIDANCE AND CONTROL

Session Chair: Maruthi Akella, University of Texas at Austin

8:00 AAS 15-269 Study on Angles-only Relative Navigation integrated with Guidance based on Observability Analyzing
Baichun Gong, Northwestern Polytechnical University; Jianjun Luo; Jianping Yuan; Weihua Ma, Northwestern Polytechnical University

An angles-only relative navigation algorithm integrated with closed-loop guidance for rendezvous is developed based on observability analysis. The systemic filtering model is established, based on which the observability is investigated from a novel prospect and the observable condition is obtained. Then, the coupling relationship between angles-only relative navigation and multi-pulse sliding guidance is analyzed, and the mathematical expresses are attained. The integrated scheme of relative navigation and closed-loop guidance is designed by using the coupling expresses. The proposed algorithm was tested by simulations, while its robustness to errors was evaluated by Monte Carlo method.

8:20 AAS 15-307 Station-keeping and momentum-management on halo orbits around L2: Linear-quadratic feedback and model predictive control approaches
Uros Kalabic, University of Michigan; Avishai Weiss, MERL; Stefano Di Cairano; Ilya Kolmanovsky, University of Michigan

The control of station-keeping and momentum-management is considered while tracking a halo orbit centered at the second Earth-Moon Lagrangian point. Multiple schemes based on linear-quadratic feedback control and model predictive control (MPC) are considered and it is shown that the method based on periodic MPC performs best for position tracking. The scheme is then extended to incorporate attitude control requirements and numerical simulations are presented demonstrating that the scheme is able to achieve simultaneous tracking of a halo orbit and dumping of momentum, while enforcing tight constraints on pointing error.

8:40 AAS 15-356 Performance Evaluation of Artificial Neural Network-based Shaping Algorithm for Planetary Pinpoint Guidance
Jules Simo, University of Strathclyde; Roberto Furfaro, The University of Arizona; Joel Mueting, The University of Arizona

Computational intelligence techniques have been used in a wide range of application areas. This paper proposes a new learning algorithm that dynamically shapes the landing trajectories, based on potential function methods, in order to provide computationally efficient on-board guidance and control. Extreme Learning Machine (ELM) devises a Single Layer Forward Network (SLFN) to learn the relationship between the current spacecraft position and the optimal velocity field. Furthermore, the proposed efficient algorithm is tested in typical simulation scenarios which include a set of Monte Carlo simulation to evaluate the guidance performances.

9:00 **AAS 15-358** **New Waypoints Generation Method for Fuel-efficient Planetary Landing Guidance**
Yanning Guo, Harbin Institute of Technology; Hutao Cui; Guangfu Ma, Harbin Institute of Technology; Chuanjiang Li

This paper aims to propose an autonomous waypoint generation approach for planetary landing guidance. The fuel optimal results of pinpoint Mars landing show that the control force magnitude always behaves in a "max-min-max" manner, indicating that it switches between extreme values twice. Therefore, we may first take those two switching states as waypoints, and then adopt certain optimal guidance algorithm, such as ZEM/ZEV guidance, to successively bring the spacecraft to waypoints and landing site. Effectiveness and Robustness of this new guidance structure are finally evaluated and analyzed through extensive numerical simulations.

9:20 **AAS 15-458** **Integrated Guidance and Control of Dual-Controlled Near-Space Rendezvous Spacecraft Based-on HOSM**
Feng Yang

Along with the evolution of advanced targets in speed, maneuvering capabilities and flight envelop, the rendezvous spacecraft needs to be enhanced in speed, maneuvering agility and trans-atmospheric flight capability. New challenges emerge in the design of a robust and accurate guidance, navigation and control systems for rendezvous spacecraft. To deal with these challenges, integrated guidance and control system based-on High Order Sliding Mode (HOSM) has been focused on. An integrated guidance and control system based on the HOSM is investigated in this paper.

9:40 **Morning Break**

10:00 **AAS 15-222** **Lunar Landing Trajectory and Abort Trajectory Integrated Optimization Design**
Chengchao Bai; Jifeng Guo; Linli Guo; Ping Wang, China Academy of Space Technology (CAST)

This article is based on Apollo research and aims at design of manned lunar landing trajectory (free return trajectory and hybrid trajectory); with consideration of abort and return after the spacecraft has faults and through application of the hybrid optimization method based on particle swarm optimization (PSO) and sequential quadratic programming (SQP), this article obtains the lunar landing trajectory that meet abort requirements and is optimal in energy consumption, so as to effectively protect lives and safety of astronauts and provide some references for manned lunar trajectory design.

10:20 **AAS 15-317** **Spacecraft safe trajectory integrated guidance and control using artificial potential field and sliding mode control based on hamilton-jacobi inequality**
Dengwei Gao, Science and Technology on Aerospace Flight Dynamics Laboratory; Jianjun Luo; Weihua Ma, Northwestern Polytechnical University

A new algorithm is proposed on the basis of hamilton-jacobi inequality (HJI) theory and the artificial potential field (APF) in the sliding mode control (SMC). Having taken into consideration the effect of bounded output errors on controller performance, this algorithm has been developed for the safe trajectory constraints between two spacecraft. The gradient of APF

provides the three dimensional sliding manifold and the robust sliding mode control laws is designed based on HJI theory. Because of the disturbances, the control laws can restrain the spacecraft around the safe trajectory which is designed by APF.

10:40 AAS 15-450 A Survey of Spaceflight Dynamics and Control Architectures Based on Electromagnetic Effects

Ryan Caracciolo, Cornell University; Mason Peck; Benjamin Reinhardt, Space Systems Design Studio

This paper provides a broad survey of electromagnetic (EM) actuator technology. There are several different technologies that fall under the EM actuator umbrella, each with its own strengths, weaknesses, and applications. The four major technologies are coulomb interaction, electromagnetic formation flight, superconductive flux pinning, dipole interactions, and induction couplers. Each section of the paper outlines the state of the art of one of these technologies, presents its underlying principles and discusses its engineering advantages, disadvantages, and applications.

11:00 AAS 15-447 Adaptive reactionless control of a space snake-arm robot for pre/postcapture of an uncooperative target

Wenlong Li; Zhao Yushan, Beijing University of Aeronautics and Astronautics; Shi Peng, Beijing University of Aeronautics and Astronautics

The dynamics and control of a space snake-arm robot before, during and after the capturing of an uncooperative target is concerned here. A reactionless controller with joint-limit avoidance is designed before the capture. The impact dynamics is discussed to derive the velocities of base and each joint after impact and the conservation of momentum will be checked to validate the model. Then an adaptive reactionless controller is designed for postcapture and the stability is analyzed. Simultaneously, the momentum-based parameter identification method is derived for estimating the unknown properties of the captured target using recursive least

11:20 AAS 15-292 A Novel Differential Geometric Nonlinear Control Approach for Spacecraft Attitude Control

Hao Sun, Northwestern Polytechnical University; Jianjun Luo; Zeyang Yin

In this paper, a novel nonlinear control approach is proposed to solve spacecraft attitude tracking control problem. The methodology presented is based on differential geometry theory and observer-based LQR algorithm. Spacecraft attitude error equations are built using MRPs, and the nonlinear model is linearized through exact feed-back linearization of differential geometry theory. Thus the observer-based LQR algorithm is used to design the controller which needs to be mapped back to the original system to obtain spacecraft attitude tracking control law on basis of differential geometry theory. Finally the proposed approach is tested and validated by numerical simulation.

SESSION 19: SATELLITE CONSTELLATIONS

Session Chair: David Dunham, KinetX Inc.

8:00 **AAS 15-238** **Station-keeping for Lattice-preserving Flower Constellations**
Daniel Casanova, Centro Universitario de la Defensa; Eva Tresaco, Centro Universitario de la Defensa

2D-Lattice Flower Constellations present interesting dynamical features that allow us to explore a wide range of potential applications. Their particular initial structure (lattice) and their symmetries disappear when some perturbations are considered, such as the J2 effect. The new Lattice-preserving Flower Constellations maintain the symmetric configuration under the J2 perturbation. However, even in this case, the initial lattice will be slightly perturbed. This paper deals with the study of the required velocity change that must be applied to the satellites to control the original structure of the constellation in time.

8:20 **AAS 15-303** **Design of constellations for earth observation with inter-satellite links**
Sanghyun Lee, Texas A&M University; Daniele Mortari, Texas A&M University

This paper addresses the problem of designing optimal satellite constellations for observing application. Earth observation missions usually require that the same particular area on Earth is likely to be imaged every certain amount of time and this is achieved by implementing repeating ground track orbits. The 2-D Lattice Flower Constellations (LFC) theory is here applied to design constellations in order to provide repeating ground track. Optimizations are performed using Genetic Algorithms to estimate constellation design parameters and constrained by connectivity of inter-satellite links (ISL) for continuous global communication. Graph theory is used to check connectivity in the constellation.

8:40 **AAS 15-308** **A novel optimization algorithm for constellation using 'superior and inferior' principle**
yao wei; Jianjun Luo; chaofei zhang

The design of Satellite Constellation is one of the most important steps to carry out space missions. This paper focuses mainly on the problem of how to design and optimize the relevant parameters of a walker constellation to achieve global discontinuous coverage mission. The time consuming of existing method are always too much. To conquer this problem, a novel constellation optimization algorithm using 'superior and inferior' and 'reverse coverage' principle is proposed. The fundamental theories, design process and numerical simulation by Matlab and STK of novel method are provided. The results verify the feasibility and effectiveness of present optimization algorithm.

9:00 **AAS 15-357** **Method of Satellite Orbit and Constellation Design for Earth Discontinuous Coverage with Minimal Satellite Swath under the Given Constraint on the Maximum Revisit Time**
Yury Razoumny, Moscow Aviation Institute

In order to provide efficient and cost-effective Earth observations, the method of minimization of satellite swath width required is introduced. The method is based on optimization of orbit and constellation parameters under the given constraint on the traditional quality index of the satellite constellations for discontinuous coverage – maximum revisit time. The optimization problem setting, basic analytic solutions, general solution of the problem and its important particular cases, as well as illustrated numerical results, are developed and presented.

9:20 AAS 15-208 Attitude maneuver strategy of agile earth observing satellite constellation
Xinwei Wang, Beihang University

Obtaining the attitude maneuver strategy of agile earth observing satellites (AEOS) constellation is a complicated combinatorial optimization problem. A decomposition optimization algorithm for this problem is proposed, which could be divided into two parts: satellites & targets matching method, and the directed acyclic graph theory. The former is to dispatch observing targets to satellites, and the latter is to obtain every single satellite attitude maneuver strategy. Furthermore, three typical observing modes are defined to describe the medium Earth orbit AEOS constellation operating conditions. Numerical results indicate the attitude maneuver strategy has been derived in every typical observing mode.

9:40 Morning Break

10:00 AAS 15-338 Optimal Control of Martian Constellations of Artificial Frozen Orbiters and Artificial Sun-Synchronous Orbiters using Continuous Low-thrust propulsion
Zhigang Wu, Tsinghua University; Qin Chen; Li Junfeng

The continuous low-thrusts control strategies of artificial frozen and Sun-Synchronous orbit are mentioned. The second part of this article focuses on the optimal structure of the Martian constellations of artificial Frozen Orbiters and artificial Sun-Synchronous Orbiters using the continuous low-thrust propulsion. The Multi-objective Evolutionary Algorithm Based on Decomposition was use as the optimization framework. Numerical Results are analyzed for the respective continuous low-thrust control and the synchronized continuous low-thrust control for Orb-As and Orb-Bs. Simulations show the synchronized control strategy can save more energy.

SESSION 20: ASTRODYNAMICS TECHNIQUES

Session Chair: Roby Wilson, Jet Propulsion Laboratory

8:00 AAS 15-217 Galerkin approximations for solving the finite-time hjb and hji equations used for feedback control in space trajectory and applications
Rajnish Sharma, University of Maryland Eastern Shore

This paper extends the traditional Galerkin methods to accommodate finite-time optimal control problems with terminal constraints. The solution procedure first encounters a time-dependent GHJB. Then the solution of governing GHJB is used to obtain the solution for the finite-time HJB, a nonlinear partial differential equation. The discussion is centralized on the iterative scheme used for feedback control synthesis. The same iterative method is investigated to solve the governing Hamilton-Jacobi-Isaacs (HJI) equation for game-theoretic problems. Including a comparative study on 1-D problems, numerous examples on spacecraft control are demonstrated in detail using the technique.

8:20 AAS 15-249 Robust high-fidelity gravity-assist trajectory generation using forward/backward multiple shooting
Martin Ozimek, The Johns Hopkins University Applied Physics Laboratory; Justin Atchison, Johns Hopkins University Applied Physics Laboratory; Christopher Scott, The Johns Hopkins University Applied Physics Laboratory

Conversion of preliminary, gravity-assist interplanetary trajectories into higher-fidelity solutions is a common need for mission design. In recent decades, this problem has benefited from the placement of free variables at the gravity-assist bodies, followed by iterative constraint reduction in deep space. This procedure, involving forwards/backwards numerical integration and multiple shooting, is essential for maintaining the trajectory's topology during differential correction, enabling robust convergence. The resulting benefit is analyzed through comparison to commonly-used single shooting approaches. The approach is also portable to many software packages, and a generalizable implementation is presented in Systems Tool Kit.

8:40 AAS 15-271 A modified UPE method to design two-impulse earth-moon transfers in a four-body model
Hongli Zhang, Beihang University; Francesco Topputo, Politecnico di Milano; Chen Zhang, beihang university; Chao Han, Beihang University

A hybrid Unscented Parameter Estimation (H-UPE) algorithm is proposed for the efficient design of two-impulse Earth-Moon transfers in the planar bicircular restricted four-body model. This scheme is an extension of Unscented Kalman Filter parameter estimation that accommodates Newton's method (NM). The original problem is firstly converted to a new state-space representation and UPE is then utilized in the initial iterations to take advantage of its wide-range convergence ability. Then NM is used in the final iterations to take advantage of fast local convergence. Numeric tests show that H-UPE obtains a good balance

9:00 AAS 15-274 Numerical Computation of a Continuous-Thrust State Transition Matrix Incorporating Accurate Hardware and Ephemeris Models
Donald Ellison, University of Illinois at Urbana-Champaign Aerospace Engineering Department; Bruce Conway, University of Illinois at Urbana-Champaign; Jacob Englander, NASA Goddard Space Flight Center

Calculation of the problem constraint gradients for direct method spacecraft trajectory optimization problems is often accomplished through the computation of the spacecraft's state transition matrix (STM). If a high-fidelity dynamics model, including the gravitational effects from multiple bodies, is used then these STM's must be computed numerically. We present a method for the computation of an STM that incorporates an accurate solar electric hardware model and a high-fidelity ephemeris. An adaptive-step embedded Dormand-Prince integrator including a method for the analytic computation of the time of flight derivatives in this framework is discussed.

9:20 AAS 15-373 Method of Particular Solutions and Kustaanheomi-Stiefel Regularized Picard Iteration for Solving Two-Point Boundary Value Problems
Robyn Woollands; Julie Read; Brent Macomber, Texas A&M University; Austin Probe; Ahmad Bani Younes, Texas A&M University; John Junkins, Texas A&M University

The Method of Particular Solutions is a shooting technique for solving nonlinear TPBVPs. We implement this with the IVP implementation of Modified Chebyshev Picard Iteration (MCPI) and solve the regularized perturbed orbital equation. In Cartesian coordinates MCPI converges over about 3.3 orbits. Regularizing using the Kustaanheimo-Stiefel transformation increases it to 8.5 orbits. The domain of convergence is also increased for the perturbed case, but more notable is the reduction in the number of nodes/iterations required for converging over the same distance. We generate pork chops for three test case orbit transfers using a parallel architecture.

9:40 Morning Break

10:00 AAS 15-309 A Novel Method Based on Displaced Orbit for Solving Non-planar Orbit Maneuver Problem
yao wei; Jianjun Luo

The ability to rapidly change the orbital plane is a decisive factor in the constellation design and non-planar rapid rendezvous mission. To conquer this, this paper presents a new non-planar orbit maneuver strategy, which uses the displaced orbit as a transfer orbit and the displaced orbit is located on a suppositional sphere which has the same radius with the initial orbit. Focusing on the problem, the general consumption for arbitrary missions are derived and analyzed. Numerical simulations verify the feasibility and effectiveness of the present strategy.

10:20 AAS 15-406 Modified encke corrector step method for semi-coupled orbit-attitude propagation
Carolin Frueh, Purdue University

Corrector step methods have been explored initially to save computational time on orbit propagations. In the age of modern computing, this seems almost superfluous. On the other hand, the computational burden is still tremendous, in the coupled and perturbed orbit-attitude propagation, as it is the case, for example with high area-to-mass ratio space debris objects.

This stiff orbital problem together with high fidelity modeling makes accurate long term propagations almost impossible. This paper investigates a modification of the classical Encke corrector step method based on information theoretic divergence for the efficient semi-coupled six DoF propagation.

10:40 AAS 15-440 Radially adaptive evaluation of the spherical harmonic gravity series for numerical orbital propagation

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

Evaluation of the Spherical Harmonic Series for Gravity is consistently one of the most computationally intensive requirements for high-accuracy orbital propagation. The Earth's gravity is non-uniform and these perturbative effects must be incorporated into orbital propagation models to ensure an accurate numerical approximation is computed. However, considering the character of the force-field allows for the judicious selection of the harmonic series degree and order as a method of reducing computational cost, without sacrificing accuracy. This paper details a method of Radial Adaptation for the Spherical Harmonic Series, supporting analysis demonstrating its accuracy, and some characteristic results.

11:00 AAS 15-417 Automated Tuning Parameter Selection for Orbit Propagation with Modified Chebyshev Picard Iteration

Brent Macomber, Texas A&M University; Austin Probe; Robyn Woollands; John Junkins, Texas A&M University

Modified Chebyshev Picard Iteration is a numerical method for integrating Ordinary Differential Equations. MCPI in a serial computation setting has been shown to improve the speed of orbit propagation computations by orders of magnitude over current state-of-the-practice methods. This paper presents an MCPI tuning parameter set for perturbed orbit propagation. A first cut MCPI parameter scheme that provides a baseline set of tuning parameters is generated using an empirical brute-force method. A more optimal scheme is generated using a genetic algorithm, and promises the same final accuracy as the baseline set, but with improved computational efficiency.

SESSION 21: CUBESAT & NANOSAT MISSIONS

Session Chair: Fu-Yuen Hsiao, Tamkang University

13:30 AAS 15-275 Lifetime Simulation of Attitude Changing CubeSat
Guanyang Luo, University of Illinois; Alexander Ghosh, University of Illinois at Urbana-Champaign; David Trachtenberg; Victoria Coverstone, University of Illinois at Urbana-Champaign

This research investigates the effect of atmospheric drag on a CubeSat that is changing attitude with respect to the body frame. The motivation is to estimate the lifetime loss for the Lower Atmosphere/Ionosphere Coupling Experiment (LACIE) due to high drag maneuvers that aim to generate more electricity to keep the science apparatus operational. Simulations that account for varying altitude during orbit propagation are performed. The results show that more lifetime loss occurs when maneuvers are conducted at high altitude, due to long term effect. Thus, high drag orientation should be avoided at high altitude and for long duration.

13:50 AAS 15-284 Dynamics of Deorbiting of Low Earth Orbit Nano-satellites by Solar Sail
yanyan li; Quan Hu; Jingrui Zhang

This paper studies the dynamics of deorbiting a nano-satellites by solar sail. The orbital motion and solar sail are modeled by considering multiple space environmental perturbations including atmospheric drag, solar radiation pressure, gravity-gradient. Approximated analytical solutions and numerical simulations of the perturbation torques are provided to demonstrate the deorbit ability of solar sail for nano-satellite system.

14:10 AAS 15-300 The Design of NPU-PhoneSat: A Foldable Picosatellite using Smart Phone Technology
Jing Yuan, National Key Laboratory of Aerospace Flight Dynamics, Northwestern Polytechnical University

In this paper, we present a novel PhoneSat design which is from a student satellite project at Northwestern Polytechnical University called “NPU-PhoneSat project”. The ultimate goal of this project is to validate the feasibility of rapid deployment a small-scale satellite network for environmental surveillance purposes at a low Earth orbit (LEO) using a group of low cost PhoneSats. We specially develop a foldable platform with multiple-slice for a better incorporation of COTS smart phone components. The testing results show that the design can meet the function and performance requirements.

14:30 AAS 15-353 LunarCube Transfer Trajectory Options
David Folta, NASA Goddard Space Flight Center

Numerous Earth-Moon trajectory and lunar orbit options are available for LunarCube (Cubesat) missions. Given the limited injection infrastructure, many designs are contingent upon the modification of an initial condition of the injected or deployed orbit. These designs can be restricted by the selection of subsystems such as propulsion or communication. Nonetheless,

many trajectory options have a wide range of transfer durations, fuel requirements, and final destinations. Our investigation of potential trajectories highlights designs with deployment from low Earth orbit (LEO), geostationary transfer orbits (GTO), and high energy direct lunar transfer orbits. We also investigate the application of Earth-Moon

14:50 AAS 15-382 An Interplanetary Microsatellite Mission Concept to Test the Solar Influence of Nuclear Decay Rates (SINDR)

Blake Rogers, Purdue University; Sarag Saikia, School of Aeronautics and Astronautics, Puurdue University; Michael Mueterthies, Purdue University; James Longuski, Purdue University; Ephraim Fischbach, Purdue University

Recent physics experiments on Earth have suggested the possibility that nuclear decay rates, traditionally assumed to be constant, may vary with distance from the Sun. In this paper, an interplanetary mission concept is proposed to test a possible solar influence on nuclear decay rates, which involves launching a microsatellite into an interplanetary orbit, completing gravity assists to place the spacecraft on an Earth resonant orbit with a small aphelion, and returning to Earth. The spacecraft is based on the Nano-ADEPT architecture to allow reentry into Earth's atmosphere.

15:10 Afternoon Break

15:30 AAS 15-463 SIGMA CubeSat ADCS Hardware Selection

Arthur Kar Leung Lin

In this paper, we illustrated the microcontroller, sensors and actuators chosen for the attitude determination and control system for SIGMA. Rate sensors, and magnetometers are used to determine the attitude of this satellite. A torque rod and 2 torque coils will be used to provide actuation for attitude control. Due to the compacted size of the satellite, the three magnetorquer onboard will interfere the magnetometer reading carried on the Attitude Control System (ACS) board. An algorithm is shown to provide an accurate attitude of the CubeSat. Moreover, a degaussing method is applied and results are shown for the proposed mission.

SESSION 22: SPACECRAFT DYNAMICS AND AUTONOMY

Session Chair: Kyle DeMars, Missouri University of Science and Technology

13:30 AAS 15-386 Operational Challenges in TDRS Post Maneuver Orbit Determination
Jason Laing, a.i. solutions, Inc.; Jessica Myers; Douglas Ward, a.i. solutions, Inc.; Rivers Lamb, NASA

The GSFC Flight Dynamics Facility is responsible for daily and post-maneuver orbit determination for TDRSS. The most stringent requirement for this orbit determination is 75 meter total position accuracy (3-sigma) predicted over one day for Terra onboard navigation. To maintain an accurate solution onboard Terra, a solution is generated and provided by the FDF four hours after the TDRS maneuver. A number of factors present challenges to this support, such as maneuver prediction uncertainty and potentially unreliable tracking from user satellites. Reliable support is provided by comparing an Extended Kalman Filter against a Batch Least Squares system.

13:50 AAS 15-259 Position Estimation using Image Derivative
Daniele Mortari, Texas A&M University; Francesco de Dilectis; Renato Zanetti, NASA JSC

This paper describes an image processing algorithm to process Moon and/or Earth images. The theory presented is based on the fact that Moon hard edge points are characterized by the highest values of the image derivative. Outliers are eliminated by two sequential filters. Moon center and radius are then estimated by nonlinear least-squares using circular sigmoid functions. The proposed image processing has been applied and validated using real and synthetic cropped Moon images.

14:10 AAS 15-248 Pose Estimation using GEO Satellites Identification
Stoian Borissov, Texas A&M University; Daniele Mortari, Texas A&M University; Thomas Pollock, Texas A&M University

Autonomous backup optical navigation is desired during cislunar missions in the case of loss of communications with Earth. Due to difficulties of position estimation from imaging the Moon or Earth, such as centroiding while compensating for surface topography and atmospheric effects, we propose an alternate approach of imaging and identifying geostationary satellites using star trackers. We first investigate what would be the visible magnitude of the observed satellites using illumination models. Secondly we propose satellite identification methods which allow discrimination between satellites and stars. Finally, we investigate observing the oblateness of the GEO orbit to estimate position.

14:30 AAS 15-220 Energy Conserved Planar Spacecraft Motion with Constant Thrust Acceleration
Sonia Hernandez, The University of Texas at Austin; Maruthi Akella, The University of Texas at Austin

Spacecraft motion with constant thrust acceleration in the direction perpendicular to the

velocity is studied. A spacecraft in an initial circular orbit obtains a minimum (perigee) radius along an inbound trajectory or a maximum (apogee) radius along an outbound trajectory, after which the vehicle returns to the initial circular orbit. The energy of the system is the only integral of motion. A full analytical solution does not exist; however, a solution to the flight direction angle is found. This solution leads to the range of acceleration magnitudes for prograde motion, proving periodicity of the position magnitude, and finding periodic orbits.

14:50 **AAS 15-301** **Autonomous Operation of Multiple Free-Flying Robots on the International Space Station**

Benjamin Morrell, University of Sydney; Gregory Chamitoff

An approach is proposed to address the challenge of real time trajectory optimization for space-based robots in restrictive and obstacle rich environments. The algorithm uses a unique transformation that enables a quick solution to complex, non-linear, non-convex trajectory optimization problems. The algorithm was implemented on the SPHERES (Synchronized Position Hold, Engage, Reorient Experimental Satellites) test facility on the International Space Station. Tests demonstrated the basic capability of the algorithm, and identified areas for improvement. An updated algorithm is tested in numerical simulations that demonstrate the ability to quickly solve problems with geometric constraints, performance constraints, dynamic obstacles

15:10 **Afternoon Break**

15:30 **AAS 15-321** **Closed-From Solution to The Attitude Kinematics Equation For An Arbitrary Angular Velocity**

Vladimir Martinusi, University of Liège; Daniel Condurache, Technical University of Iasi

The paper presents the solution to the attitude kinematics problem for an arbitrary instantaneous angular velocity. By using a direct tensor method and a representation theorem for vector valued functions, it is proven that the solution can be expressed as the product of at most three exponentials of skew-symmetric tensor functions, which furthermore can be explicitly computed. This result has the potential to replace all approximate solutions which were offered up to this date, with important applications in attitude determination, navigation problems, spacecraft attitude control or robot systems.

15:50 **AAS 15-347** **Rigid Body Attitude Uncertainty Propagation using the Gauss-Bingham Distribution**

Jacob Darling, Missouri University of Science and Technology; Kyle DeMars, Missouri University of Science and Technology

A new probability density function, called the Gauss-Bingham distribution, is proposed. The Gauss-Bingham distribution quantifies the correlation between a quaternion attitude representation and angular velocity in a more statistically rigorous manner than conventional methods because it is defined on the cylindrical manifold on which the quaternion and angular velocity naturally exist. The Gauss-Bingham distribution is derived, and a transformation to its canonical form is presented. Sigma points are generated to efficiently propagate the attitude

uncertainty forward in time. Simulations are presented to compare the attitude uncertainty propagation using the Gauss-Bingham distribution to typical methods.

16:10 AAS Touchless Electrostatic Detumbling while Tugging Large GEO Debris
15-383 *Trevor Bennett, University of Colorado; Hanspeter Schaub, University of Colorado*

Touchless detumbling of space debris is investigated to enable orbital servicing or active debris removal in the Geosynchronous belt. Using active charge transfer between a servicing spacecraft and debris object, control torques are created to reduce the debris spin rate prior to making any physical contact. Prior work has identified the limitations of electrostatic detumble for three degree rotational freedom without relative positioning maneuvers. This work extends the projection angle theory for three-dimensional tumbling motion to on-orbit relative motion. Using the Multi-Sphere Modeling method for electrostatic torques, servicer formation flying demonstrates improved detumble capability.

16:30 AAS Angles-Only Initial Relative-Orbit Determination via Maneuver
15-352 *Laura Hebert, Auburn University; Andrew Sinclair, Auburn University; Thomas Lovell, Air Force Research Laboratory*

For satellite relative motion modeled with linear, Cartesian dynamics, angles-only measurements are not sufficient for initial relative orbit determination, unless one of the satellites is maneuvering. A known, impulsive maneuver by either chief or deputy satellite, along with six total angle measurements, is sufficient to solve for the initial position and velocity of the deputy satellite. This paper presents an initial relative-orbit determination solution using this type of observability maneuver. The accuracy of the solution is evaluated against the maneuver design, measurement errors, and dynamic modeling errors.

SESSION 23: ORBIT DETERMINATION II

Session Chair: Renato Zanetti, NASA JSC

13:30 AAS 15-202 Using Onboard Telemetry for MAVEN Orbit Determination
Drew Jones, Jet Propulsion Laboratory, Caltech; Try Lam, Jet Propulsion Laboratory; Nikolas Trawny, NASA/JPL

Determining the state of Mars orbiting spacecraft has traditionally been achieved using radiometric tracking data, often with data before and after an atmospheric drag pass. This paper describes our approach and results for supplementing radiometric observables with on-board telemetry measurements to improve the reconstructed trajectory estimate for the Mars Atmosphere and Volatile Evolution Mission (MAVEN). Uncertainties in Mars atmospheric models, combined with non-continuous tracking degrade navigation accuracy, making MAVEN a key candidate for using on-board telemetry data to help complement its orbit determination process. The successful demonstration of using telemetry data to improve the accuracy of ground

13:50 AAS 15-228 Cauchy Drag Estimation For Low Earth Orbiters
Russell Carpenter, NASA/Goddard Space Flight Center; Alinda Mashiku, NASA GSFC

Idan and Speyer have developed minimum variance estimators that assume measurement noise, process noise, and initial error are all distributed as Cauchy random variables. Samples from Cauchy distributions are characterized by long stretches of fairly small variation, punctuated by large variations that are many times larger. Cauchy distributions appear to accurately model some natural features, such as density variations that affect satellites in low Earth orbit. In contrast to a Kalman filter, the covariances from the Cauchy approach fully and conservatively bound the actual error signature, even in the face of unanticipated density disturbances of hundreds of percent.

14:10 AAS 15-276 Precision Orbit Derived Atmospheric Density: An Update
Craig McLaughlin, University of Kansas; Travis Lechtenberg, University of Kansas; Sam Shelton, University of Kansas; Alex Sizemore, University of Kansas

Recent developments in precision orbit ephemerides (POE) derived densities are examined. POE derived densities for GRACE (Gravity Recovery and Climate Experiment) and TerraSAR-X are updated to include more recent time periods. In addition, Satellite Laster Ranging Data for the Atmospheric Neutral Density Experiment (ANDE) satellites are used to derive densities. The new POE derived density data also include using additional baseline density models from which density corrections are estimated.

14:30 AAS 15-451 Nonlinear Observability Measure for Relative Orbit Determination with Angles-Only Measurements
Evan Kaufman, The George Washington University; Thomas Lovell, Air Force Research Laboratory; Taeyoung Lee, George Washington University

A new nonlinear observability measure is proposed for relative orbit determination when lines-of-sight between satellites are measured only. It corresponds to a generalization of the observability Gramian in linear dynamic systems to the nonlinear relative orbit dynamics represented by the two-body problems. An extended Kalman filter (EKF) is adapted to this problem and is evaluated with various gravitational harmonics, initial orbital determination (IOD) predictions, and time step sizes. Preliminary results illustrate correspondence between the proposed observability measure with filtering errors. The final version will include extensive numerical analysis in realistic scenarios including the J2 perturbation effects.

14:50 AAS 15-365 Centroid dynamics for group object tracking

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

Immediately following a scenario like a CubeSat deployment, the presence of multiple objects in close proximity makes the observation assignment problem -- and thus individual object tracking -- difficult. One proposed method for mitigating this is to combine the observations in measurement space, and use this to update the "centroid state" of the collection of objects. One consequence of this process is that there is no physical reason that the centroid should itself behave as an orbiting object. This paper presents the first steps towards this type of tracking, describing the motion of the centroid as projected in measurement space.

15:10 Afternoon Break

15:30 AAS 15-376 Multi-object filtering for space situational awareness

Carolin Frueh, Purdue University; Emmanuel Delande, Heriot Watt University, School of Engineering & Physical Sciences; Daniel Clark, Heriot Watt University, School of Engineering & Physical Sciences; Jeremie Houssineau, Heriot Watt University, School of Engineering & Physical Sciences

This paper presents the first application to space situational awareness problems of the filter for Independent Stochastic Populations (ISP), a recent tracking algorithm derived from the novel mathematical framework for the estimation of stochastic populations, combining the advantages of traditional track-based and population-based tracking approaches. The dynamical models of Earth orbiting objects are built upon a Shepperd transition matrix and initial orbit determinations are performed based on an admissible region approach. The detection and tracking capabilities of the new filter are illustrated on a simulated five-target orbital scenario, exploiting a fixed ground-based radar.

15:50 AAS 15-318 Atmospheric re-entry prediction of uncontrolled space objects using multiple hypothesis based distributed sensor fusion approach

Deok Jin Lee, Kunsan National University; Tae Soo No, Chonbuk National University; Jin Haeng Choi, Chonbuk National University; Dae-Won Chung

In this paper, an effective tracking approach is proposed to estimate the positions and velocities of the break-up components of a reentering object into the Earth's atmosphere. For the multiple target tracking application, the data association is essential, and in this work, the Multiple Hypotheses Tracking is proposed with a linear assignment algorithm based on a score function

for a simplified hypothesis tracking approach. A distributed nonlinear information filter, which is an effective form to fuse multiple sensors without information loss is proposed for the nonlinear tracking of the multiple objects.

16:10 AAS 15-384 One-Way Radiometric Navigation with the Deep Space Atomic Clock

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

The Deep Space Atomic Clock mission is developing a small, mercury ion atomic clock with Allan deviation of less than 2e-14 at one day (current estimates ~3e-15) for a yearlong space demonstration in 2016. DSAC's stability yields one-way radiometric tracking data with better accuracy than current two-way tracking data and enables transitioning to more efficient and flexible one-way deep space navigation. This study discusses the potential for one-way radiometric navigation using DSAC; including those navigation uses that are immediately enabled, and those that require additional infrastructure and flight system development for full realization.

SESSION 17: RELATIVE MOTION

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

13:30 AAS 15-315 Analytic Solution for The Relative Motion of Satellites in Near-Circular Low-Earth Orbits
Vladimir Martinusi, University of Liège; Lamberto Dell'Elce, University of Liège; Gaetan Kerschen, University of Liège

The paper presents the solution to the problem of the relative motion between two satellites orbiting Earth under the influence of the oblateness and atmospheric drag perturbations. Starting from the analytic solution to the problem of the absolute motion, the closed-form equations of motion are obtained. No simplifying assumptions are made on the relative dynamics.

13:50 AAS 15-331 Decalibration of Linearized Solutions for Satellite Relative Motion
Andrew Sinclair, Auburn University; Brett Newman, Old Dominion University; Thomas Lovell, Air Force Research Laboratory

The motion of a deputy satellite relative to a chief satellite can be described with either a Cartesian state or orbital-element differences. The linearized equations of motion for both share an equivalence through the linearized coordinate transformations. Higher fidelity, analytic, nonlinear approximations for the Cartesian state can be extracted by introducing the nonlinear coordinate transformations. This results in a calibrated solution, which involves linearized propagation of a calibrated initial condition, and a decalibrated solution, where the inverse calibration process is applied to the calibrated solution. Both solutions are shown to have higher accuracy than the linearized solution for

14:10 AAS 15-339 State Transition Matrix for Relative Motion Including General Gravitational Perturbations
Hui Yan, Texas A&M University; Srinivas R. Vadali, Texas A&M University; Kyle T. Alfriend, Texas A&M University

Our goal is to determine the maximum degree and order of the gravity harmonics for the given accuracy for relative motion. Hence a state transition matrix is needed for the general gravitational perturbations to result in less fuel consumption and optimum on-board computation. In this paper we extended GA STM to include the general gravitational perturbations based on the Kaula modeling.

14:30 AAS 15-390 Initial Relative-Orbit Determination using Second-Order Dynamics and Line-of-Sight Measurements
Shubham Garg; Andrew Sinclair, Auburn University

This paper address the problem of determining the initial state of relative orbit between a chief and a deputy satellite using line of sight unit vectors. The relative motion is captured using second order nonlinear relative equation of motion, and the measurements are represented as a

linear matrix equation. Compared to previous such methods, the proposed formulation solves directly for the unknown ranges, and requires fewer measurements. Additionally, a new method is presented to remove the scalar ambiguity using all the constraint equations among the second-order states.

14:50 AAS Relative Satellite Motion Solutions using Curvilinear Coordinate Frames
15-437 *Alex Perez, Utah State University; David Geller, Utah State University; Thomas Lovell, Air Force Research Laboratory*

Using nonlinear transformations from a cylindrical and spherical coordinate frame to a Cartesian coordinate frame, nonlinear satellite relative motion equations can be derived. These nonlinear representations better capture the curvature and relative dynamics of an orbit due to the nature of curvilinear coordinate frames. Approximate solutions are also derived using a 2nd order Taylor series expansion of the nonlinear equations. These 2nd order approximate solutions are compared analytically to the Quadratic Volterra solution. Example trajectories are generated and compared using the novel set of solutions and the Quadratic Volterra solution.

15:10 Morning Break

15:30 AAS Control of spacecraft relative motion using angles-only navigation
15-444 *Ashish Jagat, Auburn University; Andrew Sinclair, Auburn University*

Continuous-thrust feedback control of spacecraft relative motion when full state knowledge is not available is explored. A typical approach to such problems is to separate control and estimation – estimate the state using noisy measurements and implement the control law using the estimate. For systems involving nonlinearities, control and estimation may not be separable. In such systems, control input in addition to affecting the system state also affects the quality of the state estimate. This paper investigates this dual effect of control when angles-only measurements are used to estimate relative state of a spacecraft.

15:50 AAS Hybrid linear-nonlinear initial orbit determination with single iteration
15-446 refinement for relative motion
Brett Newman, Old Dominion Univ.; Thomas Lovell, Air Force Research Laboratory; Ethan Pratt, Old Dominion University; Eric Duncan, Missouri University of Science and Technology

Application of quadratic Volterra theory to the Keplerian circular relative motion initial orbit determination problem has been considered recently. One explored solution strategy to the nonlinear measurement equations reformulates the problem as an equivalent linear equation set with constraints. A deficiency is the requirement for additional measurements. In this paper, a hybrid solution technique is considered where linear theory, only requiring six measurements, is used to obtain an initial estimate of the state vector. This state vector is then scaled using nonlinear theory. A single iteration refinement using the nonlinear measurement equations is also considered.

16:10 AAS Regularized formulations in relative motion
15-210 *Javier Roa, Space Dynamics Group - UPM; Jesus Pelaez, Technical University of Madrid (UPM)*

Solutions to the linearized rendezvous problem require the propagation of the reference orbit. The extension of regularized formulations to relative motion may lead to fully nonsingular solutions. In this work relative motion is formulated using the Kustaanheimo-Stiefel transformation and the Sperling-Burdet regularization. The corresponding variational equations are deduced, assuming that the initial separation is small. The resulting solution is valid for any type of reference orbit: circular, elliptic, parabolic and hyperbolic. Regularization introduces a fictitious time through a Sundman transformation. The solution can be synchronized by means of the physical time or by means of the fictitious time.

16:30 AAS Error propagation in relative motion
15-272 *Javier Roa, Space Dynamics Group - UPM; Jose Ignacio Gómez-Mora, Technical University of Madrid; Jesus Pelaez, Technical University of Madrid (UPM)*

When comparing existing solutions to linear relative motion by means of the error in determining the relative position, similar results are obtained. The error is not affected by the variables the problem is formulated with. Basically, the error depends on the variable through which the solution is synchronized. Synchronizing the solution through a fictitious time, introduced by a Sundman transformation, and correcting the time delay a posteriori leads to important error reductions. They depend upon the order of the Sundman transformation. The stability of several Sundman-based transformations are analyzed for drawing conclusions on their accuracy, supported by numerical

SESSION 25: ORBITAL DYNAMICS

Session Chair: Francesco Topputo, Politecnico di Milano

8:00 AAS 15-326 Advances in Ballistic Capture Orbits Computation with Applications
Francesco Topputo, Politecnico di Milano

In this paper, recent developments on the computation of ballistic capture orbits are discussed, together with a discussion on their application to practical problems. The paper focuses on the method used to derive the stable sets. These are sets of initial conditions that generate orbits satisfying a simple definition of stability, whose manipulation produces ballistic capture orbits. The way this method has evolved over the years will be illustrated, from the simple planar circular restricted three-body model to a three-dimensional high-fidelity context. Applications involve interplanetary trajectory design, lunar missions, and asteroid retrieval scenarios.

8:20 AAS 15-214 Study on resonant orbits around elongated celestial bodies
Xiangyuan Zeng, Tsinghua University; Hexi Baoyin, Tsinghua University; Junfeng Li; Kun Zhai; Fanghua Jiang; Shengping Gong, Tsinghua University; Yang Yu

The resonant orbits around elongated celestial bodies are investigated by using an unified approximate model, aiming at providing a basic understanding of the resonance effect in the vicinal orbital motion. The unified approximate model is a rotating mass dipole with four independent parameters. The essential of the 1:1 resonant orbits is first presented through the analysis of the orbital energy. The effect of the Jacobi constant on the resonant orbit is studied for the orbits in the equatorial plane. The relationship between the resonant orbits' distribution and the parameters of the approximate model are evaluated through numerical simulations.

8:40 AAS 15-435 Dynamical Instabilities in Medium Earth Orbits: Chaos Induced by Overlapping Lunar Resonances
Aaron J. Rosengren, IFAC-CNR

Understanding the long period effects in the motions of celestial bodies is the central problem in the determination of orbital stability over long timespans. In treating the problem of stability, two types of long period perturbations are of primary importance: secular perturbations and resonances. We present a qualitative analytical treatment of the secular and resonant effects in the motion of medium Earth orbit satellites under gravitational perturbations. We demonstrate the importance of the perturbed motion of the Moon, and show that chaos ensues where lunar resonances overlap. These results are applied towards the analysis of disposal strategies for MEO orbits.

9:00 AAS 15-395 Long-term evolution of highly-elliptical orbits: luni-solar perturbation effects for stability or re-entry
Camilla Colombo, Politecnico di Milano

This paper investigates the long-term evolution of spacecraft in Highly Elliptical Orbits (HEOs). The single averaged disturbing potential due to luni-solar perturbations, zonal

harmonics and solar radiation pressure is written. Maps of long-term evolution are constructed to identify conditions for quasi-frozen, or libration orbits. An analytical justification of the existence of such orbits is sought through Kozai invariant of motion. Quasi-frozen orbits can be selected as graveyard orbits for the end-of-life of HEO missions. On the opposite side, unstable conditions can be exploited to target an Earth re-entry.

9:20 AAS 15-206 On solving a generalization of the Kepler Equation

Juan Félix San-Juan, University of LA Rioja; Rosario ; Denis Hautesserres, Centre National d'`Etudes Spatiales (CNES)

In the context of general perturbation theories, we analyze the motion of an artificial satellite around an Earth-like planet perturbed by the J2 effect. By means of two Lie transforms and Krylov-Bogoliubov-Mitropolsky method, a second order theory in closed form of the eccentricity is produced. In the integration process is necessary to solve a perturbed Kepler equation. In this work, we discuss the application of the numerical techniques and initial guesses used to solve the classical Kepler equation to the generalization one.

9:40 Morning Break

10:00 AAS 15-239 Frozen orbits computation for a Mercury solar sail

Eva Tresaco, Centro Universitario de la Defensa; Antonio Elipe, Centro Universitario de la Defensa; Jean Paulo S. Carvalho, UNIFESP - Instituto de Ciéncia e Tecnologia

This paper deals with the computation of frozen orbits for a solar sail about Mercury, namely orbits whose elements remain constant on average. The orbital dynamics of the sail is governed by the oblateness of the central body and the gravity field of the third body (Sun). We also take into account the eccentricity and inclination of the third body orbit, and the solar acceleration pressure. Frozen orbits are obtained as the equilibria of a double-averaged Hamiltonian. Finally, we apply a numerical correction procedure, taking the averaged orbits as starting conditions, to recover the frozen character.

10:20 AAS 15-209 Orbit propagation in Minkowskian Geometry

Javier Roa, Space Dynamics Group - UPM; Jesus Pelaez, Technical University of Madrid (UPM)

A more adequate description of perturbed hyperbolic orbits is found in the geometry underlying Minkowski space-time. Hypercomplex numbers appear naturally when describing vectors, rotations, and metrics in this geometry. The evolution of the eccentricity vector is defined by means of its components on the Minkowski plane. The orbital plane is defined on the inertial reference using quaternions, treated as particular instances of hypercomplex numbers. The performance of the proposed formulation is evaluated in a number of numerical experiments. In these examples the accuracy of the formulation outperforms other high performance algorithms.

10:40 AAS 15-351 Test Problems for Evaluating the Performance of Numerical Orbit Propagators

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

A collection of test cases is proposed for the validation and testing of numerical orbit

propagators. These test problems are designed to characterize the performance of the propagators and intended to highlight their possible deficiencies and expose their limitations. Every problem in the collection is accompanied by an accurate solution, and the performance of several orbit propagators is shown as examples to these problems.

11:00 AAS 15-207 Hybrid Perturbation methods. Modelling the J2 effect through the Kepler problem

Juan Félix San-Juan, University of LA Rioja; Montserrat SanMartin; Ivan Perez

We present a new approach in Astrodynamics and Celestial Mechanics fields, called Hybrid perturbation theory. A Hybrid perturbation theory combines an integrating technique (General perturbation theory, Special perturbation theory or Semianalytical method) with a forecasting technique (Statistical time series model or Computational Intelligence method). This combination permits an increase in the accuracy of the integrating technique, through the modeling of higher-order terms and other external forces not considered in it. In this paper statistic time series techniques have been used to forecast in order to help an economic General perturbation theories describe the motion of an orbiter only perturbed

SESSION 26: ATTITUDE DYNAMICS AND CONTROL

Session Chair: Maruthi Akella, University of Texas at Austin

8:00 AAS 15-350 A Singularity-free DROMO-based Regularized Method for the Propagation of Roto-Translationally Coupled Asteroids
Hodei Urrutxua, Technical University of Madrid (UPM); Jesus Pelaez, Technical University of Madrid (UPM)

There are many asteroids for which the attitude coupling imposes harsh demands to the numerical propagation of their dynamics. Special regularization methods are appropriate to overcome such difficulties, where perturbations techniques make their best. The perturbation techniques used to derive the DROMO regularization method for orbital dynamics, have now been extended to the attitude dynamics problem, yielding a singularity-free formulation with equally remarkable results both in terms of speed and accuracy. The combination of these DROMO-based techniques is thus appropriate for the propagation of strongly coupled bodies.

8:20 AAS 15-215 Spacecraft Attitude Control using Neuro-Fuzzy Controller Trained by State-Dependent Riccati Equation Controller
Sung-Woo Kim, Yonsei University ; Sang-Young Park, Yonsei University; Chandeok Park, Yonsei University

A neuro-fuzzy controller is developed for spacecraft attitude control to mitigate the large computation load of the State-Dependent Riccati Equation (SDRE) controller by training a neuro-fuzzy network to approximate the SDRE controller. The stability is numerically verified using Lyapunov-based method and the performance is analyzed in terms of approximation accuracy, cost, and execution time for the developed neuro-fuzzy control system. Simulation and test results indicate that the neuro-fuzzy controller successfully/efficiently approximates the SDRE controller with asymptotical stability in a bounded region of angular velocity containing the operational range of rapid attitude maneuvers.

8:40 AAS 15-242 Characterization of Self-Excited, Asymmetric, Spinning Rigid-Body motion as an Oblate Epicycloid
S. Lauren McNair; Steven Tragesser, University of Colorado at Colorado Springs

Despite numerous analytic studies of Euler's equations of motion for spinning rigid-bodies with body-fixed torques, the solution for asymmetric objects subject to constant transverse torques has not been treated using the assumption that the deviation of the spin axis is small. The solution found herein gives accurate results while avoiding complexities of more general formulations. The simplicity of the formulation lends itself to a better understanding of the system behavior. Specifically, the motion of the spin axis for this asymmetric case is described by an oblate epicycloid, an extension of the classic epicycloid solution for axisymmetric objects.

9:00 AAS 15-279 Dynamic characteristic analysis of a moment control unit with vibration isolation capability and its application

Yao Zhang, Beijing Institute of Technology; Jinjun Shan, York University; Mou Li, Beijing Institute of Technology

A novel unitary moment control unit with vibration isolation capability is presented. This unitary moment control unit contained four control moment gyros (CMGs) in a pyramidal configuration and a number of vibration isolation struts. The arrangement of the moment control unit is presented based on the analyzing geometric characteristic of the pyramidal configuration of four CMGs. Then the dynamic model of the moment control unit considering with the vibration isolation struts is constructed, and the dynamic characteristic is analyzed. Finally, the whole spacecraft dynamic model is built, and the performance of the moment control unit is illustrated by numerical simulation.

9:20 AAS 15-288 Experimental Implementation of Riemann-Stieltjes Optimal Control for Agile CMG Maneuvering

Mark Karpenko, Naval Postgraduate School; Ronald Proulx

Standard optimal control solutions provide open-loop controls based on a nominal model of the plant. When implemented in the closed-loop, unpredictable interactions between the nominal open-loop controls and the feedback law can cause the system to fail to perform as expected. Reimann-Stieltjes optimal control is a new concept that allows the effects of such uncertainties to be addressed in an optimal control framework. This paper details the application of the idea for agile maneuvering of a CMG imaging satellite. Experimental implementation on Honeywell's momentum control system testbed demonstrates the efficacy of the approach.

9:40 Morning Break

10:00 AAS 15-327 Hybrid Switching Attitude Control of Underactuated Spacecraft Subject to Solar Radiation Pressure

Christopher Petersen, University of Michigan; Frederick Leve, Air Force Research Laboratory/Space Vehicles Directorate; Ilya Kolmanovsky, University of Michigan

In this paper, attitude control of an underactuated spacecraft with two control moments is considered. For such an underactuated spacecraft, we develop a hybrid switching feedback law based on an inner loop and an outer loop controllers. The fast inner loop control tracks periodic reference trajectories while parameters which determine the amplitude of these signals are adjusted by an outer loop controller. We demonstrate through simulations on a nonlinear spacecraft attitude model that this switching feedback law achieves convergent rest-to-rest reorientation maneuvers.

10:20 AAS 15-250 An Instantaneous Quadratic Power Optimal Attitude-Tracking Control Policy for N-CMG Systems

Daniel Lubey, University of Colorado at Boulder; Hanspeter Schaub, University of Colorado

This paper develops an attitude reference tracking control policy that is optimized with respect to power usage for a spacecraft with N Control Moment Gyroscopes (CMGs). Along with the derivation of this control policy, this paper develops the equations of motion for such a system and the control policy is proven to be globally asymptotically stable in both attitude and attitude

rate tracking. Numerical simulations are provided to show the power-optimal tracking law performance compared to other control laws such as the minimum norm law for attitude tracking applications.

10:40 AAS 15-343 Spherical Magnetic Dipole Actuator for Spacecraft Attitude Control
Joshua Chabot, University of Colorado, Boulder; Hanspeter Schaub, University of Colorado

This paper develops analytical force and torque models for a spherical attitude control device, along with a control law for singularity-free actuation. The device proposed here consists of a non-contact spherical dipole rotor enclosed in an array of coils that is fixed to the spacecraft body. Excitation of the coils as prescribed by the control law rotates the dipole rotor in such a manner as to produce a desired reaction torque for orienting the spacecraft. Due to the axisymmetric field of the dipole, two actuators are needed for full attitude control along with null motion for singularity avoidance.

11:00 AAS 15-411 Survey of Optimal Rigid-Body Attitude Maneuvers
Kaushik Basu, Pennsylvania State University; Robert Melton, The Pennsylvania State University

This paper surveys the literature on optimal rigid-body attitude maneuvers, covering a span of 45 years, with an emphasis on the newer work. The papers comprise a range of problems and methods, including time- and fuel-optimal formulations, systems with and without path constraints, and analytic and numerical approaches.

11:20 AAS 15-429 Robustification of Iterative Learning Control Produced by Multiple Zero Order Holds Each Time Step
Richard Longman, Columbia University; Te Li, Columbia University

Iterative Learning Control (ILC) iterates with a real world control system that repeatedly executes the same command, aiming to converge to zero tracking error. It has use in spacecraft for maneuvers of fine pointing sensors that repeatedly perform scanning maneuvers. It can be very effective, decreasing the tracking error of robot at NASA Langley by factor of 1000 in 12 iterations. This paper establishes that using a generalized hold of multiple zero order holds between addressed time steps, substantially improves the stability robustness of ILC to model parameter error.

SESSION 27: ORBIT DETERMINATION III

Session Chair: Brandon Jones, University of Colorado at Boulder

8:00 AAS 15-251 Robust Tracking and Dynamics Estimation with the Automated Optimal Control Based Estimator
Daniel Lubey, University of Colorado at Boulder; Daniel Scheeres, University of Colorado

All tracked objects in orbit do not have accurate dynamical models associated with them, thus we need techniques that maintain tracking of them even with inaccurate dynamical models. Given the volume of objects in orbit it is important to automate this estimation algorithm so that it may feasibly be applied to orbit tracking problems. This paper develops the Adaptive Optimal Control Based Estimator, which automatically detects the level of dynamic uncertainty, and then jointly estimates the system's state and its mismodeled dynamics. Along with the derivation, sample tracking scenarios are provided to demonstrate the abilities of this algorithm.

8:20 AAS 15-252 Estimating Object-Dependent Natural Orbital Dynamics with Optimal Control Policies: A Validation Study
Daniel Lubey, University of Colorado at Boulder; Alireza Doostan, University of Colorado Boulder; Daniel Scheeres, University of Colorado

Object-dependent dynamics for Earth orbiting objects are often poorly modeled, so they require estimation. A method proposed by the authors estimates dynamics parameters using information from optimal control policies that connect state estimates across an observation gap. In this paper we both test the validity of linear assumptions made in the original algorithm and relax Gaussian assumptions within it. To validate the linear assumptions, we demonstrate two methods of uncertainty quantification: Monte Carlo analysis, and Stochastic Collocation using Gauss-Hermite abscissas on a Smolyak sparse grid. A discussion of the results and the appropriateness of each method is included.

8:40 AAS 15-253 Particle and matched filtering using admissible regions
Timothy Murphy, Georgia Institute of Technology; Brien Flewelling, Air Force Research Laboratory; Marcus Holzinger, Georgia Institute of Technology

The main driving result for this research is to show that online orbit determination is not only possible, but profitable. A secondary result is to show the feasibility of using Admissible Region theory to create a more efficient particle filter. By using an Admissible Region as an initial guess for a Particle Filter, many of the challenges in particle filtering can be overcome, such as dimensionality. Online orbit knowledge allows feedback to image processing through a Matched Filter. This can allow measurements to be taken on objects with prior knowledge at SNR as low as 0.2.

9:00 AAS 15-432 Minimum Uncertainty JPDA Filter and Coalescence Avoidance Performance Evaluations

Evan Kaufman, The George Washington University; Thomas Lovell, Air Force Research Laboratory; Taeyoung Lee, George Washington University

Two variations of the joint probabilistic data association filter (JPDAF) are simulated extensively in this paper. First, an analytic solution for an optimal gain that minimizes posterior estimate uncertainty is derived, referred to as the minimum uncertainty JPDAF (MUJPDAF). Second, the coalescence-avoiding optimal JPDAF (C-JPDAF) is derived, which removes coalescence by minimizing a weighted sum of the posterior uncertainty and a measure of similarity between estimated probability densities. Both algorithms are tested in much further depth than prior work to show how the algorithms perform in various scenarios.

9:20 **AAS 15-398** **Quadratic hexa-dimensional solution for relative orbit determination - revisited**
Brett Newman, Old Dominion Univ.; Thomas Lovell, Air Force Research Laboratory; Ethan Pratt, Old Dominion University; Eric Duncan, Missouri University of Science and Technology

An approximate second-order nonlinear closed-form solution for relative motion, based on quadratic Volterra series, has been applied to the relative initial orbit determination problem recently. Coupled polynomial measurement equations are solved by elimination theory and Macaulay resultants. These equations are reformulated as a single resultant polynomial equation, which can be solved with eigen decomposition. This paper expands on details for the three-dimensional case. An algorithm to construct the numerator and denominator Macaulay matrices in symbolic form is offered. Numeric three-dimensional examples are presented to assess the performance of the new solution strategy.

9:40 **Morning Break**

10:00 **AAS 15-448** **Uncertainty Propagation using Polynomial Chaos and Gaussian Mixture Models**
Vivek Vittaldev, The University of Texas at Austin; Richard Linares, Los Alamos National Lab; Ryan Russell, The University of Texas at Austin

Polynomial Chaos (PC) and Gaussian Mixture Models (GMM) are combined to reduce the function evaluations required for accurately describing a non-Gaussian distribution that results from the propagation of a state with an initial Gaussian distribution through a nonlinear function. The initial distribution is converted into a GMM and PC is used to propagate each of the elements. Splitting the initial distribution into a GMM reduces the size of the covariance associated with each element and therefore, lower order polynomials can be used. Satellite orbit uncertainty was propagated using GMM-PC and it captures the shape and skewness.

10:20 **AAS 15-433** **Fault-Tolerant Dead Reckoning Navigation in a Distributed Network**
Samuel Haberberger; Jacob Darling, Missouri University of Science and Technology; Kyle DeMars, Missouri University of Science and Technology

Precision dead-reckoning based navigation typically relies on a high-cost, high-performance Inertial Measurement Unit (IMU). Low-cost navigation solutions can be obtained by dead-reckoning several inexpensive IMUs and fusing the data. This multi-sensor topology provides inherent robustness to failure while maintaining high-accuracy navigation. Different fusion methods are analyzed for a multi-sensor network using cost effective IMUs which include

direct averaging and covariance intersection. Simulations of a spacecraft in low Earth orbit will baseline a typical expensive IMU and compare the navigation solution of a network of several low-cost IMUs from fused data.

10:40 AAS 15-405 New algorithm for attitude and orbit determination using magnetic field measurements
Mohammad Abdelrahman, International Islamic University Malaysia

The duality of the modified state-dependent Riccati equation MSDRE based control and estimation has been introduced through this paper. The MSDRE scheme has been developed and adopted to solve trajectory tracking/model following problem. Based on the duality property of the MSDRE a nonlinear estimator has been designed and applied to a real test case. The estimator has been developed for attitude and rate estimation using only one reference sensor and extended to orbit estimation. The magnetometer measurements are used through this paper; however any other reference sensor can be used or added to the measurement model.

11:00 AAS 15-313 Determine geo satellite statues with long term TLE data
Gongyou Wu, State Key Laboratory of Astronautic Dynamics; Rongzhi Zhang; Jianrong Chen, School of Aerospace, Tsinghua University; Jun Zhu, State Key Laboratory of Astronautic Dynamics

Another application of TLE is proposed to determine the status of geostationary satellites by analyzing long term TLE data, including orbiting, orbit maneuver, disposal, especially satellite malfunction. With TLE data of two Chinese GEO satellites from launching date, the validation method of TLE data is proposed, the orbit prediction error of TLE data is analyzed. Then the method to judge satellite orbit maneuver is proposed and orbit adjusting time can be roughly calculated with TLE data. After unsuccessful disposal operation of BEIDOU 1B, the reason of orbit aberrance is found with perturbation force modeling with TLE data.

11:20 AAS 15-415 The estimation of angular position for a spacecraft using the tracking station
Tsutomu Ichikawa, Japan Aerospace Exploration Agency (JAXA)

The problem of estimating the angular position of a spacecraft moving at a constant velocity using two rotating tracking stations is considered. This reports on an initial phase of analytical studies on the optimal attainable estimation performance and associated receiver design. Parametric dependence of the optimum attainable estimation is also studied.

SESSION 28: DYNAMICS AND CONTROL OF LARGE SPACE STRUCTURES & TETHERS

Session Chair: Ryan Russell, University of Texas at Austin

8:00 **AAS 15-304** **Nonlinear optimal control of flexible spacecraft tracking a non-cooperative target**
Dayu Zhang, School of Astronautics, Northwestern Polytechnical University; Jianjun Luo; Dengwei Gao, Science and Technology on Aerospace Flight Dynamics Laboratory

An improved nonlinear suboptimal algorithm for flexible tracking spacecraft to approach a non-cooperative target, which exists both orbit maneuver and attitude rotation, is presented in this paper. First, a 6 DOF coupled dynamics model of relative translation and rotation is established to describe the relative motions of two spacecrafts in close distance. Second, an improved nonlinear suboptimal algorithm is derived from the combining standard Theta-D algorithm and Lyapunov min-max approach. Simulation results have shown that the effectiveness of coupled dynamic model and a good performance for the improved control algorithm, as well as vibration of flexible structures.

8:20 **AAS 15-375** **Tethered Satellite Deployment and Retrieval by Fractional Order Tension Control**
George Zhu, York University

In this paper, a new fractional order tension control of tether satellite deployment and retrieval is proposed. The nonlinear mathematical model for tether deployment/retrieval is linearized in the neighborhood of system equilibrium point. By introducing the linear tension feedback and fractional order differential of tether length rate in the tension control input, the linearized dynamic equations become asymptotically stable. Moreover, the discretized model for proposed fractional order control law is presented for engineering implementation based on the frequency domain approximation method and Tustin operator. The effectiveness and advantage of the fractional order control law are verified by numerical simulation.

8:40 **AAS 15-378** **Architectures for vibrating mass attitude control actuators**
Ozan Tekinalp, METU Aerospace Engineering Dept.; Burak Akbulut, Middle East Technical University, Aerospace Engineering Department

Reaction wheels, magnetic torque rods, momentum wheels and CMGs are the most common actuators used in attitude control. However, they use rotor and/or gimbal mechanisms susceptible to failure. An alternative solution may be vibrating mass actuators. Previous research by Reiter et al and Chang et al showed the possibility of obtaining a net output torque from vibrating actuators. To build upon this, current research aims to expand the vibratory actuators to different and more complex architectures such as double axis CMGs. Additionally simulation models will be built to investigate their effectiveness in satellite attitude pointing scenarios.

9:00 **AAS 15-388** **Attitude Control of an Earth Orbiting Solar Sail Satellite to Progressively Change the Selected Orbital Element**

Ozan Tekinalp, METU Aerospace Engineering Dept.; Omer Atas, Middle East Technical University, Aerospace Engineering Department

Solar sailing where the radiation pressure from Sun is utilized to propel the spacecraft is examined in the context of orbital maneuvers. In this vein a locally optimal steering law to progressively change the selected orbital elements, without considering others, of an Earth centered Keplerian orbit of a cubesat satellite with solar sail is addressed. The proper attitude maneuver mechanization is proposed to harvest highest solar radiation force in the desired direction for such Earth orbiting satellites. The satellite attitude control is realized using quaternion error feedback control. The effectiveness of the approach to progressively changing orbital parameters is demonstrated.

9:20 AAS 15-371 Dynamics and Control of Electrodynamic Tether for Space Debris Removal
George Zhu, York University

The paper studies the dynamics and stability control of electrodynamic tether (EDT) for space debris removal without consuming propellant. EDT is intrinsically unstable due to the time-varying excitation of the electrodynamic force and the stability of EDT is sensitive to the geomagnetic field model, especially in orbits with high inclination angles, and the high-order geomagnetic model must be used. To ensure the successful spacecraft deorbit by EDT, a piecewise two-phased optimal control scheme is proposed. Numerical results show the proposed method achieves high control accuracy and efficiency.

9:40 Morning Break

10:00 AAS 15-312 An inner structural vibration isolation method for control moment gyroscope considering manufacturing and the assembling errors
Zixi Guo, Beijing institute of technology; Yao Zhang, Beijing Institute of Technology; Mou Li, Beijing Institute of Technology; Jingrui Zhang; Hao Zeng, Beijing Institute of Technology

The manufacturing and the assembling errors of CMG can generate high frequency jitters when the CMG works. Several supporting structure are used in the internal of the CMG and between the CMG and the spacecraft body to eliminate these vibrations. The supporting structure is simplified as springs and dampers in the theoretical analysis. Dynamic models of one CMG with manufacturing and the assembling errors and one CMG with inner structural improvement are built; dynamic characteristics of the supporting structures are analyzed. The numeral simulations have shown that the supporting structure can improve the stability of the spacecraft attitude control.

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