21ST AAS/AIAA SPACE FLIGHT MECHANICS MEETING
CONFERENCE INFORMATION

GENERAL INFORMATION

Welcome to the 21st Space Flight Mechanics Meeting, hosted by the American Astronautical Society (AAS) and co-hosted by the American Institute of Aeronautics and Astronautics (AIAA), February 13 – 17, 2011. This meeting is organized by the AAS Space Flight Mechanics Committee and the AIAA Astrodynamics Technical Committee, and held at the Loews New Orleans Hotel, 300 Poydras Street, New Orleans, Louisiana 70130. Phone: 504-595-3300.

REGISTRATION

Registration Site (https://aas.pxi.com/registration/reg)

In order to encourage early registration, we have implemented the following conference registration rate structure: **Register by 14 Jan 2011 and save $50!**

Category	Early Registration (through 14 Jan 2011)	Late Registration
Full - AAS or AIAA Member	$465	$515
Full - Non-member	$565	$615
Retired*	$130	$180
Student*	$130	$180

A conference registration and check-in table will be located in the Prefunction area on the 9th floor of the Loews New Orleans Hotel and will be staffed according to the following schedule:

- Sunday Feb. 13 — 3:00 PM - 6:00 PM
- Monday Feb. 14 — 8:00 AM - 2:00 PM
- Tuesday Feb. 15 — 8:00 AM - 2:00 PM
- Wednesday Feb. 16 — 8:00 AM – 2:00 PM
- Thursday Feb. 17 — 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

Day	Start	End	Function	Room
Sun. 13 Feb.	3pm	6pm	Registration	9th Floor Prefunction
	6pm	9pm	Early Bird Reception: **FREE OPEN bar from 6-7 pm (unlimited drinks) !!!**	Parish Hall

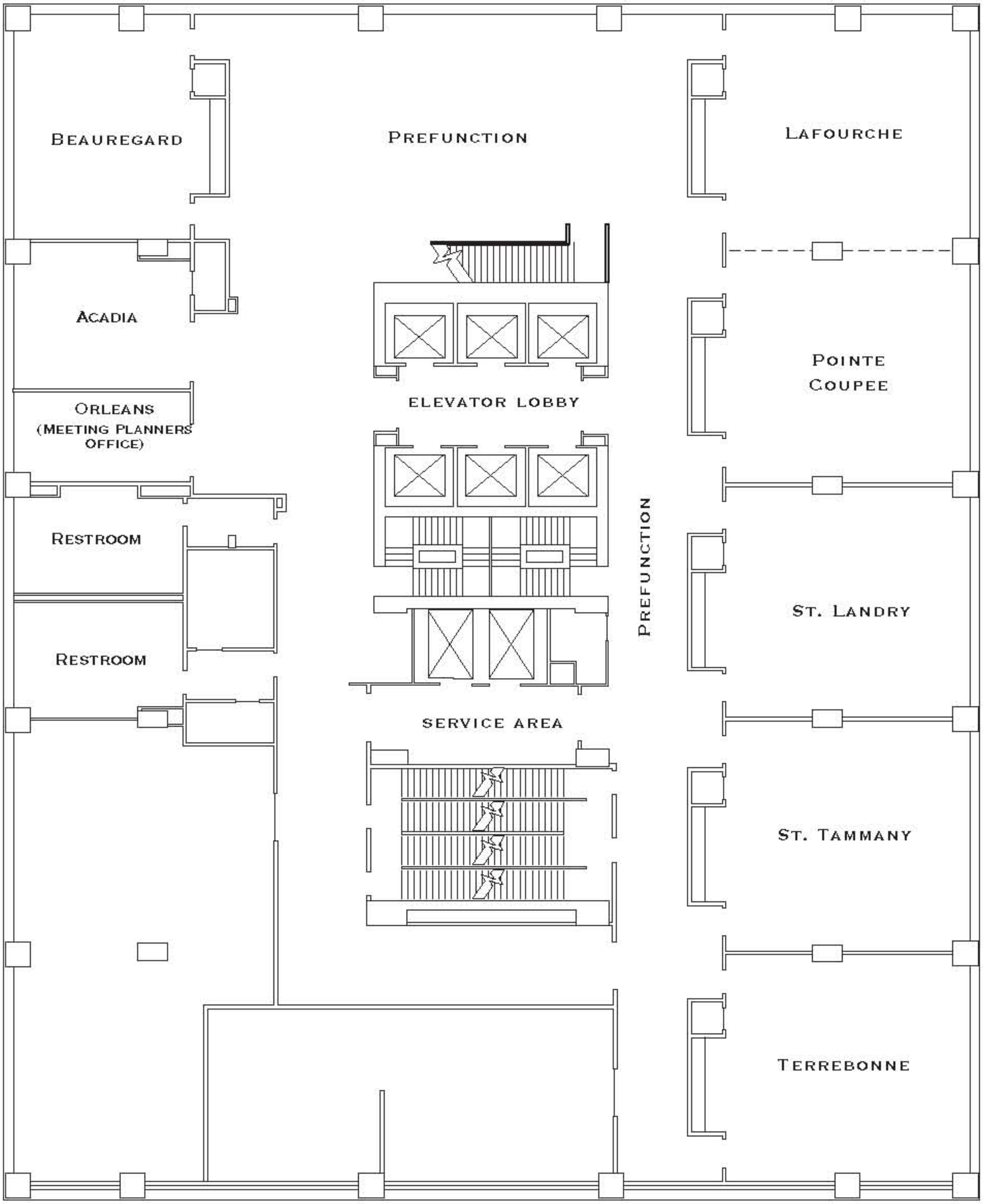
Day	Start	End	Function	Room
Monday 14 February	7am	8am	Speakers Breakfast	Terrebonne
	8am	2pm	Registration	9th Floor Prefunction
	8am	11:45am	Session 1: Asteroid Missions I	Lafourche
	8am	11:45am	Session 2: Attitude Dynamics and Control I	Pointe Coupee
	8am	11:45am	Session 3: Orbit Determination	St. Landry
	9:40am	10:05am	Morning Break	9th Floor Prefunction
	Noon	1:30pm	AIAA Astrodynamics Committee Lunch	Terrebonne
	1:30pm	5:15pm	Session 4: Trajectory Design and Optimization I	Lafourche
	1:30pm	4:50pm	Session 5: Attitude Determination I	Pointe Coupee
	1:30pm	5:15pm	Session 6: Rendezvous and Proximity Missions	St. Landry
	1:30pm	5:15pm	Session 7: Space Surveillance	St. Tammany
	3:10pm	3:35pm	Afternoon Break	9th Floor Prefunction
	5:30pm	6:30pm	Conference Administration Subcommittee	Pointe Coupee
	5:30pm	6:30pm	Technical Administration Subcommittee	St. Landry
	5:30pm	6:30pm	Website Administration Subcommittee	St. Tammany
	6pm	8pm	Student and Young Professional Reception	Parish Hall

Day	Start	End	Function	Room
Tuesday 15 February	7am	8am	Speakers Breakfast	Terrebonne
	8am	2pm	Registration	9th Floor Prefunction
	8am	11:45am	Session 8: Trajectory Design and Optimization II	Lafourche
	8am	11:45am	Session 9: Spacecraft Guidance, Navigation and Control	Pointe Coupee
	8am	11:45am	Session 10: Orbital Debris and Space Environment	St. Landry
	8am	11:45am	Session 11: Asteroid Missions II	St. Tammany
	9:40am	10:05am	Morning Break	9th Floor Prefunction
	Noon	1:30pm	AAS Spaceflight Mechanics Committee Lunch	Terrebonne
	1:30pm	4:50pm	Session 12: Decadal Survey and Interplanetary Mission Design	Lafourche
	1:30pm	4:50pm	Session 13: Special Session: Innovative GNC Test Solutions	Pointe Coupee
	1:30pm	4:50pm	Session 14: Orbit Determination and Navigation	St. Landry
	1:30pm	4:50pm	Session 15: Satellite Relative Motion	St. Tammany
	3:10pm	3:35pm	Afternoon Break	9th Floor Prefunction
	6pm	9pm	Offsite Event	Musée Conti Wax Museum

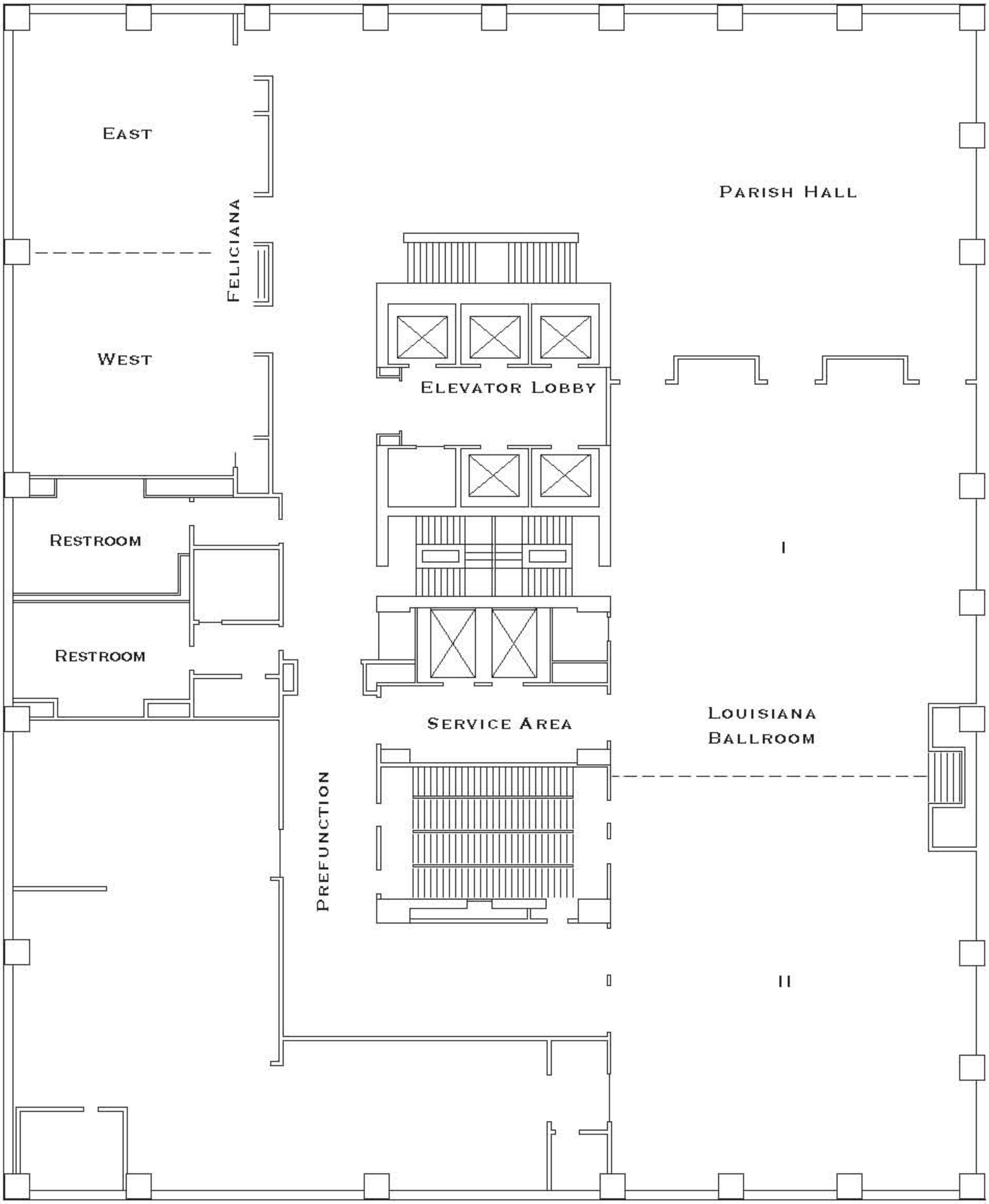
Day	Start	End	Function	Room
Wednesday 16 February	7am	8am	Speakers Breakfast	Terrebonne
	8am	2pm	Registration	9th Floor Prefunction
	8am	11:45am	Session 16: Special Session: Optical Navigation	Lafourche
	8am	11:45am	Session 17: Satellite Constellations	Pointe Coupee
	8am	11:45am	Session 18: Low-Thrust Trajectory Design	St. Landry
	8am	11:45am	Session 19: Earth Orbit and Missions	St. Tammany
	9:40am	10:05am	Morning Break	9th Floor Prefunction
	Noon	1:30pm	Joint Technical Committee Lunch	Terrebonne
	1:30pm	2:30pm	Dirk Brouwer Award Plenary	Lafourche/Pointe Coupee
	2:30pm	5:25pm	Session 20: Dynamical Systems and Orbital Mechanics	Pointe Coupee
	2:30pm	4:35pm	Session 21: Space Debris Removal	St. Landry
	2:30pm	5:00pm	Session 22: Attitude Sensor	St. Tammany
	3:45pm	4:10pm	Afternoon Break	9th Floor Prefunction

Day	Start	End	Function	Room
Thursday 17 February	7am	8am	Speakers Breakfast	Terrebonne
	8am	10am	Registration	9th Floor Prefunction
	8am	11:45am	Session 23: Trajectory and Mission Analysis	Lafourche
	8am	11:20am	Session 24: Attitude Dynamics and Control II	Pointe Coupee
	8am	11:20am	Session 25: Lunar Trajectory Design	St. Landry
	9:40am	10:05am	Morning Break	9th Floor Prefunction

LOEWS NEW ORLEANS HOTEL LAYOUT



NINTH FLOOR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Feliciana
West
Parish Hall
Elevator Lobby
Restroom
Restroom
I
Service Area
Louisiana
Ballroom
Prefunction
II

Tenth Floor

SPECIAL EVENTS

EARLY BIRD RECEPTION

Sunday, 13 February   6 – 9:00 pm
Location: Parish Hall

This reception features a **FREE OPEN bar (unlimited drinks)** for the first hour so be sure to arrive at the beginning!! A cash bar will be available for the remaining duration of the reception.

STUDENT AND YOUNG PROFESSIONAL RECEPTION

Monday, 14 February   6 – 8:00 pm
Location: Parish Hall

Texas A&M University has graciously provided for a FREE Student and Young Professional Reception in the Loews' Parish Hall. Come join us for a chance to network with friends and colleagues and learn about Texas A&M's Department of Aerospace Engineering. Hors d'oeuvres and non alcoholic beverages will be served free of charge.

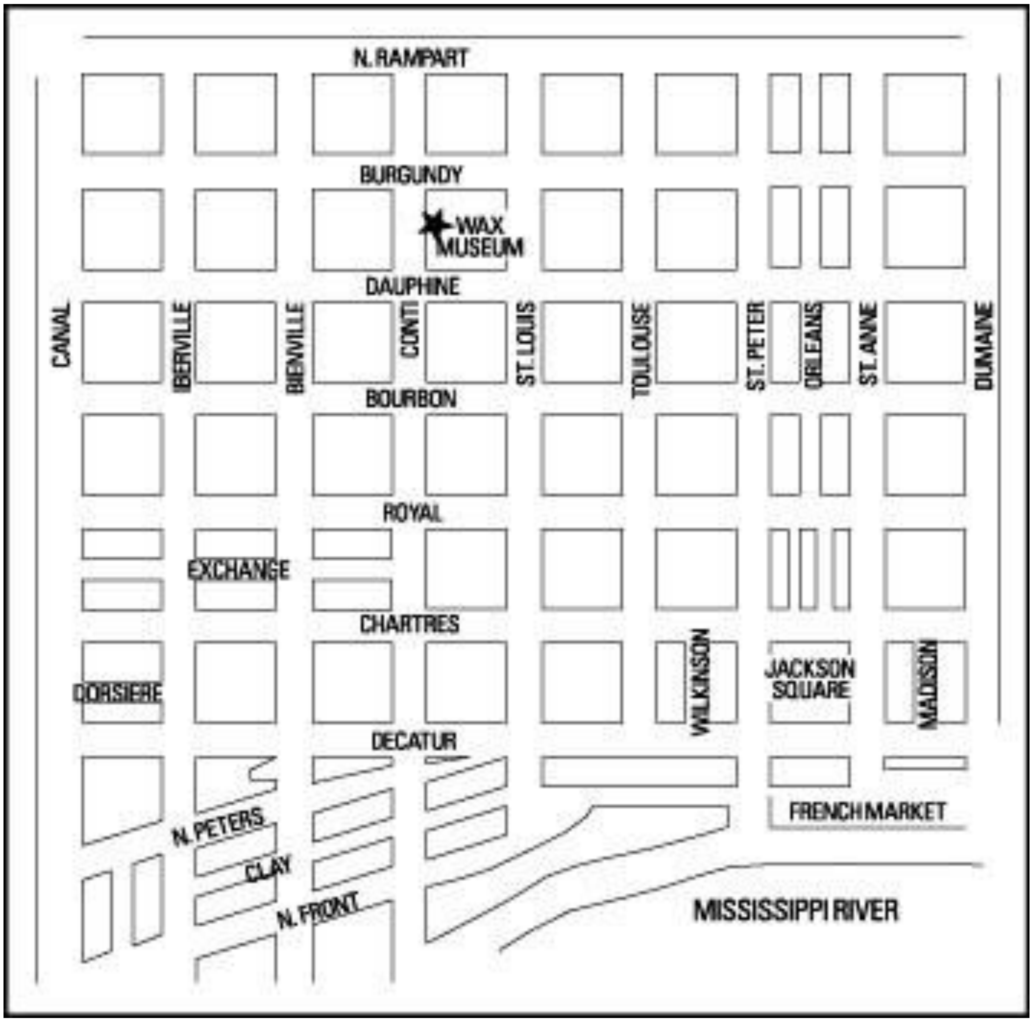
OFFSITE EVENT – MUSÉE CONTI WAX MUSEUM

Tuesday, 15 February   6 - 9:00 pm Dinner and Museum Access
Location   Musée Conti Wax Museum
Historic French Quarter at 917 Rue Conti between Burgundy & Dauphine (1½ blocks from Bourbon Street)

The Musée Conti Wax Museum depicts the exciting history of New Orleans and the Louisiana Territory. One hundred fifty four (154) life-size figures sculpted in wax are displayed in historically accurate settings in this one-of-a-kind museum. The Legend Room, located above the Museum, offers a warm, intimate atmosphere for dinner. This room is decorated in classic French Quarter style, with cypress window frames, white-washed and spot sandblasted bricks, hardwood floors, exposed beams washed in white, indirect lighting, and a skylight for accent. The adjacent Windows Room overlooks the street and will serve as the buffet room.

A buffet dinner that includes 1 drink ticket will be served. A cash bar is available for additional drink purchases. Guests will have access to the museum exhibits for the entire duration of the event.

Guests are required to find their own transportation to the Musée Conti Wax Museum. The museum is located in the French Quarter ~ 1 mile from the Loews New Orleans Hotel. This is a 15-20 minute walk from the hotel. Should guests choose to drive to the event, there are 2 pay parking lots within a 1-block radius of the Musée Conti. The lots are located on the corner of Rampart and Conti. Parking at meters on the street is often available but BEWARE of the meter maids.



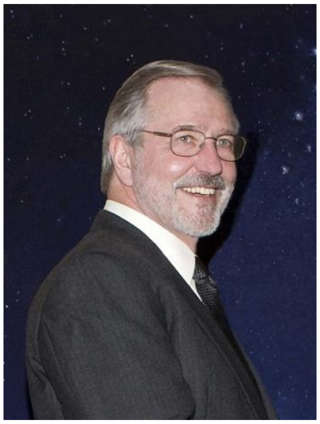
DIRK BROUWER AWARD PLENARY:

Wednesday, 16 February 1:30 – 2:30 pm (ceremony and lecture)
Location: Lafourche/Pointe Coupee (ceremony and lecture)

In the Beginning There Were Comets and Asteroids - Now There is Earth-Orbiting Debris

Early in the space program models and data were developed to understand the hazard to spacecraft from small fragments originating from asteroids and comets; by 1970 it was concluded that the hazard was manageable. However, years later, when similar models and data were used to determine the possible hazard from spacecraft fragments in Earth orbit, a different conclusion was reached: The orbital-debris hazard could quickly become unmanageable. After a rocky beginning, the NASA Orbital Debris Program is now officially over 30 years old, international in scope, and is continuing to take on increasing responsibilities. This lecture will identify the technical and political misconceptions that delayed the recognition and acceptance of the program and will discuss current findings and the direction the program must take. It will illustrate that, where statistical models applied to a small amount of data were sufficient to identify the orbital debris problem, more sophisticated models will likely be required to solve the problem.

DIRK BROUWER AWARD HONOREE



Donald J. Kessler retired from NASA in 1996 as NASA's Senior Scientist for Orbital Debris Research. He has more than 40 years of experience in scientific research associated with orbital debris, meteoroids, and interplanetary dust. He began his career at NASA modeling the interplanetary meteoroid environment. He later applied these modeling techniques to artificial satellites in Earth orbit, predicting that man-made orbital debris soon would exceed the natural meteoroid environment. This prediction, coupled with verifying data, led to the official establishment of NASA's Orbital Debris Program Office at the Johnson Space Center in 1979. There he continued to develop more complex orbital debris models, recommended and developed experiments to test those models, and analyzed data which led to the discovery of new sources of orbital debris. He conducted classes, workshops, and symposia on orbital debris, and recommended cost effective techniques to control the environment. He also participated in national and international reviews of other agencies' orbital debris programs, leading to the establishment of the Inter-Agency Space Debris Coordination Committee (IADC), an international agency to address orbital debris issues. Mr. Kessler participated in U.S. Air Force (USAF) and Strategic Defense Command tests and measurements programs, studies of orbital debris by various organizations such as the USAF Scientific Advisory Board, the AIAA, the Office of Technology Assessment (OTA), and the General Accountability Office. In 1989, he was awarded the NASA Medal for Exceptional Scientific Achievement.

Since retiring, Mr. Kessler has continued to consult with NASA and other organizations. In 2000, he received the AIAA Losey Atmospheric Sciences Award and, in 2008, received the IAASS Jerome Lederer Space Safety Pioneer Award. Mr. Kessler has published more than 100 technical papers on meteoroids and orbital debris and has been a contributing author or editor of 10 major reports. However, he may be recognized by the general public for the "Kessler Syndrome", a term propagated by the popular press to describe his 1978 publication. This publication predicted the increasing orbital debris environment from random collisions between satellites that is being observed today. Mr. Kessler is currently supporting the National Research Council as chairman of a panel to assess NASA's orbital debris program.

CONFERENCE LOCATION

LOEWS NEW ORLEANS HOTEL ACCOMMODATIONS

The conference is located at the Loews New Orleans Hotel in New Orleans, Louisiana.

Loews New Orleans Hotel
300 Poydras Street
New Orleans, Louisiana 70130 USA
Phone: 1-504-595-3300
Fax: 1-504-595-3310
Toll-free: 1-866-211-6411

www.loewshotels.com/en/New-Orleans-Hotel/GroupPages/AAS

The Conference rate for the conference is $140 plus applicable taxes. Currently, the tax rate is 13% plus a $1.00 per room, per night occupancy tax. Please request the AAS/AIAA Space Flight Mechanics Meeting rate. The deadline for securing the conference rate at the hotel is January 21, 2011.

TRANSPORTATION INFO

New Orleans is one of the world's busiest ports and the cultural capital of the South, yet the city is remarkably compact and easy to navigate. Many of the city's attractions, accommodations and event venues are within walking distance of each other. However, New Orleans does have a very accessible and reasonably priced public transportation system. Additionally, there are a great variety of guided tours throughout the city and the surrounding area.

By New Orleans Streetcars

Getting around New Orleans by streetcar is a great way to see the city. There are three different lines: St. Charles, Canal Street, and the Riverfront, each of which originates downtown but takes you to different parts of the city.

One-way fares are $1.25 and can be paid with exact change when you board. One, 3 and 5-day unlimited ride passes are also available for $5, $12 and $20 respectively. See the New Orleans Regional Transit Authority (NORTA) website (www.norta.com) for a list of places to purchase these. Please note that passes are non-refundable and non-replaceable.

Fares listed above are subject to change - check directly with NORTA for the latest information.

By Bus

Operated by NORTA, city bus lines offer a convenient, affordable way to get around New Orleans. For $1.25 one-way you can get to most areas of town. NORTA currently is operating 30 bus routes throughout New Orleans and you can find maps and schedules from their site (www.norta.com). Fares listed above are subject to change - check directly with NORTA for the latest information.

By Taxi

New Orleans is actually a geographically small town, which makes most journeys by cab very affordable. A cross-town ride from a French Quarter/downtown hotel to an uptown jazz club or neighborhood restaurant is typically under $20, and is a safe, fast way to get from point A to point B if you're unsure of streetcar or bus stop locations along the way. You can often find a cab stand near major hotels or contact the Loews Concierge at 504-595-5368 for rates and reservations.

By Tour

Get to know the Big Easy with a city tour. Visit the historical Garden District and the picturesque City Park. Tour the famed French Quarter and discover one of the many cemeteries. For a taste of the antebellum South, take a trip to Oak Alley and other plantations on River Road. Speed through private swamps on a tiny airboat at 50 mph, or cruise the waters and seek out the wildlife. No matter the season, there's always plenty to see in the mysterious swamps and bayous of Louisiana. Set off on a walking tour of some of the most interesting places throughout the city, including the historical (and haunted) French Quarter, Algiers Point, Garden District and unique cemeteries. Contact the Loews Concierge at 504-595-5368 for details about these New Orleans tours or visit the following sites for lists of tour companies:

www.neworleansonline.com/neworleans/tours/tours.php
www.neworleanscvb.com/listings/index.cfm/catID/10/subcatID/527/locID/0/startrange/All/endrange/All/substart/A/subend/G/hit/1

DIRECTIONS

From Airport:

- Take Airport Road
- Take the I-10 East ramp towards New Orleans
- Merge onto I-10 East
- Take exit 234B, then exit on the left towards Poydras Street/Superdome
- Head straight on Poydras Street for approximately twelve blocks
- The hotel is located on the right at 300 Poydras Street

From the North:

- I-55 South to I-10 East
- Follow Driving directions from Airport

From the East:

- From I-10 West, take Canal Street Exit 235B
- Proceed straight one block to Canal Street. Turn Right onto Canal Street
- Turn right onto Tchoupitoulas St. Approximately 15 blocks. Turn left onto Poydras Street.
- Hotel is located on the right at 300 Poydras Street

From the South:

- I-310 North to I-10 East
- Follow driving directions from the Airport

Alternate transportation:

- Airport Shuttle arrangements can be made through Airport Shuttle Co. (504-522-3500) www.airportshuttleneworleans.com
- Estimated taxi fare: $33.00 USD (one way)

ARRIVAL INFORMATION

Check-In and Checkout

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

Attendees may be checked in earlier depending on occupancy levels and availability. In order to streamline the check-in process, Loews New Orleans Hotel would appreciate receiving flight arrival times for conference attendees, if available. Any guest checking out after 12:00 p.m. will be assessed a fee equal to one night's room and tax. Late check-out will be extended, if possible, by individual request.

At check-in, each conference attendee will have the opportunity to reconfirm his or her departure date. Any guest departing prior to that date will be assessed one night's room rate. This charge will be posted to the guest's individual account.

Parking

- Valet parking is available in the hotel at a rate of $29.00 plus tax per night, with in and out privileges. Height restriction of 6"10". Rates are subject to change without notice.

High-Speed Internet Access

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

Swimming

- Indoor Pool (8th floor)
- Whirlpool (8th floor)

Fitness Facilities

- Fitness Center (8th floor)

Restaurants

New Orleans is known for its numerous options of diverse and incredible cuisine. See the following websites for lists of restaurants in addition to the suggestions included below:

www.neworleansonline.com/neworleans/cuisine/restaurants.php?neighborhood=1
www.neworleanscvb.com/listings/index.cfm/catID/11/hit/1/sectionID/1/sectionID/1/subsectionID/531

Hotel

Cafe Adelaide and the Swizzle Stick Bar
- Operated by the Commanders Palace Family of Restaurants

Within Walking Distance (≤ 1 mile from Loews New Orleans Hotel)

Acme Oyster House - seafood
- 724 Iberville Street, (504) 522-5973, www.acmeoyster.com

Alex Patout's - cajun
- 720 St. Louis Street, (504) 525-7788, www.patout.com

Arnaud's - French creole
- 813 Bienville Street, (504) 523-5433, www.arnauds.com

Bacco - Italian
- 310 Chartres Street, (504) 522-2426, www.bacco.com

Bayona - contemporary/eclectic
- 430 Dauphine Street, (504) 525-4455, www.bayona.com

Bella Luna - contemporary Louisiana
- 914 N. Peters Street, (504) 529-1583, www.bellalunarestaurant.com

Bombay Club - contemporary Louisiana
- 830 Conti Street, (504) 586-0972, www.thebombayclub.com

Broussard's - French creole
- 819 Conti Street, (504) 581-3866, www.broussards.com

Cafe Du Monde - coffee and beignets
- 1039 Decatur Street, (504) 587-0835, www.cafedumonde.com

Cafe Sbisa - French creole
- 1011 Decatur Street, (504) 522-5565, www.cafesbisa.com

Crescent City Brewhouse - seafood
- 527 Decatur Street, (504) 522-0571, www.crescentcitybrewhouse.com

Emeril's - contemporary/eclectic
- 800 Tchoupitoulas Street, (504) 528-9393, www.emerils.com

Felix's - seafood
- 210 Bourbon Street, (504) 522-4440, www.felixs.com

Galatoire's - French creole
- 209 Bourbon Street, (504) 525-2021, www.galatoires.com

G.W. Fins - seafood
- 808 Bienville Street, (504) 581-3467, www.gwfins.com

Herbsaint - French
- 701 St. Charles Avenue, (504) 524-4114, www.herbsaint.com

Harrah's New Orleans Casino - steakhouse, buffet
- 4 Canal Street, (504) 533-6111, www.harrahsneworleans.com

Johnny's Po-Boys - breakfast, poboys, seafood

- 511 St. Louis Street, (504) 524-8129, www.johnnyspoboy.com

K-Paul's - cajun (dinner only, lunch available Thus-Sat)

- 416 Chartres Street, (504) 596-2530, www.kpauls.com

Lil Dizzy's Cafe- soul food, lunch buffet

- 610 Poydras Street, (504) 212-5656

Mother's/Mother's Next Door - classic New Orleans home cooking

- 401 Poydras Street, (504) 523-2917, www.mothersrestaurant.net

Palace Cafe - seafood

- 605 Canal Street, (504) 523-1661, www.palacecafe.com

Pat O'Brien's - New Orleans cuisine and drinks

- 718 St. Peter Street, (504) 525-4823, www.patobriens.com/patobriens/neworleans

Pelican Club - contemporary Louisiana

- 615 Bienville Street, (504) 523-1504, www.pelicanclub.com

Pierre Mesparo's - cajun/contemporary New Orleans cuisine

- 440 Chartres Street, (504) 524-8990, www.pierremasperosrestaurant.com

Olivier's Creole Restaurant - traditional New Orleans creole/soul food

- 204 Decatur Street, (504) 525-7734, www.olivierscreole.com

Red Fish Grill - seafood

- 115 Bourbon Street, (504) 598-1200, www.redfishgrill.com

Restaurant August - French

- 301 Tchoupitoulas Street, (504) 299-9777, www.rest-august.com

Tommy's - Italian

- 746 Tchoupitoulas Street, (504) 581-1103, www.tommyscuisine.com

Other Options - A Little Further (within 2 miles from Loews New Orleans Hotel)

Angeli On Decatur - mediterranean, pizza

- 1141 Decatur Street, (504) 566-0077

Emeril's Delmonico- French creole

- 1300 St. Charles Avenue, (504) 525-4937, www.emerils.com

The Gumbo Shop - casual seafood

- 630 St. Peter Street, (504) 525-1486, www.gumboshop.com

Maximo's- Italian

- 1117 Decatur Street, (504) 586-8883, www.maximos.com

Peristyle - French

- 1041 Dumaine Street, (504) 593-9535

Port of Call - steaks, burger, and drinks

- 838 Esplanade Avenue, (504) 523-0120, www.portofcallnola.com

Snug Harbor Jazz Bistro- regional cooking and jazz

- 626 Frenchman Street, (504) 949-0696, www.snugjazz.com

Stella!- contemporary/eclectic

- 1032 Charles Street, (504) 587-0091, www.restaurantstella.com

RECREATION

All of the suggestions listed below are within 10 city blocks of the Loews New Orleans Hotel, with the exceptions of the Audubon Zoo, New Orleans Museum of Art, and the Ogden Museum of Southern Art, which vary between 3 and 5 miles away from the hotel.

Further information regarding nearby activities can be found from the following websites:

www.neworleansonline.com
www.neworleanscvb.com

Attractions and Landmarks

Aquarium of the Americas

- 1 Canal Street, (504) 581-4629, www.auduboninstitute.org/visit/aquarium

Arts District

- www.neworleansonline.com/tools/neighborhoodguide/artsdistrict.html

Audubon Zoo

- 6500 Magazine Street, (504) 581-4629, www.auduboninstitute.org/visit/zoo

Blaine Kern Mardi Gras World / Mardi Gras World Tours

- 1380 Port of New Orleans Place, (504) 361-7821, www.mardigrasworld.com

Bourbon Street

- www.neworleansonline.com/neworleans/fq/bourbonstreet.html

Central Business District

- www.neworleansonline.com/tools/neighborhoodguide/cbd.html

French Quarter

- www.neworleansonline.com/neworleans/fq/

Harrah's Casino

- 4 Canal Street, (504) 533-6111, www.harrahsneworleans.com

Jackson Square / St. Louis Cathedral

- www.neworleansonline.com/directory/location.php?locationID=1342

Louisiana Superdome

- www.neworleansonline.com/directory/location.php?locationID=1291

Riverfront Street Car

St. Charles Avenue

- www.neworleansonline.com/neworleans/architecture/saintcharles.html

Steamboat Natchez River Cruises

- (504) 569-1401, www.steamboatnatchez.com

Museums

Louisiana Children's Museum

- 420 Julia Street, (504) 523-1357, www.lcm.org

National World War II Museum

- 945 Magazine Street, (504) 528-1944, www.ddaymuseum.org

New Orleans Museum of Art

- 1 Collins Diboll Circle, (504) 658-4100, www.noma.org

Ogden Museum of Southern Art

- 925 Camp Street, (504) 539-9650, www.ogdenmuseum.org

Shopping

Chartres Street Galleries & Shops

French Market

- 1100 North Peters, (504) 522-9200

Magazine Street

- 100-6000 Magazine Street, (866) 679-4764

Royal Street Antiques

- www.neworleansonline.com/neworleans/fq/royalstreet.html

Riverwalk Marketplace

- 1 Poydras Street, (504) 522-1555

The Shops at Canal Place

- 333 Canal Street, (504) 522-9200

Family Friendly

Audubon Insectarium

- 423 Canal Street, (504) 410-2847, www.auduboninstitute.org/visit/insectarium

Audubon Zoo

- 6500 Magazine Street, (504) 581-4629, www.auduboninstitute.org/visit/zoo

Aquarium of Americas

- 1 Canal Street, (504) 581-4629, www.auduboninstitute.org/visit/aquarium

City Park Storyland

- 1 Palm Drive, (504) 482-4888, www.neworleanscitypark.com/carousel_gardens.html

Louisiana Children's Museum

- 420 Julia Street, (504) 523-1357, www.lcm.org

Golf

English Turn Golf and Country Club (~ 10 miles)

- 1 Clubhouse Drive, (504) 391-8018, www.englishturn.com/countryclub.php3

TPC of Lousiana at Fairfield (~ 9 miles)

- 11001 Lapalco Blvd, (504) 436-8721, www.tpc.com

Eastover Country Club (~ 13 miles)

- 5690 Eastover Drive, (504) 241-4400, www.eastovercountryclub.com

Mardi Gras

Mardi Gras is one big holiday in New Orleans. Mardi Gras 2011 falls on Tuesday, March 8. Although this is after the conference, the celebration in New Orleans begins several weeks in advance. The first Mardi Gras parade is scheduled for February 19, 2011, for those conference attendees interested in extending their stay a few days post conference to experience Mardi Gras in New Orleans. Please refer to www.mardigrasneworleans.com/schedule.html for further details.

Feb 14, 2011

Session 1: Asteroid Missions I

Chair: Dennis Byrnes, Jet Propulsion Lab

08:00 **AAS 11 - 100** **A MISSION ANALYSIS SURVEY OF POTENTIAL HUMAN-PRECURSOR ROBOTIC ASTEROID MISSIONS**
Michael L. Cupples, Raytheon Missile Systems; Roberto Furfaro, Carl W. Hergenrother, Badejo O. Adebonojo Jr., Daniel R. Wibben, John N. Kidd Jr., University of Arizona

A preliminary mission analyses survey for conceptual robotic asteroid missions that are precursor to potential human asteroid missions is provided, yielding a set of parametric data that can be used for preliminary mission planning. For a set of carefully chosen asteroids, the study generated a table of delta-v data that extends over a range of Earth departure opportunity dates and a range of total transfer times. A subjective comparison was performed that further evaluated the low delta-v analyses databased on a set of key performance parameters that include Earth departure C3 and total transfer time.

08:25 **AAS 11 - 101** **Interplanetary Trajectories for Robotic and Manned Missions to Asteroids**
Kevin W. Kloster, and James M. Longuski, Purdue University

Trajectories to several large, near-Earth asteroids are analyzed for potential application to a manned asteroid mission in the next 15 to 20 years. Trajectories to near-Earth and main-belt asteroids are considered for robotic precursor missions such as a lander, a rover, or even a sample return mission. Gravity-assist and direct trajectories with low launch and arrival energies and short flight time are identified using a numerical broad-search technique in combination with a simple graphical method. Fully integrated, $Delta$V-optimized trajectories to several asteroids are presented including a mission to 99942 Apophis that returns to Earth within one year of Earth-departure.

08:50 **AAS 11 - 102** **Human Exploration of Near-Earth Asteroids via Solar Electric Propulsion**
Damon Landau and Nathan Strange, JPL

There have been many proposed technologies and architectures to extend a human presence beyond the Moon. Solar electric propulsion (SEP) provides the capability to implement a wide variety of missions with relatively low injected mass to low-Earth orbit. Because of its broad applicability this technology can enable new missions while immediately benefiting a current step in human space exploration. The benefits of SEP are addressed for cis-lunar excursions, near-Earth asteroid exploration, and missions to Phobos, with the ultimate goal of landing humans on Mars. In particular, SEP expands the range of near-Earth asteroids accessible with a constrained launch capability (IMLEO).

09:15 **AAS 11 - 103** **Fictive Post-2029 Apophis Rendezvous Deflection Mission Using an Ares-V Class Launch Vehicle**
Dan Zimmerman, Sam Wagner, and Bong Wie, Iowa State University

In 2029, asteroid Apophis will have a close-encounter with Earth, in which the asteroid will pass through inside geostationary orbit. Although the chance that Apophis will return to collide with Earth on a resonant orbit seven years later in 2036 is now quite low, this paper considers a fictional case in which Apophis may be on an impact trajectory in the future. To avoid or minimize the impact damage of Apophis, a nuclear option could be used. This study examines applicable system architectures using an Ares-V class launch vehicle that could be used for deflection missions.

09:40 **Break**

10:05 AAS 11 - 104 Dynamics of Levitating Dust Particles Near Asteroids

Christine M. Hartzell and Daniel J. Scheeres, University of Colorado at Boulder

The electrostatic levitation of surface dust particles on asteroids has been hypothesized based on observations of dust ponds on Eros and dust movement on the Moon. The potential for long distance dust transport through levitation has implications for thedesign of and constraints on future asteroid exploration missions. We analyze the stability and equilibria of the linearized and fully nonlinear system. We develop an analytical expression for the smallest size dust particle capable of levitation. By further understanding the characteristics of particle levitation, we will be able to more accurately determine if levitation is a physically feasible dust transport mechanism.

10:30 AAS 11 - 105 Dynamics and Stability in a Triple Asteroid System

Julie Bellerose, Carnegie Mellon University / NASA Ames

We now count two triple asteroid systems in the NEA population. There is a need to understand the scale of perturbations and stability for spacecraft applications in such environment. We look at the dynamics of triple systems, starting from a two-body and a restricted three body dynamical models, where the mass distribution of one of the bodies may be taken into account. We numerically investigate the importance of an added body mass, and on a point mass or spacecraft, and numerically look at the long-term stability of such systems.

10:55 AAS 11 - 106 SEQUENTIAL SHAPE ESTIMATION OF AN ASTEROID USING VISION

Neha Satak, Manoranjan Majji and John E Hurtado, Texas A&M University, College Station

Proximity operations require accurate gravity model of an asteroid. A method of reconstructing the shape model is by using photographic measurements. Tracking surface-features in successive image pairs enable the reconstruction of the asteroid. At close proximity the imaging spacecraft experiences large perturbations due to gravitational harmonics of the asteroid. We develop a methodology to design optimal imaging orbits about an arbitrary asteroid. While the method starts from an ellipsoidal approximation, the shape model of the asteroid is continuously updated. Intermediate thrust differential corrections are given along the trajectory based on the updated shape model.

11:20 AAS 11 - 107 The Extended Gravity-Tractor: An Alternative to Improve Asteroid Towing Merits

Dario O. Cersosimo, University of Missouri - Columbia.

The extended gravity-tractor (xGT) concept is derived from the well-known gravity-tractor (GT). The xGT is intended to improve the towing performance of the classical GT by taking into consideration the shape and rotational state of a generic asteroid. The xGT hovering strategy consists on guiding the spacecraft towards and away the NEO’s center of mass along the towing vector. This motion is synchronized with the asteroid spin, consequently increasing the gravitational pull on the NEO. A first-order analysis using a two-body model found the xGT could improve towing merits up to 80% over the classical GT, thus reducing towing times.

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Session 2: Attitude Dynamics and Control I

Chair: Daniele Mortari, Texas A&M University

08:00 **AAS 11 - 108** **Analysis of Attitude Dynamics of IKAROS**
Takanao Saiki, Yuichi Tsuda, Ryu Funase, Hirotaka Sawada and Osamu Mori, JAXA; Yoji Shirasawa and Ryo Jifuku, University of Tokyo

This paper provides an analysis for the attitude dynamics of IKAROS solar power sail demonstration spacecraft. IKAROS is a spin stabilized spacecraft equipped with a large solar sail. The solar sail is a flexible structure and the coupled motion of the rigid main body with the flexible structure is complicated. First the simple attitude dynamics model of spinning solar sail is introduced. And the result of the frequency analysis of the flight data is shown. Then the effectiveness of the simple attitude dynamics model is confirmed via the comparison of the flight data.

08:25 **AAS 11 - 109** **Attitude Motion of Spinning Spacecraft With Fuel Sloshing and Nutation Damper**
Mohammad A. Ayoubi, Farhad A. Goodarzi, Santa Clara University; Arun Banerjee, Lockheed Martin Advanced Technology Center

We use Kane's method to formulate the equations of motion of a spinning spacecraft with three momentum wheels, a nutation damper, and a spherical pendulum. The spherical pendulum is adopted as a simple model of fuel sloshing in partially filled tanks. Theproposed model is verified with some existing results in the literature and the commercial software MSC ADAMS. Some numerical results are obtained for a typical spacecraft.

08:50 **AAS 11 - 110** **First Flight Results on Time-Optimal Spacecraft Slews**
M. Karpenko, Naval Postgraduate School; N. Bedrossian, S. Bhatt, The Charles Stark Draper Laboratory; A. Fleming, Leffler Consulting, LLC; I.M.Ross, Naval Postgraduate School

Optimal reorientation maneuvers have obvious application to spacecraft systems. Yet, despite the potential advantages, performing time-optimal reorientation maneuvers has never been tested in flight. In this paper, we apply pseudospectral optimal control techniques for designing and implementing a minimum-time reorientation maneuver for the Transition Region and Coronal Explorer (TRACE) spacecraft. The designed optimal maneuver was successfully implemented in a flight test during summer 2010, making this the first optimal reorientation maneuver ever performed on-orbit. Flight results show that the minimum-time maneuver exploits the availability of maneuvering capability that would otherwise be lost in an eigenaxis slew.

09:15 **AAS 11 - 111** **High Fidelity Simulation of SwampSat Attitude Determination and Control System**
Josue D. Munoz, Vivek Nagabhushan, Sharan Asundi and Norman G. Fitz-Coy, University of Florida

The paper discusses the development and simulation of the truth model for the attitude determination and control system of SwampSat. The truth model is generated by rigorous development of the satellite dynamics along with measurements from actuator and sensor characterization tests. The simulation also includes a high fidelity treatment of the external disturbances on the satellite, hardware and software limitations, and sensor and actuator noise. Simulations representing the mission profile are presented.

09:40 **Break**

10:05 **AAS 11 - 112** **Modeling of Attitude Dynamics for IKAROS Solar Sail Demonstrator**

Yuichi Tsuda.Takanao Saiki, Ryu Funase, Japan Aerospace Exploration Agency;
Yuya Mimasu, Kyushu University

This paper describes a method of modeling attitude dynamics developed for IKAROS solar sail demonstration mission.
Since the successful deployment of the solar sail, IKAROS has received the solar radiation pressure which strongly affects both translational and rotational motion of the spacecraft. It is essential for solar sail operations to have accurate SRP model in terms of both trajectory guidance and attitude control. Some theoretical background for the attitude modeling method used in IKAROS as wellas actual on-orbit operation results are addressed in the paper.

10:30 **AAS 11 - 113** **OPERATIONAL CONSIDERATIONS FOR ATTITUDE CONTROL OF THE RBSP SPACECRAFT**

Robin M. Vaughan and Timothy G. McGee, Johns Hopkins University Applied Physics Laboratory

The Radiation Belt Storm Probes (RBSP) mission plans to launch two Earth-orbiting spacecraft in 2012. The two spacecraft are major-axis spinners with no on-board attitude determination or control. The rotational dynamics are complicated by the interaction of the spacecraft bus with multiple appendages that include two pairs of long wire booms, one pair of shorter axial booms, four solar panels, and two magnetometer booms attached to the solar panels. This paper will describe the interaction between dynamic stability, the choice of spacecraft attitude, and timing of maneuvers to maintain that attitude in the context of optimizing science data return.

10:55 **AAS 11 - 114** **Relative Attitude Determination of Planar Formations**

Richard Linares, Yang Cheng, and John Crassidis

A relative attitude determination method for planar formations of three vehicles is presented. The three vehicles are assumed to be equipped with sensors to provide measurements of the three inter-vehicle line-of-sight vectors. The line-of-sight vectors are further assumed to be always in a plane and this knowledge is exploited to improve the accuracy of the relative attitude determination solution. Covariance analysis is provided to gain insight on the stochastic properties of the errors of the solution.

11:20 **AAS 11 - 115** **Rigid-Body Attitude Tracking with Vector Measurements and Unknown Gyro Bias**

Travis Mercker and Maruthi R. Akella, University of Texas at Austin

The problem of rigid-body attitude tracking is examined when there is an
unknown gyro bias and vector measurements are available. An adaptive control scheme is proposed that meets the attitude tracking control objective of forcing the attitude and velocity tracking errors to zero. In addition, it is shown that the bias and the quaternion estimates converge to their corresponding true values. Controllers are introduced for the cases where the body's inertia matrix is both known and unknown. Convergence is shown through a stability analysis, and performance of the controllers is shown through simulation.

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Session 3: Orbit Determination

Chair: Dr. Craig McLaughlin, University of Kansas

08:00 **AAS 11 - 116** **A Comprehensive Comparison between Angles-Only Initial Orbit Determination Techniques**

Andrew Schaeperkoetter and Daniele Mortari, Texas A&M University

With an array of different angles-only IOD techniques available for both Earth-based and space-based initial orbit determination, it is important to systematically analyze each method and its success at analyzing a variety of different orbits. While generalizations have been made in previous research, particularly about the closeness of the observations, more research is needed to make these generalizations more meaningful. In this research, the duration between observations, the measurement error, the location of the observer, and most importantly the orbit will be varied to determine the best IOD technique for a given scenario.

08:25 **AAS 11 - 117** **DISTRIBUTED ORBIT DETERMINATION VIA ESTIMATION CONSENSUS**

Ran Dai, Unsik Lee, and Mehran Mesbahi, University of Washington

This paper proposes an optimal algorithm for distributed orbit determination by using discrete observations provided from multiple tracking stations in a connected network. The objective is to increase the precision of estimation by communication and cooperation between tracking stations in the network. We focus on the dynamical approach considering a simplified Low Earth Satellite model with random perturbations introduced in the observation data which is provided as ranges between tracking stations and satellite. The dual decomposition theory associated with the subgradient method is applied here to decompose the estimation task into a series of suboptimal problems and then solve them.

08:50 **AAS 11 - 118** **ICESat Precision Orbit Determination Experiments at Low Altitude**

H.-J. Rim, S. Yoon, B. Schutz, University of Texas at Austin

ICESat was decommissioned in 2010 and the orbit was lowered to facilitate reentry, which occurred on August 31, 2010. An ICESat BlackJack GPS receiver was operated until August 14 when the perigee altitude was about 185 km. Precision orbit determination analysis was conducted with the GPS data and with the ground-based satellite laser ranging data.

09:15 **AAS 11 - 119** **Improved orbit determination using second-order Gauss-Markov processes**

Felipe G. Nievinski, Brandon Yonko, and George H. Born, Department of Aerospace Engineering Sciences, Colorado Center for Astrodynamics Research, University of Colorado at Boulder

Confronted with fundamental uncertainties regarding orbital system dynamics and the abundance of tracking data from GPS, the estimation of empirical accelerations has become standard practice in precise orbit determination (POD) of near-Earth satellites. In sequential filtering an exponentially time-correlated system noise process is typically postulated, corresponding to a first-order Gauss-Markov process (GMP). In the present work we address the possibility of using second-order GMP in POD. Improvements are demonstrated for sparse and intermittent tracking as well as for orbit predictions at unobserved future epochs, in terms of both more accurate states and more realistic covariance envelopes.

09:40 **Break**

10:05 **AAS 11 - 120** **Meteosat Orbit Determination Using Starbrook Optical Directional Observations**

Milan Klinc, independent consultant at EUMETSAT; David Lázaro, Space Operations Consulting at EUMETSAT; Dr James Dick, Space Insight Ltd.

An enhanced orbit determination method, combining standard ranging data with optical directional observations, was tested at EUMETSAT, using measurements provided by the Starbrook space surveillance sensor, operated by Space Insight Ltd. The aim was to obtain an ideal match between the optical sensor detection capabilities, optimized for its general surveillance role, and the required processing software sophistication at the control centre, forming a suitable system for use in routine Meteosat orbit determination. The obtained results during a trial period between March and June 2010, demonstrated the validity of the concept and its considerable potential for direct application to routine Operations.

10:30 **AAS 11 - 121** **ON LAPLACE'S ORBIT DETERMINATION METHOD: SOME MODIFICATIONS**

Reza Raymond Karimi, Daniele Mortari, Texas A&M University

Three modifications towards enhancing the accuracy and performance of Laplace's method of orbit determination are presented. Frst, the polynomial root solving procedure of the Laplace's method was eliminated. In the second modification, the first and second time derivatives of the middle range is approximated by the other ranges so all three ranges (if three observations) can be determined by solving just one system of equation. Finally the singularity associated with the Laplace's method for coplanar cases was resolved by modifying the method for multiple observations which is based on the modification in the previous step.

10:55 **AAS 11 - 122** **Orbit Determination for Tumbling Space Objects**

Prasenjit Sengupta and Sai Vaddi, Optimal Synthesis Inc.

Analysis of models for orbit determination of satellites in LEO are the subject of this work. The primary influence on satellites in such orbits are atmospheric drag. Whereas high-fidelity models exist for the atmospheric density, the ballistic coefficient of the satellite also influences the drag. For orbiting debris, the cross-section area varies and consequently the drag force is a function of the debris attitude. In this work we examine the requirements for inclusion of attitude effects on orbit determination.

11:20 **AAS 11 - 123** **Sequential Orbit Estimation with Routinely Sparse Tracking**

John H. Seago, Jacob D. Griesbach, and James W. Woodburn; Analytical Graphics, Inc., David A. Vallado, Center for Space Standards and Innovation.

A properly initialized sequential orbit estimator will converge to less certain state estimates whenever the density of the spacecraft tracking is relatively low; nevertheless, these estimates should remain viable as long the estimator's work-ing assumptions are met. However, when tracking data are sparse, violations of certain working assumptions may pose special problems, such as when outliers exist. In this paper, mitigation strategies are explored for such cases and these are contrasted with typical batch-least-squares techniques, with the observation that a sequential orbit estimator presents it own benefits whenever tracking data are sparsely distributed.

Feb 14, 2011

Session 4: Trajectory Design and Optimization I

Chair: Dr. Ryan Russell, Georgia Institute of Technology

13:30 **AAS 11 - 124** **Direct Method Transcription For A Human-Class Translunar Injection Trajectory Optimization**
Kevin E. Witzberger, National Aeronautics and Space Administration, Glenn Research Center; Rajnish Sharma, University of Alabama

In this paper, a TLI trajectory for a future Human-class Lunar mission similar to NASA's Apollo program is assessed by using a new computational routine constructed by using direct optimization techniques. The mission architecture includes an Earth Transfer Stage (ETS), an orbiter, lander, and a chemical engine. From a circular LEO, the trajectory starts with main engine ignition. An hour later the ETS and fuel tanks are jettisoned. The trajectory ends with the spacecraft flying over the North Pole of theMoon. The analysis includes both a three degree-of-freedom (3-DOF) trajectory optimization and a 3-DOF simulation using closed-loop guidance.

13:55 **AAS 11 - 125** **Flyby Design using Heteroclinic and Homoclinic Connections of Unstable Resonant Orbits**
Rodney L. Anderson and Martin W. Lo, Jet Propulsion Laboratory, California Institute of Technology

Tour designs using flybys have traditionally been studied using two-body patched conic methods. Previous work has shown that trajectories designed using these techniques and with optimization methods follow the invariant manifolds of unstable resonant orbits as they transition between resonances. This work is continued here by computing heteroclinic and homoclinic trajectories associated with these unstable resonant orbits. These trajectories are used with multiple resonances to design flybys that transition between these resonances in the circular restricted three-body problem without the need for two-body approximations.

14:20 **AAS 11 - 126** **Fuel-Optimal Trajectories for Continuous-Thrust Orbital Rendezvous with Collision Avoidance Constraint**
Richard Epenoy, Centre National d'Etudes Spatiales

This paper focuses on the design of a fuel-optimal maneuver strategy for the rendezvous between an active chaser satellite with continuous-thrust capability and a passive target satellite. The problem is formalized as an optimal control problem subject to a collision avoidance constraint. Then, a new method for dealing with this state constraint is developed by building a sequence of unconstrained optimal control problems whose solutions converge toward the solution of the original problem. The efficiencyof this method is demonstrated through numerical results obtained in the case of a rendezvous in Highly Elliptical Orbit.

14:45 **AAS 11 - 127** **Mesh Refinement Strategies for Spacecraft Trajectory Optimization Using Discrete Mechanics and Optimal Control**
Ashley Moore and Jerrold E. Marsden, California Institute of Technology; Sina Ober-Blöbaum, University of Paderborn

Optimal trajectory planning in space mission design provides a challenging task regarding accuracy requirements. To improve the accuracy of the discrete, optimal solution, one requires finer time-stepping near planets due to the strong influence of gravity, while for a transfer in nearly free space, few discretization points are necessary to accurately reflect the dynamics. The design of the variable step size profile, or mesh, is a manual process; hence it is favorable to use mesh refinement. The effect of a mesh refinement strategy for the optimal control scheme DMOC is investigated by means of an elliptical orbit transfer.

15:10 **Break**

15:35 **AAS 11 - 128** **MODIFIED CHEBYSHEV-PICARD ITERATION METHODS FOR SOLUTION OF BOUNDARY VALUE PROBLEMS**

Xiaoli Bai, John L. Junkins, Texas A&M University

Parallel-structured Modified Chebyshev-Picard iteration (MCPI) methods are proposed for solving boundary value problems. The convergence domain for a linear second order system can be analytical calculated. MCPI methods can also solve optimal control problems. A trajectory optimization problem is studied by using both MCPI methods and a Chebyshev Pseudospectral method. The results illustrate two significant advantages of using MCPI methods for solving BVPs. One is that the boundary conditions are always satisfied to high accuracy. Another is that the is that the method is highly computationally efficient, even prior parallel implementation.

16:00 **AAS 11 - 129** **Multiobjective Optimization of Low-Energy Trajectories Using Optimal Control on Dynamical Channels**

Thomas Coffee, Massachusetts Institute of Technology; Rodney Anderson and Martin Lo, Jet Propulsion Laboratory

We introduce a computational method to design efficient low-energy trajectories by extracting initial solutions from dynamical channels formed by invariant manifolds, and improving these solutions through variational optimal control. We consider trajectories connecting two unstable periodic orbits in the circular restricted 3-body problem (CR3BP). Our method leverages dynamical channels to generate a range of solutions, and approximates the Pareto front for impulse and time of flight through a multiobjective optimization of these solutions based on primer vector theory. We demonstrate the application of our method to a lunar libration orbit transfer and to a Europa resonance transition and capture trajectory.

16:25 **AAS 11 - 130** **OPTIMIZATION OF STABLE MULTI-IMPULSE TRANSFERS**

Nakhjiri, Navid, University of California, Irvine

This paper addresses the optimization of stable multi-impulse transfers. These transfers allow a spacecraft to coast near families of stable periodic orbits while staying within the associated stability region. They result in fail-safe transfers with respect to miss-thrust and may provide an interesting strategy for human mission to small bodies. The optimization problem considered consists of the minimization of sequences of small impulses transferring a spacecraft between two given periodic orbits within a stable family, under path and impulse constraints to stay within the stability region. A two-level optimization strategy is proposed that results in locally optimal transfers.

16:50 **AAS 11 - 131** **Trajectory Design using Periapse Poincaré Maps and Invariant Manifolds**

A. F. Haapala, K. C. Howell, Purdue University

Previous researchers have demonstrated that the periapse Poincaré map is very useful to deliver insight into trajectory behavior near the smaller primary within the context of the restricted three-body problem. In this investigation, periapse maps are employed as a design tool for the construction of both planar and three-dimensional transit trajectories with predetermined characteristics. The design strategies are demonstrated via examples that include transit trajectories, as well as heteroclinic and homoclinic connections. Besides mission design, these techniques are also applied to generate path approximations for several Jupiter family comets.

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Session 5: Attitude Determination

Chair: Dr. Don Mackison, University of Colorado

13:30 **AAS 11 - 132** **Attitude estimation for picosatellites with distributed computational platform using Murrell's algorithm of the extended Kalman filter**

Sharan Asundi, Dr. Haniph Latchman and Dr. Norman Fitz-Coy, University of Florida

Picosatellites have limited capabilities for hosting precise attitude and inertial sensors and the available computational resources are at premium. SwampSat, a picosatellite under development at the University of Florida hosts a distributed computing system comprising of a low power flight computer interfaced with coarse attitude sensors and a high speed digital signal processor interfaced with an inertial measurement unit and hosting Murrell's version of the extended Kalman filter (EKF).The work presented describes the mission design for enabling on orbit attitude estimation and the results to evaluate the effectiveness and efficiency of the algorithm.

13:55 **AAS 11 - 133** **Attitude Estimation Using Multiplicative Measurement Model**

Yu Ning and Daniele Mortari, Texas A&M University

This paper introduces a corrected measurement model for observed vectors while dealing with the Wahba problem. The corrected vector is derived from the multiplicative measurement model and the error obeys to white noises. The effects of the new measurements on the estimated principle axis and rotated angle lead to astatically better solution. With more measurements, the accuracy gains will be larger.

14:20 **AAS 11 - 134** **ATTITUDE PARAMETERIZATIONS AS HIGHER DIMENSIONAL MAP PROJECTIONS**

Sergei Tanygin, Analytical Graphics, Inc.

A generalization is proposed for a class of three-parameter attitude representa-tions that are formulated as a product of the unit rotation vector and various functions of the rotation angle. When related to a four-dimensional unit quater-nion, these three-dimensional representations are shown to be analogous to two-dimensional azimuthal map projections from a three-dimensional unit sphere. Their relationships to the rotation matrix, their composition rules and their kinematics and control laws are derived. It is shown that kinematical passivity of the Rodrigues and modified Rodrigues parameters is a special case of the more general result.

14:45 **AAS 11 - 135** **ENHANCEMENTS TO THE K-VECTOR SEARCH TECHNIQUE**

Brien R. Flewelling and Daniele Mortari, Texas A&M University

The k-vector range search technique has been applied to single and multidimensional databases and is linear in the number of solutions. The k-vector has seen extensive success in the star tracking literature as an optimal time range search technique for determining candidate matches for star identification. In the following we present three enhancements to this technique which increase the average performance of the k-vector technique for nonlinear and dynamic databases. We also evaluate these techniques ability to exploit knowledge of the learned probability density function which governs the access of information in the database.

15:10 **Break**

15:35 **AAS 11 - 136** **Integrated Power Reduction and Adaptive Attitude Control System of VSCMGs-based Satellite**

Dohee Kim, Norman G. Fitz-Coy, and Warren E. Dixon, Dept. of Mechanical and Aerospace Eng., University of Florida; Frederick Leve, Air Force Research Laboratory, Kirtland Air Force Base

An adaptive attitude controller for a VSCMG-based satellite is generated by means of a pyramidal arrangement of four single gimbal VSCMGs. The dynamic model contains contributions from both dynamic and static friction. When scaling the size of VSCMGs, the effects of friction and the variable inertias present in the system are significant. The developed controller utilizes system friction to reduce the consumption of battery power for flywheel deceleration through momentum management. Using null motion, a strategy is developed to simultaneously perform the gimbal reconfiguration for internal singularity avoidance and the wheel speed regularization for reduced power consumption.

16:00 **AAS 11 - 137** **OPTIMAL FUSION OF VECTOR AND ANGLE OR GPS PHASE DIFFERENCE OBSERVATIONS FOR THREE-AXIS ATTITUDE DETERMINATION**

Sergei Tanygin, Analytical Graphics, Inc.

The general problem of determining the three-axis attitude from a combination of vector and angle or GPS phase difference observations is examined. Two cost functions, one for vector observations and one for angle or GPS phase difference observations, are combined into a single maximum likelihood cost function. The attitude estimate is evolved from the initial guess, which can be obtained solely from vector observations, using the Gauss-Newton estimation sequence based on a homotopy continuation approach.The numerical examples are presented that demonstrate effectiveness of the new approach.

16:25 **AAS 11 - 138** **Sub-Optimal Multiple Constraints for Relative Attitude Determination**

Richard Linares, John L. Crassidis, University at Buffalo; Yang Cheng, Mississippi State University

In this paper a relative attitude determination solution of a formation of two vehicles with multiple constraints is shown. The solution for the relative attitude between the two vehicles is obtained only using line-of-sight measurements between them and a common (unknown) object observed by both vehicles. The constraint used in the solution is a triangle constraint on the vector observations. This approach is extended to multiple objects by apply this constraint for each object and the solution is cased into a Wahba problem. Simulations runs to study the performance of the approach.

Feb 14, 2011

Session 6: Rendezvous and Proximity Missions

Chair: Dr. Thomas Lovell, AFRL

13:30 **AAS 11 - 139** **Autonomous Close Proximity Resident Space Object Inspection**
James H. Meub and Henry J. Pernicka, Missouri University of Science and Technology

This paper describes a continuous thrust transfer between in-track formations while maintaining a fixed distance from the RSO. In-track formations are desirable for observation missions due to the low velocity change magnitudes required to maintain the inspection point. It is therefore desired to be able to transfer from a positive in-track position to a negative in-track position to observe and inspect multiple sides of the RSO. The method of determining the transfer path and the efficacy of various control schemes for this application are given. Non-cooperative situations are also investigated.

13:55 **AAS 11 - 140** **Autonomous Mission Concepts Using Small Satellites: Design of Self-assembling Modular Nanosatellites**
Dmitri Ignakov, Tom Dzamba, Godard, Ryerson University

Modular reconfigurable and self-assembling satellite architecture has the potential to significantly increase the utility of small satellites. Through docking, the utility of individual satellites can be increased. Lifetime of satellites can be extended by providing fuel, replacement modules, and upgrade modules allowing for complex satellites to be assembled at a significantly reduced cost. In this paper, the framework for missions involving autonomous rendezvous and docking for on-orbit self assembly ofnanosatellites is presented. A 6-DOF numerical simulation introducing an algorithm that utilizes the underactuated thruster configuration for orbit control is presented to demonstrate the feasibility of the proposed system.

14:20 **AAS 11 - 141** **Design and Implementation of the Ground Simulation System of Relative Navigation of Space Rendezvous and Docking**
Xia Hongwei, Ma Guangcheng, Li Li, Liang Ganggang and Deng Ya, Harbin Institute of Technology

The problem of design and implementation of the relative navigation simulation system of moderate-far of space rendezvous and docking is discussed. In the simulation of moderate-far distance, since the actual measurement device can not access the ground simulation system, a replacement scheme is studied with theoretical analysis and validation in the respect of function and precision, the results proved that the replacement scheme is suitable. Then, within the range of transfer of homing phase and transfer between V-bar holding points, the pose parameters as speed and acceleration are derived and transformed into design reference data of the ground semi-physical simulation equipment, using similarity theory. Finally, according to the design results, the i

14:45 **AAS 11 - 142** **Linear Quadratic Model Predictive Control Approach to Spacecraft Rendezvous and Docking**
Hyeongjun Park, University of Michigan; Stefano. Di Cairano, Ford Motor Company; Ilya Kolmanovsky, University of Michigan

We consider an application of computationally feasible linear quadratic Model Predictive Control framework to spacecraft rendezvous and docking maneuvers. In this approach, a spacecraft model is used for repeated prediction and optimization of spacecraft motion while constraints are enforced to maintain spacecraft position within Line-of-Sight (LOS) cone from the docking port on the target platform which may be rotating. In addition, constraints on thrust magnitude and on terminal velocity are fulfilledso that the spacecraft velocity matches the velocity of the docking port. We demonstrate that the MPC controller is also able to maintain small fuel consumption during the maneuver.

15:10 **Break**

15:35 **AAS 11 - 143** **Position Estimation Using Multiplicative Measurement Model**
Yu Ning and Daniele Mortari, Texas A&M University

A novel approach for position estimation of vision-based proximity navigation is presented. The method can be used in the lost-in-space case, when no approximate solution is available. A single correction and a multi-correction model for observations are developed by multiplicative measurement model. They are derived from the statistic characteristics of the measurements. Numerical tests demonstrate that the second correction is very effective.

16:00 **AAS 11 - 144** **Procedure for Determining Spacecraft Collision Probability During Orbital Rendezvous and Proximity Operations**
Michael Phillips, David Geller, Utah State University; Frank Chavez, Air Force Research Lab

The development of an algorithm intended to estimate satellite collision probability during orbital rendezvous and proximity operations is discussed. Two categories of metrics are utilized. The first category provides an estimate of instantaneous collision probability, and places an upper bound on total probability of collision. The second category provides a direct estimate of total collision probability. The metrics are arranged in a hierarchy such that the algorithm can scale. In this way it is sufficiently accurate without needless computation. This approach provides a conceptual framework in which collision probability can be systematically estimated.

16:25 **AAS 11 - 145** **Relative GPS Navigation for H-II Transfer Vehicle: Design and On-Orbit Results**
Shoji Yoshikawa and Masaharu Suzuki, Mitsubishi Electric Corporation; Jun Tsukui and Hifumi Yamamoto, Mitsubishi Space Software Corporation

Relative GPS navigation (RGPS) filter estimates relative position and velocity of H-II Transfer Vehicle (HTV) based on GPS signals received by GPS receivers on HTV and International Space Station (ISS). It starts about several hundreds of thousand meters from ISS when proximity communication between HTV and ISS is established and hands over to the next navigation sensor (rendezvous sensor) at five hundred meters below the ISS. We will describe the design philosophy of the RGPS filter and report its performance results during the verification flight of HTV in September of 2009.

16:50 **AAS 11 - 146** **Trajectory Design for Small Body Touch-And-Go**
Mark S. Wallace, Stephen Broschart, Eugene Bonfiglio, Shyam Bhaskharan, Alberto Cangahuala, Jet Propulsion Laboratory

A mission concept which has received extensive attention in the last few years is that of small body "Touch-and-Go," or TAG. TAG trajectory designs typically include three main phases: staging, descent, and ascent. The designs for these phases are driven by engineering and science requirements, spacecraft capabilities, and the dynamical environment. This paper describes these drivers and trades for TAG trajectories, as well as a few case studies: the Near-Earth Asteroid Rendezvous (NEAR) mission's descent to Eros, the Hayabusa TAG at Itokawa, and concept TAGs at the Martian moon Deimos, Comet Tempel 1, and the binary asteroid 1996 FG3.

Feb 14, 2011

Session 7: Space Surveillance

Chair: John Seago, Analytical Graphics, Inc.

13:30 **AAS 11 - 147** **Analytic Orbit Design for Earth Sites Observation**
Francesco de Dilectis and Daniele Mortari, Texas A&M University

The purpose of this study is to analyze the ground track of a compatible circular orbit around the Earth after a full repetition cycle, to identify all the points in which the track crosses itself. This in turn allows for a different design approach, focused on locating these points where they best serve the mission. Two different equations must be used to solve the problem: the compatibility condition and the equation of the ground track in the latitude-longitude plane. The X-points are shown to be located in symmetrical patterns and therefore only a subset of them has to be found.

13:55 **AAS 11 - 148** **Information Theoretic Space Object Data Association Methods Using an Adaptive Gaussian Sum Filter**
Richard Linares, Puneet Singla, University at Buffalo, John L. Crassidis, University at Buffalo

This paper shows an approach to improve the statistical validity of orbital estimates and uncertainties as well as a method of associating measurements with the correct space objects. The approach involves using an adaptive Gaussian mixture solution to the Fokker-Planck-Kolmogorov equation for its applicability to the space object tracking problem. The main purpose of this paper is to develop a technique for data association based on information theoretic approaches that are compatible with the adaptive Gaussian sum filter. The adaptive filter and corresponding measurement association methods are evaluated using simulated data in realistic scenarios to
determine their performance and feasibility.

14:20 **AAS 11 - 149** **Inverse Problems in Unresolved Space Object Identification**
Kamesh Subbarao, Laura Henderson, The University of Texas at Arlington

This paper addresses issues in Space Situational Awareness, more specifically in the area of observables. The specific questions addressed relate to handling model uncertainties in the solution of inverse problems associated with non-resolved space objects and representing confidence in the conclusions and decisions based on the solution. In this paper, we pose an inverse problem for a system of stochastic nonlinear differential equations. Additionally, we study inverse problems in identification of the orientation states and the shape and size of the space objects.

14:45 **AAS 11 - 150** **Simulating Realistic Satellite Observations**
Jacob D. Griesbach, Analytical Graphics Inc.; David A. Vallado, Center for Space Standards and Innovation; John H. Seago, Analytical Graphics Inc.

Simulating realistic satellite observations is often problematic because obtaining observations can be difficult and sensor locations are often incomplete. This paper proposes an architecture that uses the existing capabilities in the AGI's STK and ODTK software products to realistically simulate observational data. For hypothetical test cases, this is accomplished by first simulating orbits and accesses in STK. The access intervals are then modified to reflect realistic tracking tendencies. Finally, the ODTK simulator is used to generate the observations. Care is given to replicate perceived observation patterns and tracking sensor capabilities. Representative sensor locations are provided for various tracking systems.

15:10 **Break**

15:35 **AAS 11 - 151** **Ephemeris Requirements for Space Situational Awareness**

Daniel L. Oltrogge, AGI's Center for Space Standards and Innovation

Increasing international cooperation in the areas of orbital collision avoidance and electro-magnetic interference mitigation has driven the exchange of satellite ephemerides to support Space Situational Awareness, threat detection and avoidance. To be useful, such ephemeris files must conform to certain specifi-cations in order to ensure that the intended accuracy of these analyses is achieved. This paper examines the accuracy impact of various interpolation methods, ephemeris step size and digits of precision for a variety of orbital re-gimes

16:00 **AAS 11 - 152** **Sliding Window Batch Estimation Filtering for Enhanced Anomaly Detection and Uncorrelated Track Resolution**

Joshua T. Horwood, Nathan D. Aragon, and Aubrey B. Poore, Numerica Corporation

A "sliding window" batch estimation filter (SWBEF) is proposed which bypasses the expensive representation of highly non-Gaussian densities arising from the prediction step of the Bayesian state estimator. Instead, the SWBEF waits until a new report (measurement, track) becomes available and then performs the prediction and correction steps simultaneously. This filter is well suited for anomaly detection and UCT resolution. Through a LEO simulation scenario motivated from real data provided by JFCC SPACE, we demonstrate that the algorithm provides accuracy comparable to a high fidelity Gaussian sum filter yet has computational cost commensurate with a standard unscented Kalman filter.

16:25 **AAS 11 - 153** **Spectral Decomposition of Orbital Tori**

Ralph E. Bordner, Major, USAF; William E. Wiesel, Air Force Institute of Technology

The assertion that earth-orbiting satellites under the influence of the geopotential are Kolmogorov-Arnold-Moser (KAM) tori is the underlying premise of this work. Trajectory-following spectral methods were applied to decompose orbits into multi-periodic Fourier series, effectively compressing ephemerides for long-term use. The proposed approach focused on fitting local spectral structures, denoted as frequency clusters, within the orbital data as opposed to fitting every Fourier series coefficient simultaneously, which is significantly more numerically efficient. With integrated data, maximum error in the fits were as low as a few meters per coordinate axis over a 1 year period.

16:50 **AAS 11 - 154** **Covariance Error Assessment, Correction, and Impact on the Probability of Collision**

William Todd Cerven, The Aerospace Corporation

The probability of collision, the principal metric in collision risk assessment, is reliant on an accurate representation of the covariance of the state vectors at the time of closest approach. This document provides a theoretical description for how one can estimate errors in covariances and correct for them. In addition, a method is developed to calculate both the errors in these computations and the effect of these uncertainties on the probability of collision as a whole.

Feb 15, 2011

Session 8: Trajectory Design and Optimization II

Chair: Dr. Chris Ranieri, The Aerospace Corporation

08:00 **AAS 11 - 155** **A Direct Method for Trajectory Optimization Using the Particle Swarm Approach**
Pradipto Ghosh and Bruce A. Conway, University of Illinois, Urbana-Champaign

Particle Swarm Optimization is a stochastic global optimization method which relies on a group of potential solutions to explore the search space. Although successfully employed in solving discrete optimization problems, the application of swarming techniques to dynamic optimization, as posed in the Optimal Control Theory, is virtually unexplored. In this work, we use PSO to generate near-optimal solutions to several non-trivial trajectory optimization problems, including thrust programming for minimum-fuel coplanar rendezvous, and computing the maximum altitude climb path for an aircraft. The optimality claim for each tests case is verified by benchmarking its performance against a conventional gradient-based solver.

08:25 **AAS 11 - 156** **A New Numerical Optimization Method Based on Taylor Series.**
Christopher Martin and Bruce A. Conway, University of Illinois.

A new method to numerically solve trajectory optimization problems is devised. The method uses direct transcription to convert the continuous optimal control problem into a parameter optimization problem that can be solved with non-linear programming. A high-order Taylor series expansion about each node is used to convert the system equations into algebraic constraint equations. Automatic differentiation is used to compute the derivatives of the system equations required to keep arbitrarily many terms in the Taylor series. Several orbit transfer problems are solved to evaluate the performance of the new method.

08:50 **AAS 11 - 157** **Automation of Optimal Control Finite Burn Trajectories**
Cesar Ocampo and Sonia Hernandez, The University of Texas at Austin

09:15 **AAS 11 - 158** **Global Mascon Models for Simple, Accurate and Parallel Geopotential Computation**
Ryan P. Russell, Arora, N., Georgia Institute of Technology

High-fidelity geopotential calculation using spherical harmonics (SH) is expensive and relies on recursive non-parallel relations. Here, we propose a global mascon model that is memory light, extremely simple to implement (at any derivative level), and is naturally amenable to parallelism. We reduce the problem to the classic linear least squares case and overcome the ill-conditioned inversion dilemna using orthogonal solution methods and a judicious choice for the mascon distribution. A single CPU implementation is found to be approximately equal in accuracy and speed compared to SH. Parallel GPU implementations lead to order of magnitude speedups for high-resolution gravity fields.

09:40 **Break**

10:05 **AAS 11 - 159** **Optimal Autonomous Mission Planning via Evolutionary Algorithms**

Jacob Englander and Bruce Conway, University of Illinois at Urbana Champaign; Trevor Williams, NASA Goddard Space Flight Center

Many interplanetary trajectory problems may be formulated as hybrid optimal control problems that include both continuous-valued and categorical variables. The categorical variables specify a sequence of flybys, and the continuous variables represent the launch date, flight times between planets, rocket burns, flyby altitudes, etc. The method developed here uses nested loops; an outer-loop solver that finds a flyby sequence, and an inner-loop solver that optimizes the continuous-time dynamical system. A binary genetic algorithm is used to solve the outer loop problem, and a cooperative algorithm based on particle swarm optimization and differential evolution is used to solve the inner-loop.

10:30 **AAS 11 - 160** **Optimization of Relative Orbit Transfers via Particle Swarm and Primer Vector Theory**

Brianna Aubin, Bruce Conway, Soon-Jo Chung, University of Illinios Urbana-Champaign

Particle swarm optimization is an evolutionary algorithm that is used to find optimal and near optimal solutions to a variety of problems. This paper examines how particle swarm can be used to create both two and three impulse trajectories that minimize the fuel expenditures of a satellite traveling from one trajectory to another in a relative Hill-Clohessy-Wilshire frame. It then uses primer vector theory to examine the optimality of the trajectories found by particle swarm, and to improve upon them through the use of initial coasts, final coasts, and the addition of intermediate impulses.

10:55 **AAS 11 - 161** **Parallel Evaluation of Poisson Series**

Juan F. San-Juan, David Ortigosa and Montserrat San-Martín, University of La Rioja

In recent years multi-core processor technology has become a standard for desktop and laptop computers which makes for increasing the complexity and magnitude of scientific or engineering problems. One of these problems is the evaluation algorithm for Poisson series, which is the core of the analytical orbit propagator programs (AOPP). Using OMP paradigm, the evaluation algorithm is paralleled and applied to two AOPPs which consider in the first case a higher order theory, and in the second a 6x6 tesseral perturbation model.

11:20 **AAS 11 - 162** **Particle Swarm Optimization of Low-Thrust Orbital Transfers and Rendezvous**

Scuola di Ingegneria Aerospaziale, University of Rome "La Sapienza"

The particle swarm optimization (PSO) technique represents a very intuitive methodology for global optimization. It mimics the stochastic motion of bird flocks. In this research the technique is applied to determining optimal low-thrust orbit transfers and rendezvous. Hamiltonian methods are employed to translate the related optimal control problems into parameter optimization problems. Thus the parameters sought by the PSO are primarily initial values of the costates and the final time if that is unspecified. The PSO is extremely easy to program. Nevertheless, it proves to be effective, reliable, and numerically accurate in solving the optimization problems considered in this work.

Feb 15, 2011

Session 9: Spacecraft Guidance, Navigation, and Control

Chair: Dr. David Spencer, Penn State University

08:00 **AAS 11 - 163** **Hardware-in-the-Loop Validation of Control Strategies for Underactuated Spacecraft Formations**
Daren Lee, Godard, Krishna Dev Kumar, Ryerson University

A novel laboratory testbed, Satellite Airbed Formation Experiment (SAFE) platform, is introduced that enables the validation of thruster configurations and control algorithms for autonomous spacecraft formation flying using hardware-in-the-loop simulations. The SAFE platform consists of a leader and follower spacecraft floating via air pads on a two dimensional glass table. A nonlinear control algorithm is proposed that utilizes the directly actuated states to control the unactuated states. Experimental results are presented for the fully actuated and reduced input actuator configurations to demonstrate formation acquisition and formation maintenance with the SAFE testbed.

08:25 **AAS 11 - 164** **In-Orbit Inertia and Actuator Alignment Parameter Estimation**
Michael C. Norman and Mason A. Peck, Cornell University

Knowledge of the mass distribution and momentum actuator alignment parameters of a spacecraft are vital to the control of its attitude motion. The difficulty of measuring the complete set of these quantities prior to launch along with the potential for changes in the spacecraft mass distribution during operations suggests the utility of estimating these parameters in-orbit from available telemetry data. This paper develops and tests a series of possible on-board parameter estimation schemes based on measurement equations describing the angular momentum and kinetic energy states of the rigid body system.

08:50 **AAS 11 - 165** **INTEGRATED GUIDANCE AND NAVIGATION PERFORMANCE OF LUNAR DESCENT AND LANDING**
Renato Zanetti, David C. Woffindeny, The Charles Stark Draper Laboratory, Bradley A. Steinfeldt, Georgia Institute of Technology, and Christopher D'Souza, NASA Johnson Space Center.

Linear covariance analysis is a technique employed to study spacecrafts guidance, navigation, and control performance for different types of missions and at various phases of flight. This work studies lunar descent and landing and focuses on validating the linearized results with those obtained from Monte Carlo simulations with regards to both navigation errors and trajectory dispersions. The accuracy of linear covariance predictions of trajectory dispersions, navigation errors, delta-v usage, and landing time uncertainty is quantified.

09:15 **AAS 11 - 166** **Near-Optimal Feedback Guidance for an Accurate Lunar Landing**
Joseph Parsley and Rajnish Sharma, The University of Alabama

This research presents possible new guidance methods for a lunar landing. These methods allow a craft to land autonomously and more efficiently. It is proposed that the Moon can be provisioned with prepared landing zones and with very accurate navigational aids. The landing problem is modeled to fit in a new extension of the SDRE technique to a finite-time and fixed-terminal optimal control problem. After formalizing the procedure to obtain the optimal corrections, the nonlinear problem is thoroughly investigated to provide the computationally efficient guidance laws. The numerical solution is compared with the open-loop solution to justify the methodology.

09:40 **Break**

10:05 AAS 11 - 167 NON-LINEAR SLIDING GUIDANCE ALGORITHMS FOR PRECISION LUNAR LANDING

Roberto Furfaro, University of Arizona; Scott Selnick, Michael L. Cupples, Matthew W. Cribb, Raytheon Missile Systems

Two classes of non-linear guidance algorithms for lunar precision landing are presented. The first set, called Optimal Sliding Guidance (OSG) laws, determine on-line the optimal commanded acceleration and augment it with a sliding mode to provide robustness against perturbations. The second class of guidance algorithms, called Multiple Sliding Surface Guidance (MSSG) laws, employs two interconnected sliding surfaces to track an on-board generated trajectory that drive the descending lander to the desired location at the desired velocity. Both algorithms are shown to perform extremely well with very low guidance residual errors on the desired target point on the lunar surface.

10:30 AAS 11 - 168 NONLINEAR TRACKING CONTROL OF MANEUVERING RIGID SPACECRAFT

Ahmad Bani Younes, James Turner, Manoranjan Majji, and John Junkins, Texas A&M University

Nonlinear optimal control formulations have been considered where the feed-back model for the Co-State variables consists of the nonlinear state variables. This approach seeks to drive the terminal state values to zero, but requires an nth order polynomial expansion in all of the state variables. Though technically successful, the assumed tensor-based Co-State models are not assured of con-verging after the retention of a finite number of terms. This problem is over-come by reformulating the control problem in terms of an error state relative to a reference trajectory, retaining the full nonlinear error dynamics for kinematics and the equation of motion,

10:55 AAS 11 - 169 Optimal Guidance for Quasi-planar Lunar Descent with Throttling

David G. Hull, University of Texas at Austin

The pitch and yaw controls for the three-dimensional minimum-time transfer of a constant-thrust rocket over a flat moon are used to study guidance for lunar descent over a spherical moon. Because of the complexity of the fixed-downrange optimal control, the free-downrange control is calculated, and throttling is used to satisfy the downrange constraint. After assuming that the descent is nearly planar (small yaw), three approximate pitch solutions are investigated: exact pitch, first-order pitch, and zeroth-order pitch, to determine the level of approximation that can be tolerated for descent. Preliminary guidance results are presented.

11:20 AAS 11 - 170 THE EFFECTS OF TIME DELAY ON PRECISION ATTITUDE CONTROL OF PLUG-AND-PLAY SATELLITES

C. Douglas McFarland and William J. Manning, Air Force Research Laboratory Space Vehicle Directorate; Norman Fitz-Coy, University of Florida.

This paper characterizes the effects of unknown, time-variant delays on the precision attitude control of small satellites and to bound the mission performance of satellites using the Space Plug-and-Play Avionics (SPA) data bus standard. This is accomplished through a systematic examination of the attitude pointing accuracy and stability for reference Responsive Space missions. Propagation delays of varying magnitudes are introduced to sensor measurements and actuation commands to simulate the communication delays caused by the SPA data bus. Methods for mitigating delay effects are also explored as a means to increase the military utility of SPA-based spacecraft.

Feb 15, 2011

Session 10: Orbital Debris and Space Environment

Chair: Dr. Thomas Eller, Astro USA, LLC

08:00 **AAS 11 - 171** **Dynamics of Debris Cloud Motion Based on Relative Orbit Elements**
Jianfeng Yin, Ye Liang, Qinqin Luo, and Chao Han, Beihang University

This paper derives a precise analytical geometric model for debris cloud, including the effects of the reference orbit eccentricity and the primary gravitational perturbations J2. Meanwhile the linear equations for relative motion are deduced based on the relative orbit elements (ROE) and the curvilinear coordinate system. Moreover, the error analysis and simulations presented clearly show that the geometric model could describe dynamics of debris more efficiently, while the velocity increment is not very high. Additionally, spatial density is also obtained to determine the collision hazard for the operational spacecraft.

08:25 **AAS 11 - 172** **Examination Of Sgp4 Accuracy In Orbit Prediction Using The Champ Satellite**
Shaokai Wang and Chao Han, Beihang University

The accuracy of SGP4 implemented in space debris orbit prediction is important factor for collision avoidance issues. This paper examines the accuracy using quick orbit data from CHAMP satellite. A large database of accurate orbit data from CHAMP satellite was available to serve as the truth reference in this study. Then according to the “truth orbit”, the accuracy of SGP4 is analyzed. The error is displayed in the cross-track direction, in-track direction and radial direction for better use in collision avoidance, especially in the method of conjunction box.

08:50 **AAS 11 - 173** **Extension of a Simple Mathematical Model for Orbital Debris Proliferation and Mitigation**
Jarret M. Lafleur, Georgia Institute of Technology

A significant threat to the future of space utilization is the proliferation of debris in low Earth orbit. To facilitate quantification of trends and the assessment of potential mitigation measures, this paper extends a previously proposed analytic debris proliferation model consisting of two coupled differential equations. Analyzed are both the transient and equilibrium behavior of the parametric model, leading to conclusions on the likely effectiveness of potential debris mitigation measures. In addition to providing numerical results, this paper contributes a simple debris model particularly useful when more sophisticated models are unavailable or time-consuming to utilize.

09:15 **AAS 11 - 174** **Fitted Drag Coefficients as a Source of Density Information**
Craig A. McLaughlin, Travis Lechtenberg, and Steve Mance, University of Kansas

Drag modeling is the greatest uncertainty in the dynamics of low Earth satellite orbits where ballistic coefficient and density errors dominate drag errors. This paper examines fitted drag coefficients found as part of a precision orbit determination process for Stella and Starlette from 2000 to 2004, Geosat Follow-On (GFO) from 2000 to 2002 and 2005, and GFZ from 1995 to 1997. The drag coefficients for the spherical Stella and Starlette satellites are assumed to be highly correlated with density model error. The yearly mean fitted drag coefficients are calculated for each satellite for each year studied.

09:40 **Break**

10:05 **AAS 11 - 175** **Miss Distance - Generalized Variance Non-Central Chi Distribution**

Ken Chan, The Aerospace Corporation

In many applications, the probability of collision is considered as the most meaningful criterion for determining the risk to a spacecraft. When the miss distance is very small (say 100 m or less), the collision probability may not comfortably serve well for measuring the risk. To obtain the statistics of the miss distance distribution, we consider it as a non-central chi distribution with unequal variances. This method eliminates the need to perform an inordinate amount of computation such as by performing Monte Carlo simulations. Using this approach, we can reduce the computation time down by several orders of magnitude.

10:30 **AAS 11 - 176** **NORAD TLE Based Ground Orbit Determination Strategy for Mitigating Space Debris Collisions**

Hae-Dong Kim, KARI (Korea Aerospace Research Institute)

Recently, issues on space debris mitigation have been dramatically increasing since the Chinese ASAT test was carried out in January, 2007. In Korea, the space debris has become a major concern for government and satellite operator such as Korea Aerospace Research Institute(KARI) because the KOREA has been operating one multi-purpose low Earth orbit(LEO) satellite, KOMPSAT-2, and one geostationary satellite, COMS-1. In this paper, we propose a NORAD TLE based ground orbit determination strategy for mitigating space debris. The purpose of the proposed strategy is to improve the orbit accuracy of threatening space debris that is given in NORAD TLE catalog.

10:55 **AAS 11 - 177** **Progress in Standards For Space Operations and Astrodynamics**

David Finkleman, Daniel Otrogge, David Vallado, Center for Space Standards and Innovation

The purpose of this paper is to expose to the astrodynamics community advances in consensus standards for space operations and astrodynamics and to solicit participation in those developments. We will report the status, scope, and issues of standards for describing orbit determination and propagation techniques, disposing of satellites from protected orbital regions, and for orbital debris mitigation. The most noteworthy accomplishment in the past year is publication of AIAA Best Practices in Astrodynamics, a collaborative effort ongoing for almost a decade.

11:20 **AAS 11 - 178** **The Dynamics of High Area-to-Mass Ratio Objects in Earth Orbit: The Effect of Solar Radiation Pressure**

D.J. Scheeres, J. McMahon, A. Rosengren, Department of Aerospace Engineering Sciences, The University of Colorado

The effect of solar radiation pressure on high area-to-mass ratio (HAMR) debris objects in GEO synchronous orbit is explored. We show that the averaged problem can be solved in closed form for a "cannonball" model, and can yield large variations in eccentricity and inclination over time spans significantly less than a year. We also explore the effects of a more realistic solar radiation pressure model on these dynamics and compare them with reported data on HAMRs. We find that many of the extreme dynamical behaviors reported for these objects are a natural consequence of solar radiation pressure.

Feb 15, 2011

Session 11: Asteroid Missions II

Chair: Dr. Matthew Berry, Analytical Graphics, inc

08:00 **AAS 11 - 179** **A strategy for robust landings on small binary bodies: Application to asteroid system 1999 KW4.**
Simon Tardivel, University of Colorado at Boulder

Landing trajectories to the surface of a binary asteroid system are explored. The desire is to deploy a lander from orbit on a ballistic trajectory to the asteroid surface, meaning that active guidance is not needed. We develop a robust deployment scheme that can provide a guaranteed landing on the surface with minimal technological requirements. To perform this we apply concepts from the Circular Restricted 3-Body Problem, suitably modified, that enable such deployments to be designed. We test the robustness of our design by evaluating its performance about realistic asteroid models and with multiple gravitational and non-gravitational perturbations.

08:25 **AAS 11 - 180** **Dawn Statistical Maneuver Design for Vesta Operations**
Daniel Parcher and Gregory Whiffen, Jet Propulsion Laboratory

In August, 2011, the Dawn spacecraft is scheduled to begin orbital operations at the asteroid Vesta. Dawn is a NASA Discovery mission that uses solar-electric low-thrust ion propulsion for interplanetary cruise and orbital operations. Navigating between Dawn’s science orbits at Vesta requires planned trajectory correction maneuvers that account for not only thrust execution uncertainties, but also large uncertainties in Vesta characteristics – such as gravity field and pole orientation. This paper describes the placement and evaluation of low-thrust statistical maneuvers during key phases of Vesta operations and a discussion of the tools, constraints, and methods used to plan those maneuvers.

08:50 **AAS 11 - 181** **Design of Round-Trip Trajectories to Near-Earth Asteroids Utilizing a Lunar Flyby**
Sonia Hernandez, The University of Texas at Austin; Brent W. Barbee, Emergent Space Technologies, Inc.

There are currently over 7,200 known Near-Earth Asteroids (NEAs). Because NEAs have orbits in close proximity to Earth's orbit, it is possible to design short duration round-trip trajectories to NEAs. In previous work, 59 accessible NEAs were identified for missions that depart Earth between the years 2016 and 2050 and have a round-trip flight time of less than a year. We present a new method for designing round-trip trajectories to NEAs in which Moon's gravity aids the outbound trajectory via a lunar flyby. This reduces the overall required fuel mass for the mission, causing previously inaccessible NEAs to become accessible.

09:15 **AAS 11 - 182** **Low Altitude Mapping Orbit Design and Maintenance for the Dawn Discovery Mission at Vesta**
Gregory J. Whiffen, Jet Propulsion Laboratory

NASA’s Dawn discovery mission will orbit the giant asteroid Vesta beginning in the summer of 2011. Four different science orbits are planned. The lowest orbit at Vesta is by far the most challenging to design and maintain due to the strong, non-spherical gravity expected there. This paper describes the orbit selection process. The process is applied to a field based on a Hubble space telescope shape model for Vesta. Stable orbits at these altitudes do not remain stable Dawn spacecraft momentum wheel de-saturation. This paper also presents the statistical maneuver design process that resulted in the orbit maintenance plan.

09:40 **Break**

10:05 **AAS 11 - 183** **Low-Thrust Orbit Transfer Design for Dawn Operations at Vesta**
Daniel W. Parcher, Jet Propulsion Laboratory

Upon arrival at the asteroid Vesta, scheduled for August of 2011, the Dawn spacecraft will target a series of four mapping orbits, each providing a unique opportunity to observe Vesta. The unknown and complex Vesta gravity field presents challenges for designing low-thrust transfers between mapping orbits while maintaining spacecraft safety from Vesta occultation of the Sun. This paper describes the orbit transfers designed for Vesta operations along with a discussion of the constraints and methods used to design these transfers. The effect of alternate gravity fields on the viability of the designs and the the design method is also considered.

10:30 **AAS 11 - 184** **On the Performance of a Gravity-Tractor with Realistic Ion Engine Model**
Dario O. Cersosimo, University of Missouri-Columbia

The architecture of a small gravity-tractor (GT) assumes a spacecraft hovering inertially over an asteroid aided by a pair of slanted ion engines balancing the gravitational acceleration upon the spacecraft. The successful implementation of the NSTAR engine motivates us to investigate its effectiveness in a GT mission. In this work we evaluate the performance of a GT system equipped with a set of ion engines operating under realistic constraints. These constraints consider engine operational limits, maximum propellant throughput, throttling efficiency and power availability. Under these considerations we examine the maximum velocity change a GT could exert on a small asteroid.

10:55 **AAS 11 - 185** **Simplified Relative Motion Model for Dispersed Asteroid Debris**
Prasenjit Sengupta and Sai Vaddi, Optimal Synthesis Inc.

Methods have recently been proposed that utilize nuclear explosives to fragment an asteroid on a collision trajectory with the Earth. The fragments created can still remain on a collision trajectory, and for this reason, a study of their dynamics is essential from the perspective of asteroid collision mitigation. Current research employs numerical simulations that propagate the orbits of the fragments, accounting for inter-fragment gravity. When the number of fragments is large, this can result in computationally intensive procedures. Here, a simplified model is derived, that accounts for some of the effects of inter-fragment gravity. These are compared withnumerical results.

11:20 **AAS 11 - 186** **The Stability of Powered Flight Around Asteroids With Application to Vesta**
Gregory J. Whiffen, Jet Propulsion Laboratory

The reliability of trajectories between science orbits around large asteroids must be evaluated subject to the unavoidable uncertainties of orbit determination, asteroid physical parameters, momentum de-saturation maneuvers, and transfer maneuver execution error. This paper presents a computationally inexpensive way to extend the concept or orbital stability to trajectories undergoing continuously powered low-thrust flight. Trajectories that are stable using this measure are shown to be stable under the combined uncertainties expected during operations. The measure is generally applicable and relatively simple to implement. The method was applied to the asteroid Vesta in support of NASA's Dawn Discovery mission.

Feb 15, 2011

Session 12: Decadal Survey and Interplanetary Mission Design

Chair: Jon Sims, Jet Propulsion Laboratory

13:30 **AAS 11 - 187** **Interplanetary Electric Propulsion Chiron Mission Design Trades Supporting the Decadal Survey**
John W. Dankanich, Gray Research, Inc.

A Chiron orbiter mission has been evaluated as a part of this 2013-2022 Planetary Science Decadal Survey. A comprehensive Chiron orbiter mission design was completed, including a broad search of interplanetary electric propulsion transfer options. Solar electric propulsion can increase delivered mass, but does not allow for practical insertion velocities. However, it is expected that the science mission can be closed with 6 standard ASRGs with a 13 year transfer or an 11 year transfer using the next generation ASRGs combined with radioisotope electric propulsion. Interplanetary trajectory trades and sensitivity analyses are presented herein.

13:55 **AAS 11 - 188** **CONCEPTUAL MISSION DESIGN OF A POLAR URANUS ORBITER AND SATELLITE TOUR**
James McAdams, Christopher Scott, and Yanping Guo, Johns Hopkins University Applied Physics Laboratory; John Dankanich, Gray Research, Inc.; Ryan Russell, Georgia Institute of Technology

In response to NASA's planetary science decadal survey, this paper outlines the conceptual mission design of a Uranus orbiter. In the baseline design the spacecraft launches during a 21-day launch window in 2020 followed by a 13-year cruise with solar electric propulsion and a single Earth flyby. Repeatable launch opportunities are available from 2021-2023. An atmospheric probe is released 29 days prior to Uranus orbit insertion. After completion of the probe descent phase the spacecraft inserts into a highly inclined elliptical orbit for 431 days followed by the satellite tour which includes ten targeted flybys of five satellites.

14:20 **AAS 11 - 189** **Interplanetary Electric Propulsion Uranus Mission Design Trades Supporting the Decadal Survey**
John W. Dankanich, Gray Research, Inc.

A Uranus orbiter mission has been evaluated for the 2013-2022 Planetary Science Decadal Survey. A comprehensive Uranus orbiter mission design was completed, including a broad search of interplanetary electric propulsion transfer options. The scope of interplanetary trades was limited to electric propulsion concepts, both solar and radioisotope powered. The recommended baseline trajectory is a 12 year transfer with an Atlas 551, a 1+1 NEXT stage with 15 kW of power using an EEJU trajectory and a 1,000km EGA flyby altitude constraint, delivering over 2,000kg into the initial science orbit. Interplanetary trajectory trades and sensitivity analyses are presented herein.

14:45 **AAS 11 - 190** **Interplanetary Trajectory Design of Space Vehicle with Bimodal Nuclear Propulsion**
Oleksandr Dekhtiar and Oleksii Kharytonov, Taras Shevchenko National University of Kyiv

The problem of optimization of both the combination of high- and low-thrust arcs and the mass parameters of nuclear thermal and electric propulsion subsystems of bimodal propulsion system for Earth-Mars interplanetary transfer has been considered. The optimal control analysis has been carried out based on the Pontryagin's maximum principle. The optimal distribution of velocity change budget between high and low-thrust maneuvers has been carried out. Optimal values of the parameters that define the masses of high- and low-thrust subsystems of bimodal propulsion system have been derived and analyzed.

15:10 **Break**

15:35 **AAS 11 - 191** **Jupiter Trojan Orbiter Mission Design Trades Supporting the Decadal Survey**
John W. Dankanich, Gray Research, Inc.

A Jupiter Trojan rendezvous mission has been evaluated as a part of this 2013-2022 Planetary Science Decadal Survey. A comprehensive mission design was completed, including a broad search of interplanetary transfer options. The interplanetary trajectorytrades included direct and Jupiter gravity assist solutions using either radioisotope electric propulsion or chemical propulsion options. Feasible solutions exist for a several Jupiter Trojans with either chemical or electric propulsion systems. Electric propulsion options offer additional flexibility and potential for secondary targets, but is highly sensitive to spacecraft dry mass. Interplanetary trajectory trades and sensitivity analyses are presented herein.

16:00 **AAS 11 - 192** **Trajectory Design of Solar Orbiter Using Earth and Venus Gravity Assists**
Jose Manuel Sánchez Pérez, ESA

In the context of the ESA Solar Orbiter mission studies 4 new trajectories are developed, which use unpowered Earth and Venus gravity assist flybys to reach the operational heliocentric orbits with perihelion as close as 0.28 AU (60 solar radii) from which unprecedented Sun observations will be conducted until eventually reaching solar latitudes over 33 deg. This robust trajectory design enabled a “fast-track” mission approach based on the maximum re-use of technologies developed for the ESA Bepi-Colombo mission. This paper presents the driving requirements and the process followed to define the trajectories within the mission constraints and scientific objectives.

16:25 **AAS 11 - 193** **RESONANT ORBITS AND AEROBRAKING MANEUVERS TO VISIT THE NEPTUNE-TRITON SYSTEM**
Michèle R.Lavagna, Daniele Filippetto, Michele Scotti, Simone Beghella Bartoli, Politecnico di Milano, Aerospace Engineering Dept

The mission analysis solution to visit the Neptune-Triton system is presented. A lander on the Triton surface and probes to be inserted in the Neptune atmosphere are required. To minimize the fuel demand and optimize the necessary maneuvers, multi-gravity assists are exploited: the planetary sequence selection, the deep space and powered gravity assist maneuvers minimization are obtained by mixing a Tisserand’s planes analysis with a two step optimization flow. Aerobraking in the Neptune atmosphere is exploited to acquire orbits resonant with Triton to do remote science, release the lander on the Moon and visit Neptune with a single vehicle.

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Session 13: Special Session: Innovative GNC Test Solutions

Chair: Austin Lee, Aerospace Corp.

13:30 **AAS 11 - 194** **ATTITUDE SENSORS' MINIATURIZATION FACILITATES OPTIMIZATION OF TESTING ACTIVITIES**
F. Boldrini, P. Fidanzati, E. Monnini (SELEX Galileo); S. Airey (ESA)

In the frame of an ESA contract, the prototype of a miniaturized Digital Sun Sensor with high accuracy and broad field of view was developed. APS Detector, FPA driver, processing logic, SpaceWire drivers, clock oscillator and power supply sections are embedded on a single chip. Testing and characterization of the prototype gave good results, in line with the design specifications. Thanks to miniaturized dimensions and use of SpaceWire protocol, optimized testing tools and innovative mixed hardware/software testing methods are under study to allow simultaneous testing of several units, leading to a drastic reduction of production time and non recurring costs.

13:55 **AAS 11 - 195** **Control Design for a Six Degree-of-Freedom Shaker**
Walter Chung, The Aerospace Corporation

Modern fiber-optic gyros are vulnerable to low-level, high frequency vibration. To test these gyros for margin, a six degree-of-freedom shaker has been built at The Aerospace Corporation. This shaker was based upon the Stewart-Gough platform, a.k.a. a hexapod. The closed-loop control of this mechanism ran into the limits of the real-time control processor and unexpected changes to the plant dynamics. Classical and modern, i.e. LQG, techniques, were examined but ultimately a mixed-sensitivity H1 controller was chosen for the final design. Coupled with a last-minute, ad hoc damper added to the system, this compensator led to a successful design.

14:20 **AAS 11 - 196** **Development of a Fine Track System for the Aerospace Laser Communications Testbed**
Jason Cardema, Charles Klimcak, The Aerospace Corporation

In a laser communications terminal, a received beam must be coupled into a single-mode optical fiber for demodulation by the communications subsystem. Coupling free-space light into an optical fiber is difficult, especially in the presence of local jitter disturbances. To maximize received power in-fiber, The Aerospace Corporation has designed and built a fine track system, which applies a circular nutation to the light incident on the fiber, allowing the pointing error to be extracted by demodulation of the power signal. A fast-steering mirror is used for correction. This paper will discuss the development and characterization of this system.

14:45 **AAS 11 - 197** **DISTRIBUTED ARCHITECTURE FOR IMPROVED UNCONSTRAINED 3-AXIS ATTITUDE DETERMINATION AND CONTROL TEST BED**
Vivek Nagabhushan, Shawn Allgeier, Norman Fitz-Coy, University of Florida

A new approach for verification and validation (V&V) of attitude determination and control systems (ADCS) is presented. The proposed technique may significantly advance testing methodologies for responsive space missions and also provide a test bed for V&V of small satellite ADCS that is currently non-existent. Unlike the conventional approach, the proposed method uses a combination of a proprietary torque sensing platform and an attitude determination facility. The output of the torque sensors is used in the simulation of a spacecraft dynamic model on a computer. The attitude determination facility, which can be located remotely from the torque sensing platform, simulates

15:10 **Break**

15:35 **AAS 11 - 198** **FULL PERFORMANCE TESTING OF AUTONOMOUS STAR SENSORS UNDER LABORATORY ENVIRONMENT**

Jena-Optronik GmbH, Prüssingstrasse 41, 07745 Jena, Germany

The state of the art autonomous star sensors provide high quality attitude quaternion used for spacecraft control. The quaternion describes the rotation between the inertial reference frame in which the stars are reported and the present 3-axis attitude of the star sensor on board of the spacecraft. In contrast to classical star trackers, providing single star centroids only, an autonomous star sensor need to be stimulated with real star patterns in order to calculate the 3-axis attitude expressed in a quaternion. Jena-Optronik GmbH as manufacturer of star sensors since 1980 continuously developed the ground support equipment for star sensor qualification

16:00 **AAS 11 - 199** **HYDRA Star Tracker Innovative Test Solution**

Yves KOCHER, Benoit GELIN, Damien PIOT and Ludovic BLARRE, EADS-SODERN

This paper will present the innovative test platform developed by Sodern for the qualification of Multiple Heads star tracker HYDRA. The HYDRA on-ground qualification was completed in 2010 including various types of tests ranging from optical performance tests achieved with classical star simulators to more innovative multi-head software tests with the Mathlab-Simulink environment used to develop the application software. A review of all these test facilities will be provided and it will be explained why with new generation of star trackers new test techniques have become necessary (in addition to classical ones) to fully validate ever more sophisticated products.

16:25 **AAS 11 - 200** **Independent Validation of Spacecraft flight Software Using Hardware-in-the-Loop Simulations with FPGA Emulation of the Flight Hardware**

Robert Luter, Hung Ngo, David Wangerin, The Aerospace Corporation

An independent validation of spacecraft flight software with a Hardware-in-the-Loop (HIL) simulation is difficult without access to the flight hardware. FPGA technology provides a way to build clock cycle accurate emulations of the flight computers. VHDL of all computer chips must be integrated onto a FPGA board. Sensor and actuator simulations and their interfaces to the flight computer are also required. The resulting HIL is very flexible because it allows access to the gate level for more realistic tests of the software and any changes in the flight hardware can be accommodated by simply reintegrating the VHDL.

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Session 14: Orbit Determination and Navigation

Chair: Renato Zanetti, The Charles Stark Draper Laboratory

13:30 **AAS 11 - 201** **A Splitting Gaussian Mixture Method for the Propagation of Uncertainty in Orbital Mechanics**
Kyle J. DeMars, The University of Texas at Austin; Robert H. Bishop, Marquette University; Moriba K. Jah, Air Force Research Laboratory

In this paper, a splitting Gaussian mixtures algorithm which exploits the properties of the differential entropy for a linearized dynamical system is developed and applied to the problem of long-arc propagation of uncertainty for a resident space object under the influence of gravitational acceleration. It is shown that over long arcs of propagation, the new algorithm provides a more accurate approximation to the probability density function as compared to that of the extended Kalman filter or unscented Kalman filter. The more accurate representation of the probability density function can then be used to more robustly reacquire objects.

13:55 **AAS 11 - 202** **Analytical Non-Linear Propagation of Uncertainty in the Two-Body Problem**
Kohei Fujimoto and Daniel J. Scheeres, The University of Colorado-Boulder; Kyle T. Alfriend, Texas A&M University

Situational awareness of Earth-orbiting particles such as active satellites and space debris is highly important for future human activities in space. One topic of recent interest is the accurate and consistent representation of an observed object's uncertainty under non-linear dynamics. This paper is a survey of analytical non-linear propagation of uncertainty under two-body dynamics. In particular, we present ways to express, analytically and for all time, the probability distribution function (pdf) over state space, and the mean and variance-covariance matrix of the pdf. We also discuss some numerical examples.

14:20 **AAS 11 - 203** **Estimating a High-Resolution Lunar Gravity Field and Time-Varying Core Signature**
Ryan S. Park, Sami W. Asmar, Eugene G. Fahnestock, Alex S. Konopliv, Wenwen Lu, and Mike M. Watkins, Jet Propulsion Laboratory

This paper presents a sensitivity analysis of estimating a high-resolution lunar gravity field and time-varying core signature using the measurements from the Gravity Recovery And Interior Laboratory mission. An overall mission capability is presented based on detailed spacecraft dynamics and kinematics models with realistic measurement uncertainties. Also discussed is the effect of various perturbing forces and measurement models. The result shows that estimating a lunar gravity field is robust against both dynamics and kinematics errors and a nominal field of degree 300 or better can be determined whereas the core signature is more sensitive to spacecraft modeling errors.

14:45 **AAS 11 - 204** **Global Atmospheric Density Estimation Using a Sequential Filter/Smoother**
James Woodburn and John Seago, Analytical Graphics, Inc.

The application of sequential methods to the estimation of corrections to global atmospheric density models is investigated. Potential advantages over least squares include the ability to estimation correction parameters as time varying quantities, the elimination of discontinuities in correction estimates at fit boundaries and reduced computational burden. An optimal sequential filter and a variable lag smoother are utilized to determine the effect of model parameterization on observability and recovery of temperature errors within the reference density model and the relationship between the latency and accuracy of the correction estimates.

15:10 **Break**

15:35 AAS 11 - 205 Modification of Atmospheric Mass Density Model Coefficients Using Space Tracking Data – A Simulation Study for Accurate Debris Orbit Prediction

Jizhang Sang, EOS Space Systems Pty Ltd, Australia

This paper presents simulation results of a new method of improving atmospheric mass desnity modeling for the purpose of accurate orbit prediction of space debris objects. The method is to modify the coefficients of a density model using tracking data from a simulated ground network. 270 objects at altitude of 350 - 600km are chosen in the study. 30 - 50 are used as calibration objects, and the others as verification objects. The simulation results show that significant reduction of the orbit prediction errors is achieved for all verification objects.

16:00 AAS 11 - 206 Preliminary assessment of the orbit restitution capability of a multiple-antenna, GNSS receiver on a highly elliptic orbit reaching above GNSS altitud

Stefano Casotto, Massimo Bardella, Universita' di Padova, Italy; Alberto Zin, ThalesAlenia Space, Milan, Italy

Astronomical missions are often characterized by high altitude, highly elliptic orbits. We report on the results of a study on the orbit determination capability of a receiver equipped with several GNSS antennas on a 1,000 km by 25,000 km altitude orbit. Detailed visibility analysis shows how these antennas can help extend the tracking periods to GNSS constellations. Account is taken of the side lobe radio link allowed by the real GPS antennas radiation pattern. High accuracy OD is shown to be possible due to the smooth character of the force field, even in the presence of unmodelled attitude variations.

16:25 AAS 11 - 207 Sensitivity of Magnetospheric Multi-Scale (MMS) Mission Navigation Accuracy to Major Error Sources

Corwin Olson and Anne Long, a.i. solutions, Inc.; Russell Carpenter, NASA Goddard Space Flight Center

The Magnetospheric Multiscale (MMS) mission consists of four satellites flying in formation in highly elliptical orbits about the Earth, with a primary objective of studying magnetic reconnection. The baseline navigation concept is independent estimationof each spacecraft state using GPS pseudorange measurements referenced to an Ultra Stable Oscillator (USO) and including accelerometer measurements during maneuvers. MMS state estimation is performed onboard each spacecraft using the Goddard Enhanced Onboard Navigation System, which is embedded in the Navigator GPS receiver. This paper describes the sensitivity of MMS navigation performance to major error sources, including USO clock errors and thrust acceleration knowledge errors.

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Session 15: Satellite Relative Motion

Chair: Dr. Aaron Trask, Apogee Integration

13:30 **AAS 11 - 208** **A Virtual-Time Method for Modeling Relative Motion of Noncircular Satellites**
Ryan Sherrill and Andrew Sinclair, Auburn University; T. Alan Lovell, Air Force Research Laboratory; Richard Linares, University at Buffalo

The Hill-Clohessy-Wiltshire (HCW) equations describe the motion of a deputy satellite in close proximity to a circular chief. This paper presents an extension of the HCW equations to elliptic chiefs by a virtual-time approach. The relative position at each instant is approximated by evaluating the HCW solution at a virtual time. Therefore, the shape of the trajectory is approximated using an HCW trajectory, but the progress along the trajectory is modified to account for the chief eccentricity. Example solutions for the virtual time are calculated, and the errors of the HCW and virtual-time solutions are compared.

13:55 **AAS 11 - 209** **Closed-Form Solutions for Satellite Relative Motion in an Axially-Symmetric Gravitational Field**
Vladimir Martinusi, Pini Gurfil, Israel Institute of Technology, Israel

This paper offers a new insight into the relative orbital motion problem in the presence of the Earth zonal harmonics. New sets of initial conditions guaranteeing long-term ballistic formation flying are derived and numerically validated. The main idea on which the present approach relies upon is that the absolute motion in any central force field is super-integrable in the sense of Liouville, meaning that it has 4 independent first integrals.

14:20 **AAS 11 - 210** **Cluster Flight for Fractionated Spacecraft**
Leonel Mazal and Pini Gurfil, Israel Institute of Technology

Fractionated spacecraft is an emerging concept in the realm of distributed space systems. The main concept, originally conceived by DARPA through the System F6 program, is to replace a monolithic satellite by multiple free-flying, physically-separated modules interacting through wireless cross-links. This work presents an analytic method for determining initial conditions required for natural long-term distance-bounded relative motion in a real space environment, including the full gravitational potential, drag, third-body effects, solar radiation pressure, tides and general relativity. These orbits are found by writing down the Hamiltonian of the relative motion assuming that the phase-space is time invariant.

14:45 **AAS 11 - 211** **RELATIVE MOTION MODELING AND CONTROL IN A PERTURBED ORBIT**
Mohamed Okasha and Brett Newman, Old Dominion University

The dynamics of the relative motion problem in a perturbed orbital environment are exploited based on Gauss' variational and Cowell's equations. The inertial coordinate frame and relative coordinate frame (Hill frame) are studied to describe the relative motion. A linear high fidelity model is developed to describe the relative motion. This model takes into account primary gravitational and atmospheric drag perturbations. In addition, this model is used in the design of a control, guidance and navigation system of a chaser vehicle to approach a target vehicle in proximity operations. Extended simulations are performed to assess the precision of this model.

15:10 **Break**

15:35 **AAS 11 - 212** **RELATIVE MOTION NAVIGATION AND GUIDANCE IN A PERTURBED ORBIT**

Mohamed Okasha and Brett Newman, Old Dominion University

The development of relative navigation and guidance algorithms of an autonomous space rendezvous and docking system are presented. These algorithms are based on using the analytical closed-form solution of the Tschauner-Hempel equations and they are used to approach, fly around, and to depart form a target vehicle in elliptic orbits. Relative navigation uses an extended Kalman filter based on TH equations to estimate the relative position and velocity of the chaser vehicle with respect to the target vehicle. Numerical simulations that illustrate the relative navigation and guidance algorithm performance and accuracy are developed in the current paper.

16:00 **AAS 11 - 213** **Satellite Formation Design Using Primer Vector Theory**

Weijun Huang, University of Missouri

Estimating fuel consumption for each satellite is important for designing a satellite formation. In a recent paper of Huang, analytic solution of coplanar impulsive formation to formation(FTF) transfer is found by using primer vector theory. In this paper, based on Huang's algorithm, two accessory optimizations are formulated to compute the most fuel saving formation design parameters from a given set of coplanar symmetric impulsive primers. Solutions of these new problems are obtained analytically. For the three-dimensional case, algebraic formulas to approximate the optimal fuel cost are given for both time-fixed and time-free FTF transfers.

16:25 **AAS 11 - 214** **The Virtual-Chief Method for Modeling Relative Motion of Noncircular Satellites**

Ryan Sherrill and Andrew Sinclair, Auburn University; T. Alan Lovell, Air Force Research Laboratory; Kirk Johnson, Missile Defense Agency; Douglas Decker, Science Applications International Corporation

The HCW equation are often used for preliminary mission design to model the relative motion between two satellites. The virtual-chief method described in this paper is a modification to the classic HCW equation for chief satellites of non-zero eccentricity. A kinetics-based method for determining the initial conditions is also developed. Results compare the error and relative motion trajectory of the classic HCW and the virtual-chief method to Kepler's two-body motion to demonstrate the validly of thismethod.

Feb 16, 2011

Session 16: Special Session: Optical Navigation

Chair: Dr. William Owen, Jet Propulsion Laboratory

08:00 **AAS 11 - 215** **Methods of Optical Navigation**
William Owen, Jet Propulsion Laboratory, California Institute of Technology

Optical navigation is the use of onboard imaging to aid in the determination of the spacecraft trajectory and of the targets' ephemerides. Opnav techniques provide a direct measurement of the direction from a spacecraft to target bodies. Opnav data thus complement both radiometric tracking data (for instance, Doppler and range) and the groundbased astrometry which is used to determine the apriori ephemeris of the targets. We present the geometry and camera models which form the mathematical basis for optical navigation and some of the image processing techniques by which one can extract the optical observables from the pictures.

08:25 **AAS 11 - 216** **Optical Navigation Planning Process for the Cassini Solstice Mission**
Simon Nolet, Stephen D. Gillam and Jeremy B. Jones, Jet Propulsion Laboratory

During the Cassini Equinox Mission, the Optical Navigation strategy has gradually evolved toward maintenance of an acceptable level of uncertainty on the positions of the bodies to be observed. By counteracting the runoff of the uncertainty over time, this strategy helps satisfy the spacecraft pointing requirements throughout the Solstice Mission, while considerably reducing the required imaging frequency. Requirements for planning observations were established, and the planning process itself was largelyautomated to facilitate re-planning if it becomes necessary. This paper summarizes the process leading to the optical navigation schedule for the seven years of the Solstice Mission.

08:50 **AAS 11 - 217** **Optical Navigation for the EPOXI Mission**
B. P. Rush, W. M. Owen, S. Bhaskaran, S. P. Synnott, Jet Propulsion Laboratory, California Institute of Technology

The Deep Impact spacecraft flew by comet Hartley 2 on November 4, 2010 as part of its extended mission called EPOXI. Successful navigation depended critically on the quality and timing of optical navigation data processing, since pictures of the comet provided the most precise comet-relative position of the spacecraft. This paper describes the planning, including the picture timing and pointing; the methods used to determine the center of the comet image in each picture; and the optical navigation results, which provided the necessary information to allow the cameras to accurately target the comet for science imaging at encounter.

09:15 **AAS 11 - 218** **New Horizons Jupiter Data Analysis: Examining The Jovian System Using Optical Navigation Software**
Dylan O'Connell and W.M. Owen, Jet Propulsion Laboratory

The New Horizons spacecraft, bound for a Pluto encounter in 2015, acquired over 1000 pictures of Jupiter and its satellites during a 2007 gravity assist. These pictures were taken not only for science but also to calibrate its Long Range Reconnaisance Imager (LORRI) and test LORRI's optical navigation performance. We present the results from the geometric calibration, the opnav test sequence involving Callirrhoe (an outer irregular satellite), and pictures of Amalthea, Metis and Thebe.

09:40 **Break**

10:05 AAS 11 - 219 Post-flight lunar landing-site localization and reconstruction using descent camera Imagery

Joseph E. Riedel, Jet Propulsion Laboratory

This paper describes reconstruction of the surface position of a landed lunar spacecraft via descent imagery. Such reconstruction is necessary to provide scientific context and to compute the ascent and Earth return trajectory for a mission such as Moonrise. The method is twice demonstrated, for 1) LCROSS, using descent images, comparing with the radio-metric ground truth, and 2) Moonrise landing, utilizing terrain and camera simulations of the Moonrise imager as it will be used during descent. The estimation process is described, and LCROSS results from real data, and Moonrise results based on the simulations are presented.

10:30 AAS 11 - 220 Optical Navigation Near Small Bodies

Robert W. Gaskell, Planetary Science Institute

Optical navigation is a crucial component of orbit determination for spacecraft operations around a small body. Precise image-space locations of fixed points on the body are combined with Doppler measurements to unambiguously determine the spacecraft's position. A “maplet” can be located in images under a wide range of illuminations, resolutions and viewing geometry. Maplets are digital topography/albedo representations of pieces of the body's surface constructed by a process called stereophotoclinometry. They are also used to determine the body's global shape and topography. We shall discuss the construction of maplets and observational strategies to optimize navigation and surface characterization.

10:55 AAS 11 - 221 Evaluation and Improvement of Passive Optical Terrain Relative Navigation Algorithms for Pinpoint Landing

Yang Cheng, Dan Clouse, Andrew Johnson, Bill Owen, Andrew Vaughan, Jet Propulsion Laboratory, California Institute of Technology

Future solar system in situ exploration will deploy pin-point landing (PPL) capability, which lands a spacecraft within 100 meters of a targeted site. PPL relies solely on terrain relative navigation (TRN) technology, which recognizes the local terrain and locates the spacecraft within it. In this paper, first, we present the findings in evaluating two TRN algorithms: MAIA and OBIRON using ALHAT field test 3 data and we point out the strengths and weaknesses of both. Then we suggest some modification and improvement about these two algorithms. Finally, we give a brief report of the performance of the modified TRN algorithm.

11:20 AAS 11 - 222 Optical Navigation for Dawn at Vesta

Nickoloas Mastrodemos, Brian Rush, Drew Vaughan, Bill Owen, Jet Propulsion Lab

The Dawn S/C, launched in September 2007, towards Vesta and Ceres, will enter into orbit about asteroid Vesta in July 2011 and will conduct science remote sensing operations for approximately one year at various orbital altitudes. Vesta navigation operations begin with early approach in May 2011 until departure to Ceres in July 2012. A key navigation aspect is optical navigation, which will be conducted at all mission phases. Here we review the optical navigation plan, imaging, methodology, data types, aswell as expected performance.

Feb 16, 2011

Session 17: Satellite Constellations

Chair: Dr. Matthew Wilkins, Schafer Corporation

08:00 **AAS 11 - 223** **Application of UKF in Autonomous Orbit Determination of Navigation Constellation**
Xiaofang Zhao, Shenggang Liu and Chao Han, BeiHang University.

The autonomous Orbit Determination of navigation constellation uses cross-link measurement and the data obtained from communication as input of distributed Kalman Filter to estimate satellite orbit.In this article, the autonomous OD algorithm based on Unscented Kalman Filter including standard UKF, SSUKF which is based on spherical simplex sigma-point and modified SSUKF is proposed. Simulation results show that the selected nonlinear estimation algorithms can maintain long term autonomous OD and the modified SSUKF gets the best result. Besides, the modified SSUKF is proved to be able to restrict filter divergence caused by the non-observable error of satellite initial orbit.

08:25 **AAS 11 - 224** **Effect of Initial Conditions on Satellites Formation**
Bidul T. Narayanan and Manoranjan Sinha, IIT Kharagpur, India

Initial conditions play a major role in the maintenance of formation. An analytical solution to the equation of motion which accounts for high eccentricity and also takes into account the J_{2} and the drag forces is provided. Moreover, optimized initial conditions are derived based on minimization of shift in the formation. In this paper the effect of angle of inclination is included. Sensitivity study is carried out and the results are compared when the angle of inclination is not included in the optimization process. It is observed that the obtained initial conditions keep the orbit for a longer time.

08:50 **AAS 11 - 225** **Linear Stability and Shape Analysis of Spinning Three-Craft Coulomb Formations**
Erik Hogan, Hanspeter Schaub, University of Colorado at Boulder

This paper describes the discovery of families of multiple invariant shape solutions for collinear three-craft invariant shape Coulomb formations, as well as the results of linear stability analysis on such formations. It is found that up to three invariant shape solutions are possible for a single set of craft charges. Linear stability analysis yields the first examples of marginally stable collinear invariant shape formations. Marginally stable behavior is only observed when two invariant shape solutions result for one set of charges, where one shape will be unstable and the other marginally stable.

09:15 **AAS 11 - 226** **Necklace Theory on Flower Constellations**
Daniel Casanova, Martin Avendano, and Daniele Mortari

Theory of Flower Constellation have been improved with the 2-D and 3-D Lattice Flower Constellation. However, place a satellite in each admissible location isn't an optimal way to design a constellation, the necklace theory tries to optimize the number of satellites in the Flower Constellation choosing a suitable necklace and an appropriate shifting to reduce the cost of the mission. Furthermore, the symmetric necklaces will have an important role because will be easier find suitable patterns to identify the (Omega,M)-space with a 3-D torus and reduce the number of satellites in the constellation.

09:40 **Break**

10:05 **AAS 11 - 227** **On-Orbit Servicing of Satellites in Circular Constellation Using a Single Service Vehicle**

Atri Dutta , Georgia Institute of Technology

In this paper, we consider the problem of determining the optimal way of servicing (delivering fuel and other commodities) multiple satellites, moving in a circular orbit, by a single service vehicle. We assume that the servicer employs a chemical propulsion system. We develop a formulation that allows the consideration of a general objective function taking into account both servicing time and fuel expenditure. The formulation also allows for inclusion of fuel budget and time constraints. We present numerical results for sample constellations, and demonstrate the impact of choice of objective and constraints on the optimal solution.

10:30 **AAS 11 - 228** **Optimization of Hybrid-orbit Constellation Servicing for Constellations**

Zhongxing Tang and Chao Han, Beihang University

The hybrid-orbit constellation is proposed to perform the servicing mission for the constellation which needs on-orbit servicing operations. The objective of such hybrid-orbit constellation is to service as many satellites as possible with the restrictions of the satellite's transfer time and fuel cost. Firstly, the tent-map particle swarm optimization (TCPSO) is adopted to optimize the optimal fuel problem for Lambert orbital maneuver. Then it is used again to optimize the orbital slots in the hybrid-orbit constellation. The numerical simulation shows that the hybrid-orbit constellation has a better servicing ability to service for all the satellites of the constellation.

10:55 **AAS 11 - 229** **Optimizing Spacecraft Placement for LiAISON Constellations**

Channing Chow, University of Southern California; Benjamin Villac, University of California, Irvine; Martin Lo, Jet Propulsion Laboratory

A navigation and communications network is proposed to support an anticipated need for infrastructure in the Earth-Moon system. Periodic orbits will host the constellations while a novel, autonomous navigation strategy will guide the spacecraft along their path strictly based on satellite-to-satellite telemetry. In particular, this paper investigates the second stage of a larger constellation optimization scheme for multi-spacecraft systems. That is, following an initial orbit down-selection process, this analysis provides insights into the ancillary problem of spacecraft placement. Two case studies are presented that consider configurations of up to four spacecraft for a halo orbit and a cycler trajectory.

11:20 **AAS 11 - 230** **Peer-to-Peer Servicing of Satellites in Circular Constellation**

Atri Dutta, Georgia Institute of Technology

During the Peer-to-Peer (P2P) phase of a mixed servicing strategy, a set of satellites (already serviced by a service vehicle) redistribute their resources (fuel and other commodities) among other satellites, by engaging in P2P maneuvers. In this paper, we consider the P2P problem for multiple satellites moving in a circular orbit, and employing chemical propulsion system. We develop an integer programming based formulation that considers minimization of a general objective taking into account both P2P maneuver time and fuel expenditure. The optimization framework also includes fuel budget and time constraints. We demonstrate our methodology by presenting numerical examples.

Feb 16, 2011

Session 18: Low-Thrust Trajectory Design

Chair: Ryan Park, JPL

08:00 **AAS 11 - 231** **A Simple Method for Improving Recovery Characteristics of Fuel Optimal Low-thrust Transfers**

Iman Alizadeh and Benjamin Villac, University of California, Irvine

This paper aims at designing recoverable low-thrust trajectories subject to temporary engine failure. The recoverable trajectory is obtained by backward propagation of an optimal trajectory with a prescribed recovery time. Comparison of the life-time between the optimal and recoverable trajectories shows reduction of the impact risk. The concepts are illustrated in the Jupiter-Europa system for different transfer scenarios. This method has an advantage that the optimal retargeting trajectories after engine recovery lie on a single optimal trajectory. Cost of retargeting the final state after engine recovery can be computed for the whole trajectory by solving a single optimal control problem.

08:25 **AAS 11 - 232** **Low Thrust Spacecraft Trajectory Control Using Receding Horizon Control Techniques**

Joseph A. Starek, Ilya Kolmanovsky, University of Michigan

The use of feedback control based on receding horizon optimization is considered for spacecraft trajectory maneuvers using low thrust propulsion. Two receding horizon control approaches are investigated: 1) linearization and correction about an optimal trajectory, and 2) a contractive framework that enforces sufficient decay of the spacecraft state towards a target state. A simple Earth-to-Mars coplanar heliocentric transfer is studied. A comparison is made between the receding horizon control laws with the open-loop optimized trajectory in terms of fuel consumption, transfer time and ability of the low-thrust spacecraft to follow an optimal trajectory under the influence of perturbations and disturbances.

08:50 **AAS 11 - 233** **Low-Thrust Transfers with Earth-Shadow and Power-Degradation Effects**

Craig Kluever, University of Missouri-Columbia

Optimizing low-thrust transfers is a challenging problem which is exacerbated when real environmental effects, such as Earth-shadow eclipses (zero thrust) and solar-cell degradation (due to radiation), are included. In many cases, mission analysts need to perform preliminary trade studies in order to determine general trends among electric propulsion system parameters. This paper presents a new low-thrust trajectory program that can easily accommodate both Earth-shadow and power-degradation effects. The new method utilizes Edelbaum's analytic solution, and therefore does not require numerical integration of the system dynamics or an iterative search. Several low-thrust transfers are presented in order to demonstrate its effectiveness.

09:15 **AAS 11 - 234** **Optimum Low-Thrust Elliptic Transfer for Power-Limited Spacecraft using Equinoctial Elements and Numerical Averaging**

Zahi Tarzi, Jason Speyer, and Richard Wirz, University of California Los Angeles

Low-thrust trajectory optimization is becoming increasingly important as more spacecraft missions are using low-thrust electric propulsion due to its high propellant efficiency. Previous researchers obtained analytical results for limited sets of low-thrust orbit transfers using Keplerian orbital elements and averaging. This paper uses analytical methods to obtain the fuel optimum rates of change of the equinoctial orbital elements using variable thrust. The equations are then averaged and integrated numerically to a specified final time. A shooting method is used to solve the optimization problem based on an initial guess.

09:40 **Break**

10:05 **AAS 11 - 235** **Low-Thrust Transfer between Jovian Moons Using Manifolds**
Keita TANAKA, The University of TOKYO; Jun'ichiro KAWAGUCHI, ISAS/JAXS

The development of electric propulsion systems such as ion engines has brought low-thrust control into practical use. This has made the design of spacecraft trajectories with low continuous thrust more and more demanding. This work concerns low-energy transfer trajectories between the Jupiter satellites using effectively the n-body dynamics in the Jupiter system and low-thrust controls. To analyze the dynamics of n-body models, we use the three-body problem as a model and apply the patched three-body approximation. We use invariant manifold tubes and the result provides how to connect two different manifolds with low-thrust, low-energy trajectories.

10:30 **AAS 11 - 236** **Extension of the Molniya Orbit using Low-Thrust Propulsion**
Pamela Anderson, University of Strathclyde, Glasgow

The objective is to enlarge the set of Earth-centered orbits, using low-thrust propulsion to extend the Molniya orbit. Continuous low-thrust propulsion is applied to vary the critical inclination from 63.4deg, to, for example 90deg, creating a so-called Polar-Molniya orbit. An analytically derived constant continuous, switching control profile in the transverse direction allows the spacecraft to achieve any inclination with the lowest acceleration. This can be reduced by combining constant continuous radial and transverse thrust. Finally, the fuel optimal solution is presented using the analytically derived constant continuous, switching control profile as an initial guess, solving using pseudospectral numerical optimisation techniques.

10:55 **AAS 11 - 237** **Quasi-periodic orbits around Artificial Equilibrium Points via variable low-thrust control**
Michèle R.Lavagna, Politecnico di Milano

Within the presented study the generation of Artificial Equilibrium Points in the CRTBP is analyticially faced. Artificial points are looked for by defining a low thrust profile with no contraints but those imposed by the current technology. The variable thrust profile is modeled as a second order polynomial the coefficient of which come from an optimization loop. The obtained analytical solutions are critically compared with numerical results for selected scenarios. Results show that the stability region is enlarged with respect to constant low thrust assumption approaches, available in literature. Possible real applications are also proposed.

11:20 **AAS 11 - 238** **Fourth Order Expansions of the Luni-Solar Gravity Perturbations along Rotating Axes for Trajectory Optimization**
jean albert kechichian,The Aerospace Corporation, El Segundo, California, USA

A fourth order extension of the analytic form of the accelerations due to the luni-solar gravity perturbations along rotating axes is derived in order to increase the accuracy of the dynamic modeling of perturbed optimal low-thrust transfers between general elliptic orbits. A set of rotating axes attached to the thrusting spacecraft is used such that both the thrust and perturbation accelerations due to Earth's geopotential and the luni-solar gravity are mathematically resolved along these axes prior to numerical integration of the actual trajectory. Analysis reveals that further extensions to higher orders are not needed to extract more accuracy.

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Session 19: Earth Orbit and Missions

Chair: Xiaoli Bai, Texas A&M University

08:00 **AAS 11 - 239** **Deep Resonant GPS-Dynamics Due to the Geopotential**
Martin Lara, Real Observatorio de la Armada; Juan F. San-Juan, Universidad de la Rioja; Paul J. Cefola, University at Buffalo (SUNY)

On time scales of interest for mission planning of GNSS satellites, the qualitative motion of the semi-major axis and the node evolves primarily from resonances with the Earth's gravitational field. The relevant dynamics of GPS orbits, which are in deep 1:2 resonance, is modeled with an integrable intermediary that depends only on one angle, the stroboscopic mean node, plus a two degrees of freedom perturbation factored by the eccentricity. Results are compared with long-term runs of the GTDS DSST showingvery good agreement

08:25 **AAS 11 - 240** **Effect of Density Model Time-Delay Errors on Orbit Prediction**
Rodney L. Anderson, Christian P. Guignet, George H. Born and Jeffrey M. Forbes, University of Colorado at Boulder

Geomagnetic storms can produce large variations in atmospheric density, causing satellites to deviate from their predicted orbits. Modeling of these variations is thus very important, and several models exist to do so. This paper seeks to quantify the effects of storms on the NRLMSISE-00 empirical atmosphere model. Satellite orbits are simulated using densities obtained from CHAMP and the model to quantify the errors in the model. Also, time delays are introduced to the model to quantify their effects on density predictions.

08:50 **AAS 11 - 241** **Extension of ICESat Ephemerides to Upper Atmospheric Density Corrections**
Jason M. Leonard, Bradley W. Cheetham and George H. Born, University of Colorado at Boulder

The largest uncertainty in density modeling occurs at altitudes below 300km coinciding with the region of highest satellite drag. Extension of density correction techniques to GPS solutions allow for more precise density corrections to be made specifically for altitudes below 300km. NASA's Program to Optimize Simulated Trajectories II (POST2) was used to simulate ICESat's orbital decay during reentry and to determine the density corrections for certain altitude regimes. Orbit determination and reentry prediction can be greatly improved through precise density corrections since drag is one of the primary perturbations on LEO satellites.

09:15 **AAS 11 - 242** **Hypersonic, Aerodynamically Controlled, Path Constrained Reentry Optimization in SOCS**
Christopher L. Ranieri, The Aerospace Corporation, El Segundo, CA

Hypersonic, aerodynamically controlled reentries are optimized with the SOCS optimization package. The reentries incorporate state and control path constraints and interior waypoint constraints to address heating, stability, and recession issues and no-fly zones. SOCS helped determine the capabilities of the new reentry vehicle by optimizing trajectories too complicated for TOP, a separate program used for less stressing reentries. The stressing trajectories spanned various flight regimes, highlighting the dynamic environments experienced during hypersonic reentries. SOCS was used in an iterative process with various subsystem experts to shape the reentries to optimize heating, recession, and stability performance.

09:40 **Break**

10:05 **AAS 11 - 243** **On-Orbit Range Computation Using Gauss' Variational Equations for Mean Orbit Elements with J2 Perturbations**

Marcus J. Holzinger and Daniel J. Scheeres, University of Colorado at Boulder; R. Scott Erwin, Air Force Research Laboratory

Aircraft range is a critical intuitive measure that provides strategic and tactical insight to the end user. Currently there is no rigorously defined and derived range measure for on-orbit spacecraft operations with which to inform strategic and tacticaldecisions and planning. This paper illustrates how range may be applied in the context of orbital motion using optimal control theory and how existing results in reachability set computation may be leveraged. Numerical examples of on-orbit range are given and their application to spacecraft operations detailed.

10:30 **AAS 11 - 244** **Optimization Deployment Of Mobile Ground Station For Disaster Monitoring Satellite Mission**

Shengggang Liu, Chao Han, Beihang University, Beijing, China

Several disaster monitoring satellite missions like DMC program constructed by SSTL and HJ-1A/1B of China are in operation presently. In case of an emergency like earthquake, there is an urgent need for obtaining remote sensing data from these satellites.This paper analyzes the data transmission mode and the use of mobile ground station in this situation. An optimal deployment strategy is given based on evolutionary algorithm. This method is applied in a simulation of the mission monitoring Yushu earthquake in China. The results show that data can be obtained rapidly and efficiently via optimization deployment of mobile ground station.

10:55 **AAS 11 - 245** **TerraSAR-X / TanDEM-X Formation Acquisition - Analysis and Flight Results**

Ralph Kahle, Benjamin Schlepp, Florian Meissner, Michael Kirschner and Reinhard Kiehling, German Aerospace Center (DLR), German Space Operations Center (GSOC)

The TerraSAR-X (launched 15 June 2007) and TanDEM-X (launched 21 June 2010) satellites form the first configurable SAR interferometer employing formation flying. The primary objective is to generate a global digital elevation model with unprecedented accuracy as the basis for a wide range of scientific research as well as for commercial DEM production. The paper summarizes the work performed in the fields of launch injection collision assessment, target orbit acquisition analysis and in-flight realization of the formation acquisition, which was successfully performed in July 2010.

11:20 **AAS 11 - 246** **Trajectory Reconstruction of the Ikaros DCAM2**

Andrew Klesh, Osamu Mori, Hirotaka Sawada and Yuichi Tsuda, JAXA; Sabro Matunaga, Tokyo Institute of Technology; Shinichi Kimura, Tokyo University of Science

After deployment of the Ikaros solar-sail in June 2010, a small camera, DCAM2, was released to provide external imagery and verification of full sail deployment. Though the initial parameters were known, no inertial sensors were placed onboard the DCAM unit and the trajectory taken by DCAM2 relative to Ikaros is unknown. In this paper we analyze the images taken by the camera and attempt to use them to supplement the known initial parameters of the imager to reconstruct the trajectory of the micro-spacecraft. We also attempt to find evidence of warping or distortion within the sail based on image data.

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Session 20: Dynamical Systems and Orbital Mechanics

Chair: Dr. Kathleen Howell, Purdue University

14:30 **AAS 11 - 247** **DYNAMICS AT CUSP POINTS ON THE REPEATING ORBITS**
Mohammed Ghazy and Brett Newman, Old Dominion University

Cusp curves are formulated when an orbit touches its zero velocity curve in a rotating coordinate system. Dynamics at cusp points is studied in de-tails; a dynamic system approach is compared with the known power se-ries solution. The relative dynamics atthe cusp point is introduced and analyzed in a proposed direct-repeating constellation in which a satellite on a direct orbit can maneuver around another satellite on a retrograde orbit.

14:55 **AAS 11 - 248** **Fokker Planck Equation based Uncertainty Propagation for Space Applications**
Mrinal Kumar, University of Florida

This paper presents a spectral approach for solving the Fokker-Planck equation (FPE). Focus will be placed on long term uncertainty propagation problems in space applications, such as uncertainty propagation for potentially hazardous asteroids. It will be shown that for dynamical systems that do not admit a steady state solution, e.g. the two-body problem, the FP operator admits numerous modes with purely imaginary eigenvalues. A systematic method based on global error minimization of the FP operator eigenvalue problem will be presented to extract these quasi-steady modes. This FPE approach method will be compared with Gaussian closure for the two-body problem.

15:20 **AAS 11 - 249** **Gravity assisted flybys in the planar, circular, restricted, three-body problem**
Stefano Campagnola, JSPS postdoctoral fellow, ISAS/JAXA, Sagamihara Campus, Japan

Gravity assisted flybys are important mechanisms in celestial mechanics, yet even for planar trajectories, their dynamics have not yet been fully analyzed when considering the gravity of more than one body. Inspired by recent works on the Keplerian map and on the T-P graph, this paper presents a new way to analyze and design flybys in the pcr3bp, giving a new insight on the flyby dynamics and on the accuracy of the linked-conics model. A follow-up paper will present a design method developed from this work, which was applied for endgame scenarios in collaboration with JPL and ESA.

15:45 **Break**

16:10 **AAS 11 - 250** **Lagrangian Coherent Structures in the Restricted Three-Body Problem**
Cody R. Short, Kathleen C. Howell, and Xavier M. Tricoche, Purdue University

The Circular Restricted Three-Body Problem (CR3BP) is an autonomous dynamical system that displays both ordered and chaotic behavior. This balance of complexity creates an excellent case for application of relatively straightforward tools like the Finite-Time Lyapunov Exponent (FTLE) and Lagrangian Coherent Structures (LCS), typically common to more complex problems. This paper contributes to the establishment of LCS as a useful tool for investigating the CR3BP through a series of example applications. Generation of LCS typically involves extensive numerical simulation, and some methodologies toward this end are discussed including parallel computation and interactive visualization.

16:35 **AAS 11 - 251** **Three-Impulse Rendezvous near Circular Orbit Determined Through a New Primer Vector Analysis**

Thomas Carter, Eastern Connecticut State University; Mayer Humi, Worcester Polytechnic Institute

A new approach is presented for the optimal impulsive rendezvous of a spacecraft in an inertial frame near a circular orbit. Using a form of primer-vector theory the problem is formulated in a way that leads to relatively easy calculation of the optimal velocity increments. A certain vector that can easily be calculated from the boundary conditions determines the number of impulses required for solution of the optimization problem and also is useful in the computation of these velocity increments.

17:00 **AAS 11 - 252** **Two-Impulse Rendezvous near Circular Orbit Determined Through a New Primer Vector Analysis**

Thomas Carter, Eastern Connecticut State University; Mayer Humi, Worcester Polytechnic Institute

This is the second of three papers on optimal impulsive rendezvous of a spacecraft in an inertial frame near a circular orbit. This study is restricted to non-degenerate two-impulse and one-impulse solutions. Optimal non-degenerate nonsingular two-impulserendezvous is found to consist of four categories of solutions depending on the four ways the primer vector locus intersects the unit circle. Necessary and sufficient conditions for each category of solutions are presented. The region of the boundary values that admit each category of solutions are found, and in each case a closed-form solution of the optimal velocity increments is presented.

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Session 21: Space Debris Removal

Chair: Dr. Thomas Starchville, The Aerospace Corporation

14:30 **AAS 11 - 253** **A Preliminary Systems-Level Analysis of Candidate Active Space Debris Removal Architectures**
Jesse Quinlan, Georgia Institute of Technology.

To prevent a future cascading of space debris collisions in low-earth-orbit (LEO), a multi-tiered approach to space debris remediation is necessary. Active debris removal (ADR) of massive debris is necessary, in addition to current mitigation guidelines.This study compares the effectiveness of proposed ADR concepts at a systems-level by first outlining a baseline ADR mission to LEO based on results from recent debris environment sensitivity studies. The author develops an independent set of figures ofmerit (FOMs) and subsequently uses the Analytic-Hierarchy Process (AHP) to compare the effectiveness of candidate ADR concepts against the baseline mission.

14:55 **AAS 11 - 254** **Active Debris Removal – a Grand Engineering Challenge for the Twenty-First Century**
J.-C. Liou, NASA

The collision between Iridium 33 and Cosmos 2251 has reignited the interest in using active debris removal to remediate the environment. A recent NASA study shows that, in order to stabilize the environment for the next 200 years, active debris removal of about five massive (1 to more than 8 metric tons) objects per year is needed. To remove five of those objects per year in a cost-effective manner truly represents a grand challenge in engineering and technology development in the areas of launches, orbit rendezvous, precision tracking, stabilization (of the tumbling motion), capture, and deorbit of the targets.

15:20 **AAS 11 - 255** **Coupled Ion-Beam-Electrodynamic-Tether System for Space Debris Removal**
Claudio Bombardelli, Hodei Urrutxua, Jesus Peláez, Mario Merino, Eduardo Ahedo, Technical University of Madrid; and Joris Olympio, European Space Agency

A new concept for active debris removal is proposed involving a targeted ion beam and an electrodynamic tether system. The system consists of a central module hosting a high specific impulse ion engine producing a collimated beam of ions which is directedagainst the space debris transmitting a contactless deorbiting momentum. At the same time the module is connected to two external platforms by two bare electrodynamic tethers which compensate the reaction of the ion beam while producing onboard power . The system dynamics are analyzed and possible design and control solutions are proposed.

15:45 **Break**

16:10 **AAS 11 - 256** **SLING SATELLITE FOR DEBRIS REMOVAL WITH AGGIE SWEEPER**
Jonathan Missel and Daniele Mortari: Texas A&M University

Low Earth Orbit is cluttered with rogue objects. Traditional satellite missions are not efficient enough to collect an appreciable amount of debris. This paper proposes an efficient mission structure, and bespoke hardware, to deorbit debris by capturing and appropriately expelling them. Momentum from these plastic collisions can assist transfers to subsequent debris without burning fuel! Optimizing the order and method of interaction is a primary focus of this research. The proposed hardware also exploits existing momentum by capturing debris at the ends of a spinning satellite, adjusting angular rate, and then simply letting go at a specified time.

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Session 22: Attitude Sensor

Chair: Al Treder

14:30 **AAS 11 - 257** **A New Spectral Photometric Star Tracker**
Geoffrey McVittie and John Enright, SAIL, Aerospace Engineering Ryerson University

Abstract--- In this paper, we develop a new star tracker detection methodology that estimates both star position and spectral characteristics. Spectral estimation is achieved through the application of classical photometric techniques in combination with a bayer patterned, colour filtered image detector. Characterization of the spectral properties is provided with particular focus on distinguishing stellar spectral types. The issue of pixel saturation, and the effect on spectral estimation, is also addressed. The proposed estimation techique is finally evaluated using a combination of simulated star images and empirical, ground-based field testing.

14:55 **AAS 11 - 258** **Geometrical Configuration Comparison of Redundant Inertial Measurement Units**
Hector D. Escobar-Alvarez and Maruthi R. Akella, The University of Texas at Austin; Robert H. Bishop, Marquette University.

Inertial measurement units (IMUs) are used in a wide range of applications to estimate position, velocity, and attitude of vehicles. The high cost of tactical grade IMUs makes the low-cost microelectromechanical systems (MEMS) based IMUs appealing. These types of IMUs are less accurate, so to counteract this effect, multiple and different configurations should be used. The work presented here provides efficient and low cost solutions using different configurations of redundant (multiple) MEMS-IMU swarms,which increase the level of accuracy to potentially the order of that of a tactical IMU. Several configurations are presented and compared through different methods.

15:20 **AAS 11 - 259** **Model refinement of a target-based focusing procedure for nanosatellite star trackers**
Tom Dzamba, John Enright, Ryerson University, Toronto, Canada.

The availability of a star trackers attitude solution is directly dependent on the number of detectable stars. The effects of defocus can alter an imaged stars size and shape, both of which are factors in its detectability. This study presents a refined focusing procedure for nanosatellite star trackers that allows the user to select a desired spot size. We have developed a new model for focus error that accounts for the effects of astigmatism. Using this model, the accuracy of the existing procedure has been increased by 50% to allow for achievable spot sizes of less than 10 pixels.

15:45 **Break**

16:10 **AAS 11 - 260** **Star Tracker Real-Time Hardware in the Loop Testing Using Optical Star Simulator**
Malak Samaan and Stephan Theil, German Aerospace Center (DLR), Bremen

In order to achieve a high accuracy for any star tracker the hardware and the software should be tested on-ground with high accurate optical simulator. The proposed work presents an open-loop and closed-loop testing systems for a hardware-in-the-loop demonstration of star tracker attitude determination system. The facility required for these tests include optical star field real-time simulator and the tested star camera with the integrated image processing software. By using the dSPACE system the real time attitude could be simulated and provided to the star simulator.

16:35 **AAS 11 - 261** **Uniform Distribution of Points on a Sphere with Application in Aerospace Engineering**

Daniele Mortari, Martin Avendano, and Pedro Davalos, Texas A&M University

The capability of uniformly distributing points on a sphere has important theoretical consequences in mathematics and important applications in engineering, allowing the development of optimal algorithms. An application in aerospace engineering is the capability of building uniform star catalogs.

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Session 23: Trajectory and Mission Analysis

Chair: Dr. Sergei Tanygin, Analytical Graphics, Inc.

08:00 **AAS 11 - 262** **Analytical and Numerical Solutions for Error Transfer Matrix in Precision Transfer Trajectory Design and Midcourse Correction**
Zhong-Sheng Wang, Embry-Riddle Aeronautical University

The computation of error transfer matrix is critical in precision transfer trajectory design and mid-course correction for lunar or Mars missions. This paper discusses an analytical solution in detail, and shows that the end error in realistic simulations is significant for long flight time because the dynamic model used in analytical derivation has to be relatively simple. Then a numerical solution is introduced that allows the use of sophisticated dynamic models during design process so that the end error in realistic simulations is negligible. The effectiveness of the numerical solution is confirmed by numerical results.

08:25 **AAS 11 - 263** **GPU Accelerated Lambert Solution Methods for the Orbital Targeting Problem**
Sam Wagner and Bong Wie, Asteroid Deflection Research Center, Iowa State University

In this paper the efficiency of several solution algorithms to Lambert's problem. Each method will be developed for use on a GPU, to enable highly parallelized mission design software to be developed. An example mission to asteroid 99942 Apophis will then be using each solution method in order to compare the efficiency of each solution.. The methods tested will include, but are not limited to, Battin's method, the classical BMW universal method, Thorne's series inversion method, and the universal Lancaster method using Gooding's improvements.

08:50 **AAS 11 - 264** **Natural Loose Formation Flying Around Halo Orbits**
Triwanto Simanjuntak, The Graduate University for Advanced Studies, JAPAN; Masaki Nakamiya, Yasuhiro Kawakatsu, Japan Aerospace Exploration Agency (JAXA)

Two spacecrafts are assumed to fly naturally in a formation flying around L2 point of the Sun-Earth Circular Restricted Three-Body Problem systems. Orbit of choice for reference is Halo orbit and the follower is conceived to follow loosely in a range of set of maximum and minimum relative distances from the leader and possible geometrical orientations, e.g. frozen orientation in the rotating frame. This type of formation will be useful in future for constructing space based ports, space telescope, astronomical spacecrafts requiring sun shield, and etc. The design is based on Dynamical System Theory approach.

09:15 **AAS 11 - 265** **Numerical Solutions To A New Type Of Orbital Boundary-Value Problem With Specified Flight-Path Angle**
Jian Li, Chao Han, Beihang University

A new type of orbit boundary-value problem is investigated in this paper. Being different from the classic Lambert’s problem, the new problem has a given flight-path angle but the time of flight or the range angle is not fixed. Analysis shows that if flight-path angle and time of flight are fixed, to ensure the existence of solutions, the range angle must be bounded and the corresponding boundary values are obtained.Using numerical simulation, a procedure is developed to solve the time of flight equation.The numerical simulation suggested that there are at most four solutions to a given problem.

09:40 **Break**

10:05 **AAS 11 - 266** **Optimized GPU Simulation of a Disrupted Near-Earth Object Including Self Gravity**

Brian D. Kaplinger and Bong Wie

This paper focuses on the development of a simulation model for disrupting a Near-Earth Object (NEO) on terminal approach with the Earth. The problem is simulated numerically using a Graphics Processing Unit (GPU) architecture, and is designed to highlight the benefits of this technology. High-fidelity models, including mutual gravitation and collisions between NEO fragments, are developed and tested for the GPU. The unique limitations of this computational infrastructure are presented, as well as optimization strategies applied to the present model. The results of this project reflect a new range of high-performance computing options available to the planetary defense research community.

10:30 **AAS 11 - 267** **Parameter Variation In Near-Earth Object Disruption Simulations Using GPU Acceleration**

Brian D. Kaplinger and Bong Wie

This paper focuses on the problem of disrupting an NEO on terminal approach with the Earth, weighing the overall importance of both explosive power and timing the fragmentation. Analysis of previous results have shown that fragmenting and dispersing a hazardous NEO could lower the total mass impacting the Earth for some orbits. The problem is simulated numerically using the computational capabilities of a GPU to accelerate calculations and enable variation of several mission parameters. Higher resolution simulation capabilities are demonstrated for an Apophis-like orbit. Unique benefits and limitations to the GPU architecture are discussed, and preliminary results are presented.

10:55 **AAS 11 - 268** **Solution Methods for Kepler's Problem Reconsidered**

Brian Jamison, University of Illinois, Urbana-Champaign

In this work, solution of Kepler's equation by iterative methods is reconsidered. Earlier works considered methods according to the number of iterations required. In this approach, methods are considered according to the computational time required. Also, for Newton's method, the relationship between the initial guess and convergence will be considered, and it will be seen that good initial guesses can be guaranteed. With these two considerations in place, initial results indicate that on average Newton's method may be more than twice as fast as other popular methods.

11:20 **AAS 11 - 269** **Trajectory Analysis of Spacecraft Propelled by Photonic Laser Propulsion System**

Fu-Yuen Hsiao, Tamkang University

This paper studies the application of photonic laser propulsion (PLP) system to the trajectory analysis in a space mission. The PLP system is an innovative technology proposed by Dr. Bae. With repeated reflections of laser beam, it can generate continuous and tremendous power by consuming very small energy. When applying to the trajectory analysis in space flight, we model the problem as a circular Hill's problem, and the corresponded Jocobi integral is found. A contour of zero-velocity lines is presentedand A trajectory of martian mission is provided as a potential application.

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Session 24: Attitude Dynamics and Control II

Chair: Zhiqiang Zhou, NASA Langley Research Center

08:00 **AAS 11 - 270** **DESIGN OF THE SATELLITE ATTITUDE CONTROL SYSTEM USING MULTI-OBJECTIVE GENERALIZED EXTREMAL OPTIMIZATION**

Igor Mainenti Lopes, Luiz C. Gadelha DeSouza, Fabiano L. De Sousa, National Institute for Space Research

In this work a new multi-objective optimization algorithm is developed and used to design a non-linear controller for a rigid-flexible satellite. The control algorithm, called M-GEOreal, is based on the M-GEO algorithm. The M-GEOreal algorithm objective is to optimize, simultaneously, the time and the energy when controlling a rigid-flexible satellite. . The multi-objective approach is able to deal with a set of optimized trade-off creating a region of solutions (non-dominated) available to the designerfor posterior choice of an individual solution to be implemented.

08:25 **AAS 11 - 271** **Impact-Angle Control of Asteroid Interceptors/Penetrators**

Matt Hawkins and Dr. Bong Wie, Iowa State University

Nuclear penetrator devices for asteroid deflection require a controlled impact angle for maximum effectiveness. A terminal guidance strategy to achieve high-speed intercept at a commanded angle is investigated. Performance considerations of the penetratordevice and the available maneuvering thrusters on an interceptor spacecraft are taken into account to design a control strategy that successfully achieves impact at a commanded angle. Requirements and limitations for a penetrator mission are examined. A guidance strategy is developed for a variety of potential targets, and simulations are performed to show the effectiveness of the guidance strategy, leading to successful impact at a commanded angle.

08:50 **AAS 11 - 272** **Inverse Dynamic Neural Control of Flexible Large Satellite in an Elliptic Orbit**

Poola Chaitanya and Manoranjan Sinha (Deaprtment of Aerospace Engineering, IIT Kharagpur, India)

A flexible large satellite consists of distributed masses and is a complex nonlinear system where the system parameters may change at random because of the movement of the crew. Such system is dominated by the strong coupling and presence of a number of vibration modes. Inverse control using dynamic neural network is implemented which is adaptive and dynamic in nature. Stability of the system under the disturbances is proved. The performance of the system is shown through simulation and theoretical proof is provided for the stability and convergence of the system.

09:15 **AAS 11 - 273** **Lorentz force based magnetic attitude control using conjugated coulombic shells**

Poolla Chaitanya, IIT Kharagpur

The need for low power propellantless attitude control is driven by small weight and limited power constraints. Although accomplished by magnetic actuators and charged sheets, component demagnetizing effects and deployment difficulties drive for an alternate. In this method, Lorentz force generated by the magnetic field acting on conjugated Coulombic shells is responsible for the torque generation. The surface charging phenomenon could be dovetailed for the charge management mechanism of the shells. Drag minimization requires reduced shell size for same charge which is accomplished by filling thickness with high k dielectrics. System stability is proved analytically and verified by simulations.

09:40 **Break**

10:05 AAS 11 - 274 Passivity-based Output Feedback Control of Flexible Spacecraft

In this paper the problem of attitude control to carry out maneuver of flexible spacecraft is addressed. A passivity-based control design methodology is used, which aims at revising the potential energy of the closed-loop. To achieve the objective of vibration suppression for large angle reorientation maneuvers, a more general passivity-based output feedback control law is proposed, in which the unit quaternion is adopted to represent the orientation. Sufficient conditions ensuring global asymptotic stability of the controller is derived via Lyapunov analysis. The validity of the proposed approach is demonstrated in a typical application of an earth observation satellite for large angle rapid maneuvers.

10:30 AAS 11 - 275 The exact attitude of a triaxial free rigid body revisited

A. Elipe,Centro Universitario de la Defensa de Zaragoza; J.I. Montijano, L. Randez and M. Calvo, Instituto Universitario de Matematicasy Aplicaciones

The aim of this paper is to give a new description of the exact solutions of an asymmetric rigid body that combines a simplified 3D vector form of the angular velocity with a quaternion form for the attitude matrix. The main advantage in using such a quaternion expression for the attitude is that is free from singularities and with four parameters in the unit sphere of R^4 permits us to perform linear transformations within the simple algebra of quaternions. Because of this, it is well suited for the numerical integration of forced motions, and can be used as a benchmark.

10:55 AAS 11 - 276 Unidirectional Magnetic Detumbling of Small Satellites

Shawn Johnson, University of Florida

This paper shows that having bidirectional actuation is not necessary when detumbling a satellite using magnetic actuators. Two switching controllers are developed for using three unidirectional magnetorquers. The first is a unidirectional B-dot controller and the second is a unidirectional on-off B-dot controller. Both controllers and the conventional B-dot controller are compared by looking at a power consumption and rotational kinetic energy performance index. It is shown that under certain conditions the unidirectional controllers have performance advantages over their bidirectional counterparts for the performance index.

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Session 25: Lunar Trajectory Design

Chair: Lisa Policastri, Applied Defense Solutions

08:00 **AAS 11 - 277** **A Survey of Ballistic Transfers to Low Lunar Orbit**

Jeffrey S. Parker and Rodney L. Anderson, Jet Propulsion Laboratory, California Institute of Technology; and Andrew Peterson, Georgia Institute of Technology

A simple strategy is identified to generate ballistic transfers between the Earth and Moon, i.e., transfers that perform two maneuvers: a Trans-Lunar Injection maneuver to depart the Earth and a Lunar Orbit Insertion maneuver to insert into orbit at the Moon. This strategy is used to survey the performance of numerous transfers between varying Earth parking orbits and varying low lunar target orbits. The transfers surveyed include short 3-6 day direct transfers, longer 3-4 month low-energy transfers, and variants that include Earth phasing orbits and/or
lunar flybys.

08:25 **AAS 11 - 278** **A Survey of Ballistic Transfers to the Lunar Surface**

Rodney L. Anderson and Jeffrey S. Parker, Jet Propulsion Laboratory, California Institute of Technology

In this study techniques are developed which allow an analysis of a range of different types of transfer trajectories from the Earth to lunar landing. Trajectories ranging from those obtained using the invariant manifolds of unstable orbits to those derived using other mathematical techniques are analyzed. These techniques allow the computation of trajectories encompassing low-energy trajectories as well as more direct transfers. The range of possible trajectory options is summarized, and trades between time and maneuver costs are discussed. These results are then classified and compared to previous missions using similar types of trajectories.

08:50 **AAS 11 - 279** **AN EXPLORATION OF THE OPTIMUM TWO-IMPULSE PLANAR TRANSFERS TO CYCLERS IN THE EARTH-MOON SYSTEM**

Saghar H.Sianaki, University of California, Irvine

This paper explores the optimum two-impulse transfer problem in a PCRTBP framework between a low Earth orbit and cyclers. We can find the feasible transfers by employing the Lambert's problem to provide effective initial guess to optimize the error in target position. Once the feasible trajectories are found, the impulse is a function of transfer time and the end points' phases. Next, impulse is optimized over transfer time for fixed end points. As end points are varied, we can study the optimal solutionsby contours. It is shown that Lambert does not work as initial guess for some regions.

09:15 **AAS 11 - 280** **An Onboard Targeting Algorithm for Lunar Missions**

Phillippe Reed, University of Tennessee; Greg Dukeman, NASA Marshall Space Flight Center; Evans Lyne, University of Tennessee

A targeting algorithm for use onboard a spacecraft has been developed. The algorithm determines the appropriate propulsive burn for trans-lunar injection to obtain desired orbital parameters upon arrival at the moon. The primary design objective was to minimize the computational requirements for the algorithm but also to ensure reasonable accuracy, so that the algorithm’s errors did not necessitate large mid-course corrections. The algorithm will serve as a viable alternative to uploading ground-based targeting solutions and bypass the problems of delays and disruptions in communication, enabling the craft to conduct a trans-lunar injection burn autonomously.

09:40 **Break**

10:05 **AAS 11 - 281** **Characterization Of Numerical Error In The Simulation Of Translunar Trajectories Using The Method Of Nearby Problems**

Ashish Jagat and Andrew Sinclair, Auburn University

This paper focuses on analyzing the effect numerical error has on the simulation of translunar trajectories. "Method of Nearby Problems" is employed to estimate the numerical error. A simulation is developed to generate translunar trajectories. Analytical curve fits are generated to this numerical solution to compute the source terms. These source terms would be used to construct a nearby problem to the original problem and the curve fits serve as an exact solution to the nearby problem. Numerically Solving the nearby problem will help calculate numerical error in it. This facilitates the characterization of numerical error in the original problem.

10:30 **AAS 11 - 282** **Research of the Free-Return Orbit Between Earth-Moon**

Qinqin Luo, Jianfeng Yin and Chao Han, Beihang University

A new design method for the free-return orbit between earth and moon is developed in this paper. Pseudostate technique is adopted to get the initial guess of free-return orbit. On basis of the initial guess, a iteration algorithm combines differential-correction method and Newton's method is employed to find a final solution in a more complicated dynamic model. The global characteristics of free-return orbit between earth and moon is studied via the design method proposed in this paper, and some valuable results are obtained.

10:55 **AAS 11 - 283** **Ways to the Moon: A Survey**

Giorgio Mingotti, Institut für Industriemathematik, Universität Paderborn
Francesco Topputo, Dipartimento di Ingegneria Aerospaziale, Politecnico di Milano

This paper presents some works by the authors where a number of new ways to reach the Moon has been described. The aim is assessing these solutions for the sake of comparison with existing examples. This survey contains low- and high-energy transfers, with both low- and high-thrust means. Solutions considered ranges from classic low energy transfers, to transfers using distant periodic and halo orbits. A thorough comparison is made in terms of flight time, propellant fraction, total Delta v, number of maneuvers, duration of thrust and coast arcs, and gravitational model.