Conference Program

15th AAS/AIAA Space Flight Mechanics Meeting

23-27 January 2005
Copper Mountain, Colorado

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Analytical Graphics Inc.

AAS Technical Chair
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AIAA

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TABLE OF CONTENTS

General Information ……………………………………………………………………… 4
Local Information ………………………………………………………………………… 5
Resort Map ……………………………………………………………………………… 7
Conference Center Floorplan …………………………………………………………… 8
Special Events …………………………………………………………………………… 9
Area Attractions ………………………………………………………………………… 10
Technical Program ……………………………………………………………………… 14
Schedule of Events ……………………………………………………………………… 16

Technical Sessions
Monday
Session 1: Formation Flying I……………………………………………………… 18
Session 2: Attitude I ……………………………………………………………… 20
Session 3: Interplanetary I ………………………………………………………… 22
Session 4: *Genesis I* ……………………………………………………………… 24
Session 5: Space Surveillance …………………………………………………… 26
Session 6: Optimization I ………………………………………………………… 28
Tuesday
Session 7: Orbit Determination …………………………………………………… 30
Session 8: *NEO and Lunar Missions* …………………………………………… 32
Session 9: Constellations ………………………………………………………… 34
Session 10: Formation Flying II ………………………………………………… 36
Session 11: Identification and Controls ………………………………………… 38
Session 12: Propagation ………………………………………………………… 40
Wednesday
Session 13: Interplanetary II …………………………………………………… 42
Session 14: Optimization II ……………………………………………………… 44
Session 15: Orbit Mechanics …………………………………………………… 46
Session 16: Formation Flying III ………………………………………………… 48
Session 17: *Astrodynamics – How can we better meet tomorrow's requirements?* …….. 50
Session 18: Tethers I …………………………………………………………… 52
Thursday
Session 19: Rendezvous and Relative Motion ………………………………… 53
Session 20: *Mars Missions* ……………………………………………………… 54
Session 21: 3-Body ……………………………………………………………… 56
Session 22: *Genesis II* ………………………………………………………… 58
Session 23: Tethers II …………………………………………………………… 59
Session 24: Attitude II…………………………………………………………… 60

Author Index …………………………………………………………………………… 61
Record of Meeting Expenses ………………………………………………………… 64

Note: Special Sessions are in italics

GENERAL INFORMATION

Registration

The following registration fees are in effect for this conference:

• AAS or AIAA Members	**$300.00**
• Nonmembers (includes one year membership in the AAS)	**$385.00**
• Full-time Students	**$100.00***
• Retired Professionals	**$100.00***

* Does not include ticket to Tuesday Social

Times of registration:

• Sunday Jan 23		4:00 – 7:00 PM
• Monday Jan 24	7:00 – 10:00 AM	4:00 – 7:00 PM
• Tuesday Jan 25	7:00 – 10:00 AM	4:00 – 7:00 PM
• Wednesday Jan 26	7:00 – 10:00 AM	4:00 – 7:00 PM
• Thursday Jan 27	7:00 – 8:00 AM	

Conference Proceedings

The proceedings are available for purchase at a reduced prepublication cost. A three-volume hardcover set and CD-ROM will be issued. Orders for the proceedings are accepted at the registration desk. The costs are

• Conference Rate	**$190.00**
• Post-published List Price	**$390.00 (approximate)**
• List Price with Author Discount	**$190.00 (approximate)**

LOCAL INFORMATION

Area Description

After completing the first surveys of Copper mountain the US. forest service said...

"If there were a mountain that had terrain for skiing it would be Copper Mountain. It is probably the most outstanding potential ski area in the Arapahoe National Forest, and possibly Colorado. The north facing peaks of Copper Mountain offer an excellent variety of development for expert, intermediate and beginner skiers. The unique thing is that all three varieties are separated by definite terrain features, and in all three cases the skier can ski back into the base area. The mountain has good snow and sparse tree cover created by old burns, which offers a tremendous opportunity to create natural type runs that blend in with the surrounding countryside." Copper is one of Colorado's best ski areas, enjoying thirty years of awesome skiing and snowboarding.

Travel from Denver

Colorado Mountain Express (**888-219-2441**) is the easiest way to travel to Copper in the summer or winter. Ground transportation shuttle transfers from Denver International airport can be reserved on CME, or for more upscale arrival experiences, choose CME Premier transfers in private sedans, SUVs and executive vans. Effective November 20, 2004 - April 19, 2005:

- Shuttles depart from Denver every hour on the half hour from 8:30 am to 9:30 pm plus an 11:00 pm shuttle
- Shuttles depart Summit County every hour on the half hour from 5:30 am to 7:30 pm
- Cost is $56 per person for one way or $112 per person for round-trip - *effective 11/20/04*
- Discounted rates are available for groups of three or more on same flight, using same vehicle and credit card

Note: The trip between Denver International Airport and Copper takes approximately 2 hours. (Special Discounts may apply for large groups. Call 970-241-1822 for details on group rates.)

Travel within Copper Mountain

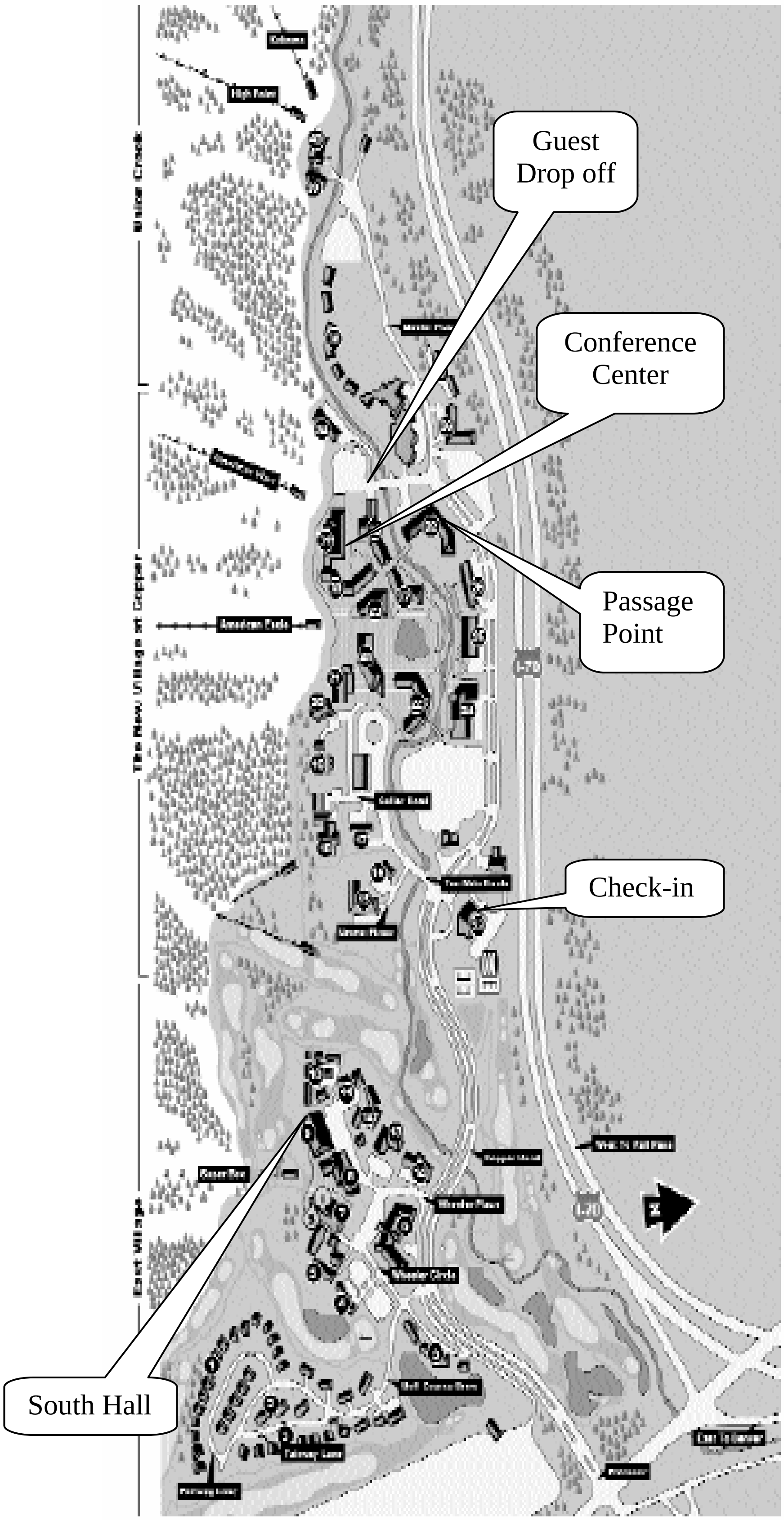
Copper provides free shuttle transportation within Resort.

Winter transportation consists of Express buses from the Alpine and Corn Parking lots to all three base areas and an intra-village system. Transportation runs 6:00 a.m. to 9:00 p.m. early season and then extends till 11:00 p.m. around Christmas until early April.

To arrange special group transportation please call 970-968-2318 x12202

Travel from Copper Mountain

Free bus shuttle service is available to Frisco, and then from there to anywhere in Summit County (Dillon, Silverthorne, Breckenridge, Keystone, etc.). The buses run from Passage Point in Copper about every 30 minutes. Their phone number is 970-668-0999.



EAST VILLAGE

1 The Masters at Copper Creek
2 The Legends at Copper Creek
3 The Woods at Copper Creek
4 The Greens at Copper Creek
5 Village Point
6 Copper Springs Lodge
7 Copper Station
8 Snowflake
9 Foxpine Inn
10 Elk Run
11 Wheeler House
12 Anaconda
13 Peregrine
14 Summit House East (Carbonate Real Estate)

THE VILLAGE AT COPPER

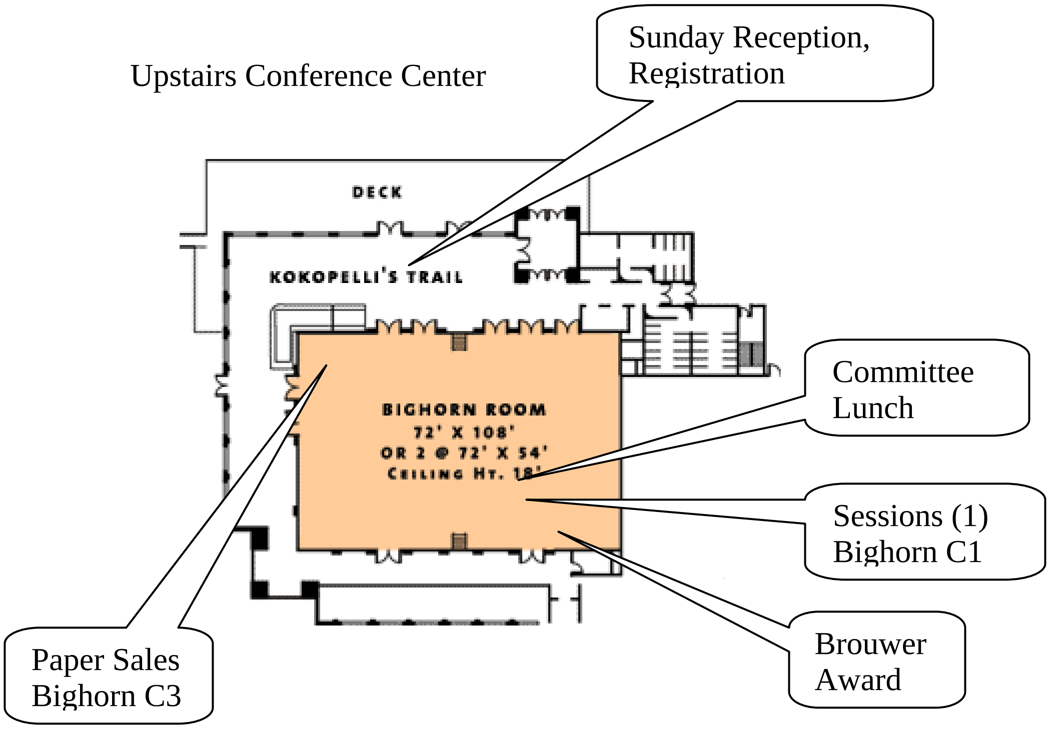
15 Copper Valley
16 Togwotee
17 Summit House
18 Timber Creek
19 Copper Mountain Inn
20 Spruce Lodge
21 Copper Junction
22 Village Square
23 Copper Mountain Racquet & Athletic Club/Lodging Check-in
24 Snowbridge Square
25 Westlake Lodge
26 Bridge End
27 Taylor's Crossing
28 Mountain Plaza
29 The Mill Club
30 Copper One Lodge
31 Copper Conference Center
32 Passage Point
33 Tucker Mountain Lodge
34 The Lodge at Copper
36 Telemark Lodge
37 Beeler Townhomes

UNION CREEK

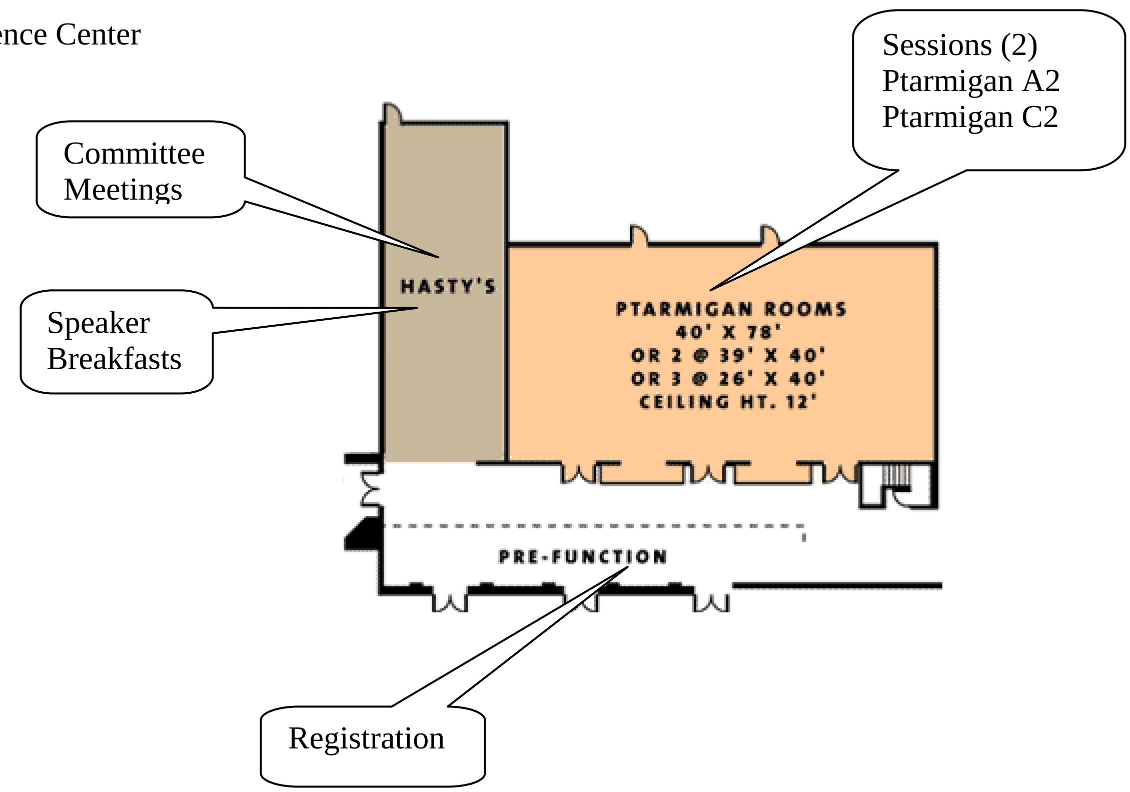
38 Townhomes at Trail's End
39 The Schoolhouse
40 Union Creek

Copper Conference Center

Upstairs Conference Center



Downstairs Conference Center



SPECIAL EVENTS

Liftside Cocktail Reception

All registered attendees and their guests are invited to the Liftside Cocktail Reception to be held lift front at the Kokopelli room in the Conference Center on Sunday evening from 6:00 PM to 8:00 PM. Join us for drinks and hors d'oeuvres and catch up with friends and colleagues.

Monday Brouwer Award Lecture

Attendees are encouraged to listen to this years winner, Dr Kathleen Howell from 7:45 PM to 9:15 PM. This presentation is always an opportunity to enjoy words of wisdom from one of our esteemed colleagues.

Tuesday Mountain Social

Attendees should plan on socializing at this evening event from 7:15 PM to 930 PM. Situated in the South Hall in the East Village, the change of location and excellent cuisine should offer ample time to mingle with fellow friends and colleagues. Special Buses will depart at 7:00 and 7:20 PM from the guest drop off area, just west of the conference center, but if you miss these, you can catch the regular Copper Mountain shuttles.

Additional tickets may be purchased at the registration desk at a discounted group rate. Children may also purchase reduced price tickets.

AREA ATTRACTIONS

SKIING!!!

Why ski Colorado? Summit County, Colorado offers the longest ski season in the Western U.S. Last season, Copper was open from November 1, 2003 to April 18, 2004. And Colorado is renowned for its sunny, blue-sky days along with some of the best powder in the world. Copper is Summit County's largest ski area with over 2,400 skiable acres, a vertical drop of 2,601 feet, and it averages 280" of snowfall during our ski season. The base elevation is 9,712 feet, and the summit is 12,313 feet.

TUBING HILL : Experience the thrills and spills of tubing at the Copper Mountain tubing hill. Great family fun after a spectacular day of skiing. Children must be taller than 40" to ride by themselves. Located on the Treble Cliff trail under the Super Bee chairlift in the East Village.

SNOWSHOEING : Enjoy the peaceful exhilaration of snowshoeing on all 25 kilometers of designated cross country ski trails. Snowshoe rentals are available at all Copper Mountain rental shops. How about a guided moonlight tour? It's a great way to explore the mountain in a different light.

SNOWMOBILE TOURS : Professionally guided snowmobile tours are available to take you on an unforgettable Rocky Mountain backcountry adventure.

SNOWCAT TOURS : These two-track machines, fully enclosed and heated, take 12 people touring near the town of Vail. Passengers are carried as high as 10,500 feet to sip hot chocolate in a rustic, 1930's cabin then visit the ghost town of Gilman as well as see the back bowls of Vail ski resort and the White River National Forest.

DOG SLEDDING : On the 1 hour 30 minute back country trip, you get to alternate with your friends between mushing the dogs and riding in the sleigh. A thrill at every level!

HORSEBACK RIDING : This winter horseback tour winds along the Blue River and foothill of our national forest. Dress warmly, the horses do!

WINTER VILLAGE ACTIVITIES

ICE SKATING : A classic winter activity that is truly fun for the whole family. Ice skating is free and skate rentals are available from 9600' retail store. Located on West Lake in the Center Village.

COPPER MOUNTAIN RACQUET AND ATHLETIC CLUB : Copper offers one of the premier full-service athletic clubs in the Rocky Mountains. The Center features an indoor pool, cardiovascular equipment and full weight room, indoor racquetball and tennis. The club also offers spas, steam rooms, saunas, massage services and facials. Club access is free to most lodging guests. Located on Copper Road in the Center Village.

DINNER SLEIGH RIDES : After a full day of skiing, enjoy one of Copper's horse-drawn sleigh rides. Sip winter warmers and then step into a sleigh for a 45-minute guided adventure through the woods. Arrive at our cozy miners tent where a delicious Old West meal will set your mouth watering, while the live
entertainment sets your toes tapping. Reservations are required.

LOCAL AREA ACTIVITIES

FACTORY OUTLET SHOPPING IN SILVERTHORNE: There are over 200 shops and 100 restaurants just a snowball's toss from Copper. The Prime Outlets at Silverthorne and the towns of Frisco, Vail and Breckenridge await you.

CASINO SHUTTLE: Try your luck gambling in Colorado's historic gaming districts of Blackhawk and Central City. Daily excursions depart from your lodging location.

COPPER AMBASSADORS
Look for our Ambassadors both on and off the mountain. They can assist you with everything from dining and ski school information, to the latest on trail and snow conditions.

COPPER TOURS
Discover Copper's hidden secrets, best trails and history with a free tour hosted by Copper Mountain Ambassadors. Tours are available at the Blue, Blue-Black, and Black levels of skiing ability. Reservations are recommended and can be made at the Information Booth off the top of the American Eagle lift before 3 p.m. on the day prior to the tour.
Where and When
Times: 10:30 a.m. and 1:30 p.m. daily
Duration: 1 1/2 to 2 hours

Restaurants on the Mountain:

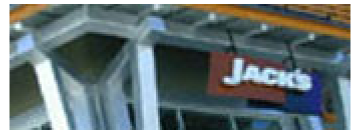
T-REX GRILL: The place to be on sunny days. The T-Rex, an outdoor grill, serves such specialties as brontosaurus burgers, Dino fries, snacks, beer and wine. In the spring, the afternoon deck parties are the best on the mountain. Located mid-mountain at the base of the Timberline Express.

SOLITUDE STATION: Enjoy breakfast or lunch with the best views on the mountain. Solitude offers panini sandwiches, homemade pizzas, fresh sandwiches, burgers, soups, chili, salads and delicious vegetarian fare. Located mid-mountain between the American Eagle and The Excelerator.

AMERICAN FLYER BBQ: Flyers offers a sundeck complete with outstanding vistas of the upper mountain and serves up sandwiches, snacks and drinks. Located at the top of the American Flyer lift.

Restaurants off the Mountain:

JACK'S SLOPESIDE GRILL



Energize your body with hearty soups or chili, gourmet pizzas, tortilla wraps, and fresh salads. On sunny days, enjoy a burger and brew on our slopeside deck. Open for breakfast, lunch and afternoon snacks. Located at the base of the American Eagle Lift. Open daily from 7:30am.

CAMP HALE COFFEE

Stop in for a quick bite between runs and enjoy bagel sandwiches, pastries and a cappuccino bar. Located on the first floor of Copper One in the Mountain Adventure Center at the base of the American Eagle. Open daily from 7:30am - 4pm.

IMPERIAL PALACE

Chinese cuisine specializing in Mandarin, Taiwanese and Szechwan dishes. All food is prepared with no MSG, low cholesterol and low sodium. Domestic beers are two for the price of one during happy hour, daily 2 – 5:30pm. Open daily for lunch and dinner. Located in the Village Square Plaza. Open daily from 11am – 10pm. (970) 968-6688.

SALSA MOUNTAIN CANTINA

Serving authentic Mexican cuisine. Enjoy homemade tamales, rellenos and South Western specialties, and even a kids section on our "south-of-the-boarder" menu. Kids eat free on Sunday nights, local's favorite bar, and non-smoking dining room. Open for lunch and dinner. Located in Snow Bridge Square. West of Chapel Lot. Open daily from 11:30am - 10pm (970) 968-6300.

CREEKSIDE

Features delicious pizza and uses only fresh ingredients and homemade dough. Creekside also offers salads, sandwiches, and a full bar. Open for lunch and dinner. Located in Snowbridge Square. Open daily from 11am – 9pm. Delivery available after 5pm. (970) 968-2033.

THE BLUE MOOSE

Located slopeside by the American Eagle Lift, serving every day from 11am - 11pm. New York style pizza, slices, great subs, salads and French fries. Order in, take out, or try our free delivery 4 -9 pm. Great deck and après with our $2 dollar deck - all items are only $2 dollars - slices, drafts, margaritas and shots. 968-9666.

ALEXANDER'S ON THE CREEK

Fine dining without the attitude. Open for après & dinner. Kids menu, wine list, and tempting desserts in an upscale atmosphere. Open daily. Reservations suggested 970-968-2165.

FRANK'S FRANKS

Frank and his outdoor hot dog stand have become a fixture here at Copper. Stop by any Saturday or Sunday from 11:00am to 3:00pm. In addition to enjoying an incredible dog or brat, you'll have lots of fun just meeting and hangin' with Frank.

PRAVDA

A Russian Vodka bar and dance club. Check out the great selection of Vodkas and dance the night away at Copper's first dance club.

SCOTT AND STEPH'S COLUMBINE CAFE

"Any time is a good time for breakfast" - Scott and Steph's will be serving breakfast all day and lunch too! This Cafe is located in the heart of our new Village by the covered bridge. Come check it out this winter.

BONJOUR BAKERY

The Bonjour Bakery is a European classic featuring fine coffees and teas, pastries and Artisan Breads, sandwiches and soups. Located in Passage Point in the Village at Copper. Open daily at 7:00am.

TECHNICAL PROGRAM

In keeping with Western and Ski traditions, attendees are reminded that Ski Attire is permissible at all conference functions!

Technical Sessions

- This conference presents about 125 papers on space flight mechanics and related topics in 24 sessions, of which four are special sessions described below. Three sessions run in parallel each morning and afternoon of the conference for three days.
- Morning sessions start at 7:00 AM and usually end by 10:00 AM.
- Afternoon sessions commence at 4:00 PM and usually conclude by 7:00 PM.
- The sessions break for 25 minutes each morning and afternoon. Refreshments are served in the pre-function area on the lower level of the Conference Center.
- The meeting rooms are on the lower and upper levels of the Conference Center.

Special Sessions

- There will be two sessions on the **Genesis** mission. One is Monday afternoon, and the other is Thursday morning.
- **Near Earth Objects and Lunar missions** will be examined on Tuesday morning.
- The **Open Astrodynamics** session will be held Wednesday afternoon in the Ptarmigan A2 Room.
- **Mars missions** will be discussed on Thursday morning.

Plenary Sessions

- Dr. Kathleen Howell, the 2004 Dirk Brouwer Award recipient, will give a lecture on Monday evening at 7:45 PM in the Bighorn C1 Room. The Brouwer Award was established to honor significant technical contributions to space flight mechanics and astrodynamics and to recognize Dirk Brouwer's outstanding role in celestial mechanics and his widespread influence on workers in space flight and astrodynamics. We will also present the Breakwell Student Travel Award and the Best Paper Award.

Presentations

- Each presentation is allocated 25 minutes total time, including questions and any preliminary setup. Session chairs will maintain this pace to assure that presentations proceed according to the posted schedule.
- Each room will be equipped with a computer and projector. Authors should contact their session chairs to get their presentations loaded if using the computer projection system.
- The NO PAPER NO PODIUM rule will be enforced. The session chairs will verify the delivery of a reproducible plus 50 copies for every presentation in their sessions by the end of the applicable Speakers Breakfast (see below). Lack of such timely delivery will constitute withdrawal of the paper.

Speakers Breakfast

Authors <u>who are making presentations</u> and session chairs of the day will meet in Hasty's Room for a short briefing at 6:30 AM on the morning of their session. A continental breakfast will be served.

Paper Sales

Authors are required to bring 50 copies of their paper to the conference. The preprints will be on sale for $1.00 per paper in the Bighorn C3 room adjacent to the meeting rooms. Bound copies of the conference proceedings may be ordered at the registration desk.

Committee Meetings

Committee meetings will be held according to the following schedule in the Hasty's:

AIAA Committee on Standards	Monday	8:00 – 9:00 PM
AIAA Astrodynamics TC	Monday	10:00 – 12:00 PM
AAS Space Flight Mechanics TC	Monday	1:30 – 3:30 PM

Reminder for Summer 2005 Meeting

2005 AAS/AIAA Astrodynamics Specialist Conference

August 7-11, 2005

Embassy Suites Hotel - Lake Tahoe Resort

ABSTRACT DEADLINE: March 4, 2005

For additional information, see www.space-flight.org

SCHEDULE OF EVENTS

Date/Time	Event	Location
Sunday, 23 January		
1600–1900	Registration	Kokopelli
1800–2000	Liftside Cocktail Reception	Kokopelli
2000–2100	AIAA COS Mtg	Hasty's
Monday, 24 January		
0630–0700	Speakers Breakfast	Hasty's
0700–1000	Registration	Lower Pre-function
0700–1000	Paper Sales	Bighorn C3
0700–1000	Formation Flying I	Bighorn C1
0700–1000	Attitude I	Ptarmigan A2
0700–1000	Interplanetary I	Ptarmigan C2
0815–0840	Morning Break	Lower Pre-function
1000–1130	AIAA Astrodynamics TC Mtg	Hasty's
1130–1300	AAS/AIAA Combined Lunch	Bighorn C1
1330–1530	AAS Space Flight Mechanics TC Mtg	Hasty's
1600–1900	Registration	Lower Pre-function
1600–1900	Paper Sales	Bighorn C3
1600–1900	Special Session Genesis I	Bighorn C1
1600–1900	Space Surveillance	Ptarmigan A2
1600–1900	Optimization I	Ptarmigan C2
1715–1740	Afternoon Break	Lower Pre-function
1945–2130	Brouwer Lecture	Bighorn C1
Tuesday, 25 January		
0630–0700	Speakers Breakfast	Hasty's
0700–1000	Registration	Lower Pre-function
0700–1000	Paper Sales	Bighorn C3
0700–1000	Orbit Determination	Bighorn C1
0700–1000	Special Session NEO and Lunar Missions	Ptarmigan A2
0700–1000	Constellations	Ptarmigan C2
0815–0840	Morning Break	Lower Pre-function
1600–1900	Registration	Lower Pre-function
1600–1900	Paper Sales	Bighorn C3
1600–1900	Formation Flying II	Bighorn C1
1600–1900	Identification and Controls	Ptarmigan A2
1600–1900	Propagation	Ptarmigan C2
1715–1740	Afternoon Break	Lower Pre-function
1915–2130	Social	South Hall

Wednesday, 26 January

0630–0700	Speakers Breakfast	Hasty’s
0700–1000	Registration	Lower Pre-function
0700–1000	Paper Sales	Bighorn C3
0700–1000	Interplanetary II	Bighorn C1
0700–1000	Optimization II	Ptarmigan A2
0700–1000	Orbit Mechanics	Ptarmigan C2
0815–0840	Morning Break	Lower Pre-function
1600–1900	Registration	Lower Pre-function
1600–1900	Paper Sales	Bighorn C3
1600–1900	Formation Flying III	Bighorn C1
1600–1900	Special Session	
	Astrodynamics – How can we better meet tomorrow’s requirements?	Ptarmigan A2
1600–1900	Tethers I	Ptarmigan C2
1715–1740	Afternoon Break	Lower Pre-function

Thursday, 27 January

0630–0700	Speakers Breakfast	Hasty’s
0700–0800	Registration	Lower Pre-function
0700–1100	Paper Sales	Bighorn C3
0700–0905	Rendezvous and Relative Motion	Bighorn C1
0700–0905	Special Session	
	Mars Missions	Ptarmigan A2
0700–0905	3-Body	Ptarmigan C2
0905–0930	Morning Break	Lower Pre-function
0930–1100	Special Session	
	Genesis II	Bighorn C1
0930–1100	Tethers II	Ptarmigan A2
0930–1100	Attitude II	Ptarmigan C2

Session 1: Formation Flying I
Chair: Hanspeter Schaub
Virginia Polytechnic Institute

07:00 **AAS 05 - 100** **A Practical Method of Relative Satellite Navigation for Close Proximity Missions**

Frank R. Chavez and T. Alan Lovell, Air Force Research Laboratory

A practical approach to relative satellite navigation is taken by investigating estimation of a state variable set that is more geometric in nature than the standard position and velocity component state vector. Relative ranging data are processed through both a recursive least-squares technique and a Kalman filter, both designed to yield state estimates that describe the shape of the relative orbit trajectories. Results obtained by both methods are compared, and the duty cycle of the filter is varied in order to uncover the effect on the overall estimation problem.

07:25 **AAS 05 - 104** **Static Equilibrium Configurations In Coulomb Spacecraft Formations**

John Berryman and Hanspeter Schaub, Virginia Tech University

Coulomb control of spacecraft formations benefits include minimal power usage, virtual lack of propellant, and low mass. Before this method of formation control is mission-worthy, the dynamics that govern the motion of charged spacecraft must be better understood. The purpose of this research is to use evolutionary strategies to numerically search for steady-state equilibriums in which the sum of the forces on each satellite is zero, essentially freezing the satellite formation with respect to the rotating Hill frame. Difficulties encountered will be discussed as well as methods to circumnavigate these difficulties.

07:50 **AAS 05 - 101** **Optimal Bounded Low-Thrust Reconfiguration for Close Proximity Earth Orbiting Satellites**

Christopher J. Scott and David B. Spencer, The Pennsylvania State University

The goal of this paper is to compute and analyze the optimal reconfiguration of an n-spacecraft formation where the distances are small compared to the radius of the reference orbit. An optimal low-thrust continuous transfer scheme with no upper or lower bounds on thrust acceleration is chosen to simplify the analysis. Trends and concepts of a single transfer are examined with the goal of extending this information to a full reconfiguration. In this analysis, effects of relative phasing, position within the absolute orbit, and transfer time are related to a chosen performance index. The constrained n-satellite reassignment problem proves to be a three fold optimization that can not be solved analytically. Therefore, an evolutionary strategy is applied to solve for the costates and reconfiguration parameters.

08:15 **Break**

08:40 **AAS 05 - 102** **Application of a Relative Motion Guidance Algorithm to Formation Flying and Rendezvous Problems**

Johnathan F. Berryman, Virginia Polytechnic Institute, T. Alan Lovell, Air Force Research Laboratory, and Mark V. Tollefson, Dynacs Military & Defense, Inc.

In this paper a previously developed impulse maneuver algorithm for relative motion trajectory guidance is applied to two different problems of interest. The first is a formation flying application involving reconfiguration of a satellite cluster when one or more members of the cluster fails. The second problem involves planning a circumnavigation of one satellite about another following rendezvous/acquisition of the satellite. For both problems, the main objective is to determine the most fuel efficient trajectories that will satisfy given requirements, and to observe aspects of these trajectories.

09:05 **AAS 05 - 103** **Optimal Configuration Of Spacecraft Formations Via A Gauss Pseudospectral Method**

Geoffrey Huntington and Anil V. Rao, Charles Stark Draper Laboratory

The problem of minimum-fuel formation reconfiguration for the Magnetospheric Multi- Scale (MMS) mission is studied. This reconfiguration trajectory optimization problem can be posed as a nonlinear optimal control problem. In this research, this optimal control problem is solved using a spectral collocation method called the Gauss pseudospectral method. The objective of this research is to provide highly accurate minimum-fuel solutions to the MMS formation reconfiguration problem and to gain insight into the underlying structure of fuel-optimal trajectories.

Session 2: Attitude I
Chair: Mark Pittelkau
Swales Aerospace

07:00 **AAS 05 - 108** **Characteristics of High Frequency Attitude Motion of ICESat**

SungPil Yoon, Sungkoo Bae, and Bob E. Schutz, The University of Texas at Austin Center for Space Research

The Ice, Cloud and land Elevation Satellite (ICESat) was launched January 23, 2003 into a near circular sun-synchronous orbit with 94° inclination and 590 km altitude. The primary goal of ICESat is to measure long-term changes in the volumes of the Greenland and Antarctic ice sheets through the Geoscience Laser Altimeter System (GLAS), which is the primary and only instrument onboard ICESat. Solar-array is continuously articulating to provide the power necessary to run spacecraft bus and instrument electronics. It was observed that ICESat attitude motion contains high frequency components near 1 Hz and 3 Hz. This high frequency component is believed to be induced by solar-array articulation. This paper discusses the characteristics of these high frequency components of ICESat attitude motion.

07:25 **AAS 05 – 105** **Observability and Calibration of a Redundant Inertial Measurement Unit (RIMU)**

Mark E. Pittelkau, Swales Aerospace

A calibration model for a redundant inertial measurement unit (RIMU) comprises a bias, a symmetric and an asymmetric scale factor, and two misalignment angles for each of n sense axes ($n > 3$) for a total of 5n parameters. A linear combination of these parameters is observable through the attitude kinematics model and attitude measurements; an orthogonal linear combination is observable through null space angular rate measurements. Transformations are derived to separate the 5n calibration parameters into two independent reduced-order parameter sets, from which the observability of the parameters is characterized. These parameters can be estimated by a pair of cascaded or decoupled Kalman filters. Sensitivity matrices needed to construct these filters are derived.

07:50 **AAS 05 – 106** **Autonomous Generation of Guidance Profiles for Constrained, Minimum-Time, Large-Angle Attitude Manoeuvres**

Jean de Lafontaine, NGC Aerospace Ltd and Catherine LePeuvédic, Alcatel Space

In many space missions, there is often a requirement to re-orient a spacecraft from a given attitude to another. This paper presents analytical guidance algorithms that generate the commanded attitude profile (quaternion, angular velocity, angular acceleration) between specified initial and final states, under various constraints: minimum time, minimum torque, minimum angular momentum, no excitation of structural flexible modes and compatibility with an on-board implementation. Such guidance laws are convenient since a linear attitude controller can be fed with small errors between the current and the commanded profile, instead of large attitude errors between the initial and final states. The basic acceleration profiles are generated to form a constant-jerk profile to which are superimposed so-called 1-cos profiles to avoid excitation of flexible modes. Two categories of manoeuvres are analysed: (1) those for which the manoeuvre duration is fixed and the maximum torque and/or the maximum variation of angular momentum is minimised and (2) those for which the manoeuvre duration is minimised and the maximum variation of angular momentum and/or maximum torque are below saturation levels. The equations and algorithms are presented and numerical simulations of the attitude dynamics show their accuracy.

08:15 **Break**

08:40 **AAS 05 – 107** **Ground Based Satellite Attitude Estimator**

Narendra Gollu, Concordia University, and Yuri Kim, Canadian Space Agency

Future space missions call for unprecedented levels of accuracy, reliability and high performance, there by increasing the demands on attitude determination and control system. In this paper, we address the problem of attitude accuracy by developing a GROUND BASED ATTITUDE ESTIMATOR for evaluating the attitude accuracy and to evaluate the novel attitude determination algorithms. The ground based attitude estimator is formulated based on modified Kalman filter, where it is considered that there is a correlation between the process noise and measured noise. In this paper we assume that there is a correlation between the process and measured noise. The efficiency of this ground based attitude estimator will be demonstrated by using the telemetry obtained from the SCISAT-1 satellite.

Session 3: Interplanetary I
Chair: Dennis Byrnes
Jet Propulsion Laboratory

07:00 **AAS 05 - 111** **Low Energy Interplanetary Transfers Using Halo Orbit Hopping Method with STK/Astrogator**

Tapan R. Kulkarni and Daniele Mortari, Texas A&M University

The principal objective of this investigation has been to find low energy interplanetary transfers from Earth to distant planets. This has been accomplished by the methods of halo orbit insertion at Sun-Planet L2 Lagrangian point. This method provides two simultaneous advantages coupled to the low energy interplanetary transfer trajectories, namely, maintaining a seamless radio contact with Earth and extensive exploration of the planets simultaneously. This method has been found to be 35% more fuel efficient than the conventional gravity assisted trajectory method but approximately 5 times slower. The mission has been conceived in STK/Astrogator 5.0.

07:25 **AAS 05 - 110** **Exploration of Distant Retrograde Orbits around Europa**

Try Lam, Jet Propulsion Laboratory

The applications of Distant Retrograde Orbits (DROs) are explored around Europa. Such orbits are of particular interest due to proposed missions such as the NASA Jupiter Icy Moon Orbiter (JIMO). Dynamically, Europa proves to be very interesting; at low altitudes Europa's harmonics cause drifts in eccentricity (among other orbital elements), which eventually leads to collision with the surface. At higher altitudes third body perturbation from Jupiter dominates which may lead to collision or escape after a few revolutions. Regardless, preliminary investigation has found DROs to be ideal quarantine orbits due to their long-term stability and savings in propellant and time in transferring to a DRO, in comparison to escaping the Jovian system or impacting Jupiter. Key characteristics of DROs that are investigated are their dynamics.

07:50 **AAS 05 - 112** **Venus and Mars Gravity Assist Trajectories to Jupiter Using Nuclear Electric Propulsion**

Daniel W. Parcher and Jon A. Sims, Jet Propulsion Laboratory

Optimal low-thrust gravity-assist trajectories to Jupiter using nuclear electric propulsion are presented. Venus, double Venus, and Mars gravity assist cases are examined. For each of these cases two local optima, differentiated by number of heliocentric revolutions, are considered. The solutions that use fewer heliocentric revolutions perform better at short flight times, but do not perform as well at long flight times. Of the gravity assist types examined, the Mars gravity assist offers the most delivered mass to Jupiter for most flight times.

08:15 **Break**

08:40 **AAS 05 - 113** **Orbit Determination Results for the Cassini Titan-A Flyby**

Ian M. Roundhill, Peter G. Antreasian, Kevin E. Criddle, Rodica Ionasescu, M. Cameron Meek, and Jason R. Stauch, Jet Propulsion Laboratory

The Cassini spacecraft entered Saturnian orbit on July 1, 2004 after nearly 7 years of interplanetary cruise. After 4 months in this orbit, the next target for Cassini was a Titan flyby on October 26, 2004 with a planned altitude of 1200 km. To ensure a successful flyby, the Navigation team needed to adjust and optimize the orbit determination process. This task includes modeling the spacecraft, satellite, and Saturnian dynamics and the radiometric and optical measurements. The optical measurements are the result of pictures of the satellites taken by the narrow angle camera onboard Cassini. This paper will discuss the results and performance of the orbit determination processes for the Titan-A encounter navigation.

09:05 **AAS 05 - 114** **Thrust Vector Control of the Jupiter Icy Moons Orbiter Spacecraft**

Marco B. Quadrelli, Edward Mettler, Jerry K. Langmaier, and Konstantin Gromov, Jet Propulsion Laboratory

In NASA's proposed Jupiter Icy Moons Orbiter mission's baseline spacecraft, attitude and orbital dynamics interactions are present due to the designed low-thrust trajectory. In order to investigate this coupling, which originates due to the thrust vectoring control, sensitivity analyses and simulation studies were carried out using complex orbital and attitude dynamics models describing the vehicle's dynamics arising during the low-thrust spiraling maneuvers of the spacecraft. The results of these studies point out that a new approach is needed to integrate the trajectory design and the attitude control.

09:30 **AAS 05 - 115** **A Novel Approach to Planetary Precision Landing Using Parafoils**

Marco B. Quadrelli, Jet Propulsion Laboratory

In this paper, we address the problem of how to achieve precision landing, in an autonomous manner, through an actively controlled parafoil. By precision landing we mean the capability of steering the vehicle to a pre-specified target area on the ground. The mechanization to achieve this maneuverability is provided by a parafoil, i.e. a high glide parachute characterized by airfoil type canopy cross-sections and wing type plan forms, which can actively be steered to control the trajectory. The preliminary results obtained so far indicate that precision control of these types of vehicles can be achieved provided enough control authority, and enough knowledge of the atmospheric parameters (density, wind magnitude and direction) are available.

Session 4: Genesis I
Chair: L. Alberto Cangahuala
Jet Propulsion Laboratory

16:00 **AAS 05 - 116** **Genesis Earth Return: Refined Strategy and Flight Experience**

Kenneth Wiliams, Roby S. Wilson, Clifford E. Helfrich, Christopher L. Potts, Jet Propulsion Laboratory

As part of NASA's Discovery Program, GENESIS is the first NASA mission since the Apollo Program to return samples collected in deep space. Launched in August 2001, GENESIS collected solar wind constituents near the Earth-Sun L1 point over a period of about 29 months through March 2004 with an additional five months required subsequently for Earth return. The original strategy for Earth approach was revised to maximize the safety of people and property on the ground in light of possible anomalies and contingencies, while preserving the capability to meet nominal entry requirements. A series of Earth approach maneuvers were performed.

16:25 **AAS 05 - 117** **Genesis Orbit Determination for Earth Return and Atmospheric Entry**

Dongsuk Han, George Lewis, Geoffrey Wawrzyniak, Eric Graat, Diane Craig, Darren Baird, Shyamkumar Bhaskaran, Jet Propulsion Laboratory

After collecting solar wind samples for more than two years while orbiting the Sun-Earth Libration point, the Genesis spacecraft released its Sample Return Capsule (SRC) containing the science samples on September 8, 2004. The final location of the landed SRC, which is well within the allowed recovery area in the Utah Test and Training Range, shows that the operation of the Genesis spacecraft, including the navigation, leading up to the SRC's atmospheric entry, was successful and accurate. This paper describes Genesis orbit determination activities during the final approach and atmospheric entry phase, covering from the spin calibration to the SRC release, in more detail.

16:50 **AAS 05 - 118** **Doppler Aided Attitude Determination for Spin Stabilized Spacecraft**

Dongsuk Han, Tim McElrath, Jet Propulsion Laboratory, Dale K. Howell and Christopher Voth, Lockheed Martin Astronautics Operations

Spinning spacecraft with offset antennae present problems for Doppler-based orbit determination due to the presence of the spin signature in the tracking data. If not removed, the spin signature can alias into spacecraft state estimation or (if deweighted) increase the state covariance, as well as masking data signatures that are important, but much smaller than the spin signature. Removing the spin signature cures these problems, as well as helping attitude determination by finding the spin axis pointing direction. This paper describes the theory of spin signature removal and the results obtained during the Genesis and Contour missions, during which spin axis pointing measurement errors of 1 degree or less were achieved.

17:15 **Break**

17:40 **AAS 05 - 120** **Genesis Earth Return Propulsion System and Mass Properties Modeling**

J. Greg McAllister, LMA Propulsion

The Genesis spacecraft was designed to spend 26 months collecting solar wind samples and return these samples to the Earth on September 8, 2004. The spacecraft was required to be precisely navigated and controlled to place the sample and return capsule (SRC) on a desired trajectory to re-enter the Earth's atmosphere. This was designed to be accomplished through "Open-loop" propulsion burns where-by all manuevers were executed without accelerometers to cut-off the burns when the desired change in velocity had occurred. This required precise modeling of both the propulsion system performance and knowledge of the spacecraft mass properties (Inertia, principle axis of rotation). This paper will outline the successful pre-launch analysis tool design and the in- flight "tuning" required to maintain the models.

18:05 **AAS 05 - 121** **Entry, Descent, and Landing Operations Analysis for the Genesis Re-Entry Capsule**

Prasun Desai, NASA Langley Research Center and Dan Lyons, Jet Propulsion Laboratory

The Genesis capsule re-entered Earth on September 8, 2004 after spending three years collecting solar wind particles. Four hours prior to Earth entry, the Genesis SRC was spun-up and separated from the main spacecraft. The spin-up maintains the entry attitude during coast until atmospheric interface. Throughout the atmospheric entry, the passive sample return capsule relied solely on aerodynamic stability for performing a controlled descent through all aerodynamic flight regimes. This paper describes the high-fidelity six-degree-of-freedom simulation that was developed to substantiate the robustness of the Genesis entry, descent, and landing to assure all entry mission requirements were satisfied.

Session 5: Space Surveillance
Chair: John Seago
Honeywell TSI

16:00 **AAS 05 - 122** **Effectsof Orbital Uncertainty on Handover and Breakup Processing**

Thomas J. Eller, Kenneth D. Kople, MarkW. Sousa, Omitron, Inc., Richard L. Hollm, ESC/NDW, Stephen Six, MITRE, Inc., Timothy McLaughlin, Northrop Grumman

Breakups, handovers, UCTs, and detecting small space objects have in common marginal viewing conditions, sparse data, uncertain ELSET quality, older ELSET age, etc. This study illustrates that under these conditions, the time scale for successful space surveillance operations is much shorter than is commonly believed. Computations, tasking, messaging, and analysis must take place in minutes to hours if objects are to be cataloged and repeatedly viewable. Otherwise, the uncertainty box may extend for thousands of kilometers and tens of minutes, making searching for the object a costly event with little likelihood of success.

16:25 **AAS 05 - 123** **Comparison of Collision Risk from COLA and Kinetic Gas Theory for Sun-Synchronous Orbits**

Glenn E. Peterson, The Aerospace Corporation

Near polar orbits in LEO, such as sun-synchronous orbits, are heavily utilized. This paper examines the average risk that satellites in such orbits can expect to face over a 10-year mission. This risk is computed from both simulated collision avoidance (COLA) runs based on historical data and through the kinetic gas theory. The results are compared and it is found that the average risk as found by COLA runs can be up to 3 times larger than the kinetic gas theory and can be larger for a 4-meter (wingtip-to-wingtip) satellite at LEO than a 40-m satellite at GEO.

16:50 **AAS 05 - 124** **Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space (SOCRATES)**

T.S. Kelso and Salvatore Alfano, Analytical Graphics Inc, Center for Space Standards & Innovation

As a service to the satellite operator community, the Center for Space Standards & Innovation (CSSI) offers SOCRATES—Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space. CSSI runs a list of all satellite payloads on orbit against a list of all objects on orbit using the catalog of all unclassified NORAD two-line element sets (TLEs) to look for satellite conjunctions. The runs are made using STK/AdvCAT and the NORAD SGP4 propagator. This paper will discuss how SOCRATES works and how it can help satellite operators avoid undesired close approaches through advanced mission planning.

17:15 **Break**

17:40 **AAS 05 - 125** **Cataloging with an Upgraded Space Surveillance Fence**

Felix R. Hoots, Geoffrey S. Pierce, and Lester Ford, AT&T Government Solutions, and Hugh Hadley, Syracuse Research Corporation

Air Force Space Command maintains a catalog of over 12,000 satellites. More than 275,000 observations are processed daily to determine updated element sets for all satellites. More than half of the total observations are contributed by one resource, theSpace Surveillance Fence. Currently the Government is considering a replacement of the fence operating at S band. The higher frequency will detect many more objects and require specialized new algorithms for cataloging. We have developed a simulation of the fence and used it to demonstrate the capabilities of the fence and the algorithms to create a catalog of newly detected satellites using only the upgraded fence.

18:05 AAS 05 - 126 The Validation of SimFence -A Simulation of the Air Force Space Surveillance System

Keith Akins, Shannon Coffey, Bernie Kelm and Michael Zedd, Naval Research Laboratory, Byron Summers, Anteon Corporation, Felix Hoots, Timothy Cox, Geoff Pierce, AT&T Government Solutions, Hugh Hadley, Syracuse Research Corporation.

This paper presents results on the validation of a simulation, SimFence, of the Air Force Space Surveillance System (AFSSS). SimFence simulates observations of the AFSSS VHF radars and the processing of the observations into orbit updates. It is based on comparisons of simulated observations to actual observations for 11 Satellite Laser Ranging Satellites. The observations are constructed from either of two radar sensor models. Our paper outlines the validation procedures and demonstrates that SimFence produces observations very nearly the same as the real system. SimFence's subsequent processing of the simulated observations into orbit updates closely duplicates the real updates that are performed at Dahlgren, VA.

18:30 AAS 05 - 127 Error Variance of Space Surveillance Sensors

John H. Seago and Mark A. Davis, Honeywell Technology Solutions, Inc., and Walter Reed Smith IV, Naval Research Laboratory

Forecasts of error bias and error standard deviation, based on sample estimates, are customarily used as inputs for weighted special-perturbations orbit determination. However, the textbook estimator of standard deviation is not robust to the presence ofoutliers. As the practice of outlier rejection may contribute measurably to the optimism of satellite-state covariance, the authors discuss several issues surrounding the estimation of weights for space-surveillance data. This summary concludes, among other things, that alternative estimators of sensor-error variance may yield less-biased estimates of sensor uncertainty as compared to the most common operational practices involving outright outlier rejection. Ample reference is made to supporting literature in the statistical sciences.

Session 6: Optimization I
Chair: Don Mackison
University of Colorado

16:00 **AAS 05 - 129** **A Robust Algorithm for Solving Unconstrained Two-Point Boundary Value Problems**

C. F. Minter and T. J. Fuller-Rowell, University of Colorado

The difficulty of solving two-point boundary value problems by indirect numerical techniques comes from their often nonlinear, coupled formulation and the inability to specify the initial adjoint variables accurately enough to ensure convergence. This method proposes first solving a simplified analytic version of the problem for initialization where some terms are set to 0. The 0 terms are then augmented stepwise, and each step is solved using a single shooting method. Single shooting is sufficient since the adjoint variables at each step always lies in the valley of the solution for the next step, resulting in a robust, simple algorithm.

16:25 **AAS 05 - 130** **A Shape Based Approach to Spacecraft Trajectories: Analysis and Optimization**

Prashant Patel, Daniel Scheeres, and Thomas Zurbuchen, The University of Michigan

Traditional spacecraft trajectory optimization approaches attempt to find a thrust profile that produces an optimal trajectory. This usually involves solving a multidimensional two point boundary value problem (2PBVP) defined by optimal control theory or solving a non-linear programming problem (NLP). Both of these methods attempt to find the optimal thrust and the resulting optimal trajectory that minimizes the cost function. Our shape based method assumes a path then solves for the optimal acceleration to maintain the path. This approach differs from traditional trajectory optimization in that the path is assumed and only the rate at which the path is traversed needs to be optimized. This involves solving a single 2PBVP which can be done with very little computational cost.

16:50 **AAS 05 - 133** **Kinematics of N-Dimensional Principal Rotations**

Andrew J. Sinclair, John E. Hurtado, and John L. Junkins, Texas A&M University

Whereas N-dimensional orientations and principal rotations have been described, this work has not been extended to N-dimensional kinematics. This paper develops the kinematics for N-dimensional rotations in terms of the principal planes and angles. The components of the angular velocity lying in the principal planes are the principal-angle derivatives and the out-of-plane components are related to the derivative of the principal planes. Additionally, the kinematic optimal control problem for N-dimensional reorientation is solved while minimizing a quadratic function of the angular velocity. The optimal angular velocity is a constant-rate rotation in each principal plane relating the initial and final orientations.

17:15 **Break**

17:40 **AAS 05 - 132** **Incorporating Observability Into Trajectory Optimization**

Scott Zimmer, Cesar Ocampo, and Robert Bishop, The University of Texas at Austin

A method of determining trajectories that optimize a combination of fuel consumption and observability is presented. It is shown that trajectories requiring little more propellant than the mass optimal trajectory can significantly reduce the trace of the spacecraft covariance. Example problems show this technique can reduce a trajectory's covariance by over ten percent with less than a one percent increase in the integral of the thrust acceleration. Although the example problems all involve transfers from low Earth orbit to geostationary Earth orbit, the technique is general and can be applied to a transfer between any initial and final states.

18:05 **AAS 05 - 128** **A Comparison of Differentiation and Integration Based Direct Transcription Methods**

Paul Williams, RMIT University

Direct transcription methods differ fundamentally in the way the state equations are approximated. All methods that are currently used may be classified as either integration methods or differentiation methods. Integration methods rely on integrating polynomial approximations of the vector field, whereas differentiation methods rely on differentiating polynomial approximations to approximate the tangent bundle. In some instances, differentiation methods rely on both the vector field and tangent bundle to form approximations of the state equations. All of these methods result in considerably different nonlinear programming problems with different sparsity patterns and primal-dual approximations of the optimal control problem.

18:30 **AAS 05 - 131** **Hermite-Legendre-Gauss-Lobatto Direct Transcription Methods in Trajectory Optimization**

Paul Williams, RMIT University

Among the popular methods for trajectory optimization are the Hermite-Simpson and Legendre pseudospectral methods. In this paper, a framework is developed for implementing arbitrary higher order direct methods that belong in the class of Hermite-Simpson methods. This class has been termed Hermite-Legendre-Gauss-Lobatto. In these methods, a Hermite interpolating polynomial is used to construct approximations to the state trajectories using a set of Legendre-Gauss-Lobatto (LGL) points. The state equations are enforced at an additional set of collocation points, belonging to a different set of LGL points. It is shown that the Lagrange multipliers obtained from the NLP do not suffer from defects at the boundaries, as in the standard Legendre pseudospectral method, and hence the multipliers provide excellent costate information.

Session 7: Orbit Determination
Chair: Paul Cefola
Massachusetts Institute of Technology

07:00 **AAS 05 - 134** **Geosynchronous Orbit Determination Using Space Surveillance Network Observations and Improved Radiative Force Modeling - Real Data Kalman Filter Resul**

Zachary J. Folcik, Richard H. Lyon, and Paul J. Cefola, MIT/ Lincoln Laboratory

This paper is an extension of two previous AAS papers: AAS 03-523 and AAS 04-269. It is also an extension of Richard Lyon's MIT SM Thesis completed in May 2004. Correct modeling of the space environment, including radiative forces, is an important aspect of orbit determination for geostationary (GEO) spacecraft. Solar radiation pressure has traditionally been modeled using a rotationally-invariant sphere with uniform optical properties. This study is intended to improve orbit determination accuracy for 3-axis stabilized GEO spacecraft via an improved radiative force model. The paper will report on the work completed in this study since February 2004, with a focus on real data results. The real data tests utilize observation data including NOAA owner/operator range measurements and HANDS optical measurements for the TDRSS test case. The testing also highlights implementations of various observations corrections, including ionospheric and tropospheric refraction corrections, light-time corrections, and measurement biases. Additionally, the improved radiative force models have been implemented in the Extended Semi-analytical Kalman Filter (ESKF) in GTDS, and results of real data testing using the ESKF are presented. The results of this paper give a better understanding of the process of determining precise orbits for GEO spacecraft with the box-wing model.

07:25 **AAS 05 - 135** **Geosynchronous Orbit Determination Using High Accuracy Angular Observations**

Benjamin Visser, U.S. Air Force Academy, Chris Sabol, Air Force Research Laboratory, and Scott R. Dahlke, U.S. Air Force Academy

As part of the High Accuracy Network Determination System (HANDS), the Raven-class telescopes were built to provide observations with less than an arcsecond of error. The challenge is being able to fully utilize that data to produce deep-space orbits with great certainty. This paper presents findings which will help HANDS users know the limitations of the current angles-only observation sets and help direct research and development towards the areas which, when fully understood, will result in the greatest improvements in orbital accuracy. This research was accomplished by analyzing a geosynchronous satellite (TDRS-5) and a decommissioned supersynchronous defense satellite (DSCS-3/A1).

07:50 **AAS 05 - 136** **Orbit Determination During High Thrust and Low Thrust Maneuvers**

Richard S. Hujsak, Analytical Graphics, Inc.

This analysis is motivated by the recent launch of ANIK-F2, which employed a combination of thrusting methods to raise perigee and then circularize in geosynchronous orbit. A series of bipropellant motor firings across multiple apogee passes were used to raise perigee and change inclination. The result was a zero inclination, eccentric orbit with a period of one orbit per day. The orbit was then circularized by employing a low thrust Xenon Ion Propulsion System (XIPS) continually over the next month. The ANIK-F2 mission poses an interesting orbit determination challenge, and is a harbinger of future missions.

08:15 **Break**

08:40 **AAS 05 - 137** **Using HANDS to Augment AFSCN Tracking**

Megan Quick, Case Western Reserve University, and Michael Gabor, Center for Research Support

This study analyzed whether the Air Force Satellite Control Network (AFSCN) should consider augmenting the tracking capabilities with high accuracy optical tracking. The Maui Space Surveillance Site and the RAVEN telescopes provide high accuracy angles data that could potentially benefit AFSCN users. The AFSCN's need for augmentation, optical tracking technology's capabilities and potential benefit to the AFSCN, and options for implementation are explored. Potentially, if the customer base increases in the future, some of the AFSCN assets could be negatively affected. As HANDS' abilities improve in the future, more AFSCN missions could take advantage of the tracking data.

09:05 **AAS 05 - 138** **ICESat Precision Orbit Determination over Solar Storm Period**

Hyung-Jin Rim, Sungpil Yoon, Yuchan Kim, and Bob E. Schutz, The University of Texas at Austin Center for Space Research

Over the last solar storm period, the ICESat GPS receiver reset frequently resulting in many data gaps. This affected unfavorably to ICESat Precision Orbit Determination (POD). Also, there were no SLR data collected for ICESat during this period, and this made POD accuracy assessment difficult. Over the same period, GPS receivers on GRACE satellites performed nominally, and there were sufficient SLR tracking data for GRACE satellites to evaluate GRACE orbit accuracy. By processing GRACE GPS data, performance of drag related models was evaluated on GRACE POD. Model drag accelerations were compared with the accelerometer data to assess the performance of each model. Also, by creating fictitious data gaps in GRACE GPS data, resembling ICESat GPS receiver's behavior, the effect of the data gap on GRACE POD was modeled.

09:30 **AAS 05 - 139** **Low Earth Orbit Prediction Accuracy Using Optical Data**

David Wiese and Chris Sabol, Air Force Maui and Optical Supercomputing Air Force Research Laboratory

This paper explores two methods of accuracy assessment of low Earth orbit predictions using high accuracy angular observations from ground-based telescopes. An analytical model was developed that performs well in determining the along-track orbit error, but can not observe cross-track errors to acceptable levels for moderate to low elevation passes. Therefore an estimation-based method was developed to provide accurate accuracy assessment over the course of the observation period. In addition to detailed error analysis, the validity of the two methodologies was gauged by comparing the updated satellite position to a "truth" satellite position derived from satellite laser ranging data.

Session 8: NEO and Lunar Missions
Chair: Rao Vadali
Texas A&M University

07:00 **AAS 05 - 142** **Analysis and Identification of Three Asteroid (NEO) Rendezvous Missions**
Scott Mitchell, Ball Aerospace and Technologies Corporation
Described in this paper is a method to identify missions to rendezvous with multiple asteroids with reasonable velocity change (delta-v) requirements. Modern Solar Electric Propulsion (SEP) systems can provide several km/s of delta-v; the Dawn mission has the capability of up to 11 km/s. Systematic analysis is described and used to identify and develop timelines for several three asteroid missions.

07:25 **AAS 05 - 143** **Trajectory Design for a Lunar Mission to Map, and Return Samples from, the South Pole**
David Dunham and Daniel P. Muhonen, The Johns Hopkins University Applied Physics Laboratory
Samples returned from the lunar far-side South Pole-Aitken (SPA) Basin would be valuable for Solar System origins studies. Trajectories are described that could map the SPA Basin for selecting a good site for landing, followed by an ascent and return of samples from the site to the Earth. The paper describes the transfer trajectories from Earth to the Moon, the polar lunar mapping orbit, a larger equatorial orbit for two small comsats to provide communications for far side operations, the lunar landing, the ascent from the Moon, and the return of the samples to the Earth.

07:50 **AAS 05 - 144** **Landing Uncontrolled Probes on Airless Bodies**
Jeffrey Van Cleve and Scott Mitchell, Ball Aerospace and Technologies Corporation
Described in this paper is a method to place uncontrolled packages on the surface of an airless body such as the moon with tolerable impact loads. The main advantage of this concept is that the lander does not require a control system, which will reduce cost and mass significantly. The method uses careful trajectory control and a solid rocket can cause the lander to drop to the surface from less than a few hundred meters altitude. The impact loads will be attenuated by the deformation of a combination of both the natural surface and the lander itself.

08:15 **Break**

08:40 **AAS 05 - 145** **Laboratory Demonstration of Fuel Optimal, Hazard Avoidance Techniques for Autonomous Planetary Landing**
Jean de Lafontaine, Karina Lebel, David Neveu, Charles-Étienne Lemay, NGC Aerospace Ltd, and Charles-Antoine Brunet, Université de Sherbrooke
Future planetary exploration missions will aim at landing a spacecraft in hazardous regions of a planet, thereby requiring an ability to autonomously avoid surface obstacles and land at a safe site. Landing site safety is defined in terms of the local topography: slope relative to gravity and surface roughness. Inspired by earlier publications on the subject, the authors have developed in a recent paper the so-called topographic cost maps and fuel cost maps that allow the autonomous determination of the best landing site from safety and fuel consumption points of view. This paper presents the implementation of these algorithms in a laboratory environment which is then used to demonstrate the performance of the algorithms using real LIDAR data.

09:05 **AAS 05 - 146** **Augmentations to the Polyhedral Gravity Model to Facilitate Small Body Navigation**

L. Alberto Cangahuala, Jet Propulsion Laboratory

One of the challenges with using a polyhedral gravity field is to minimize the computation time penalty for more detailed shape models, especially when the scale of the detail is on the order of the spacecraft dimensions. A second challenge is to modify the surface relief modeling around potential landing areas to facilitate compiling meaningful landing or contact statistics. This paper describes variants of the polyhedral model and their relative performance. One variant is to use polyhedra that include quadrilateral faces. Another variant set involves approximations to the more computationally intensive terms or disproportionately detailed terms in the acceleration and partial calculations.

09:30 **AAS 05 - 147** **Strategies for Near Earth Object Impact Hazard Mitigation**

Dario Izzo, Andres Galvez, Franco Ongaro, and Roger Walker, ESA

The Near Earth Object population poses an impact hazard to Earth. However, space technology is reaching a sufficient level of capability whereby the deflection of an Earth impactor could be possible within the next decades. ESA has recently selected a small kinetic energy impactor precursor mission (named Don Quijote) as the highest priority for near-term implementation of NEOs missions. The present study focuses on a detailed assessment of two methods - kinetic energy interceptors and surface-attached propulsive devices – for impact mitigation. Some detailed calculations on real cases are presented for both methods taking into account issues like asteroid spin.

09:55 **AAS 05 - 141** **On the deflection of Potentially Hazardous Objects**

Dario Izzo, ESA

More than half a thousand asteroids have already been individuated that pose a potential hazard to our planet. The question whether our society has a sufficiently developed technology level to detect and deflect one of such objects is a question that has no easy answer. In this paper a general analytical expression that returns the miss distance of a deflected asteroid is found and discussed. A comparison with a numerical simulation of the asteroid deflection problem shows a very high degree of accuracy of the formula. The expression might be used for any kind of asteroid and deflection strategy (impulsive, continuous, inertially fixed, velocity aligned, etc. etc.).

Session 9: Constellations
Chair: Ron Proulx
Draper Laboratory

07:00 **AAS 05 - 148** **Satellite Constellation Design for Earth Observation**

Ossama Abdelkhalik, Daniele Mortari, Keun Park, Texas A&M University

In this paper, Typical Earth observation missions will be addressed and design methods will be presented using the Flower Constellations (FCs). The Flower Constellations advantages in achieving both the mission requirements and in the design process are demonstrated. Earth Observation missions goals are usually achieved by using repeating ground track orbits. Then, having repeating ground track constitutes one of the main advantages in FCs with respect to other constellations in such missions. A FC depends on the choice of eight parameters. Design a FC means, therefore, to derive these parameters which are associated with the most suitable (or the best, or the optimal) constellation to accomplish the mission requirements. This paper shows how to derive these parameters in order to design a specific Earth observing mission.

07:25 **AAS 05 - 151** **Relative Flower Constellations with Applications for Planetary Explorations**

Daniele Mortari, Ossama Abdelkhalik, and Christian Bruccoleri, Texas A&M University

This paper introduces the theory of the Relative Flower Constellations, which constitutes a novel methodology to design Flower Constellations synchronized with the motion of two celestial objects (e.g., Earth and Mars) orbiting about the same gravitational mass (e.g., Sun). These two “objects” can be planets orbiting about the Sun, as well as natural or artificial satellites (e.g., planet moons, spacecraft) orbiting about a planet and also one of these two objects could be the central body itself. Any Relative Flower Constellation is, therefore, associated with two objects and its dynamics is such that the geometry of the constellation with respect to the two objects’ positions is dynamically repeated after the synodic period of the two objects. Two applications of the Relative Flower Constellations theory are here proposed. The first one proposes a Space Network Architecture for Earth/Mars planetary communications, while the second one proposes novel architectures for global navigation through the Solar System.

07:50 **AAS 05 - 154** **Streets of Coverage Constellations to Minimize Revisit Time in Low Earth Orbit**

Thomas J. Lang, The Aerospace Corp.

In the design of satellite constellations, continuous coverage of a region of interest is not always necessary. By allowing viewing gaps or revisit times, it may still be possible to meet mission objectives while substantially reducing the required number of satellites. The “streets of coverage” (SOC) method has been used with great success to find optimal constellations for continuous global and zonal coverage. In this study, the SOC method has been employed in the search for constellations that minimize the largest viewing gap to any point on the Earth (referred to as the global maximum revisit time). Streets of Coverage constellations use circular polar orbits in non-symmetric arrangements with multiple satellites per plane to achieve coverage.

08:15 **Break**

08:40 **AAS 05 - 149** **Optimization of Hybrid Satellite and Constellation Design to Achieve GEO-Belt Space Situational Awareness Using Genetic Algorithms**

Eugene Fahnestock, University of Michigan, and R. Scott Erwin, Air Force Research Laboratory

This paper summarizes the determination of designs for a hybrid constellation consisting of two types of satellites to provide capabilities required for space situational awareness in the vicinity of equatorial GEO. This task is cast as an optimization problem to minimize the sum of the actual dollar cost of the constellation / system and the performance-dependent cost components, over the space of parameters such as the optical subsystem aperture and semi-major axis for each satellite type. A brute-force enumeration of the parameter space and three slight variants of genetic algorithms are used to identify solution architectures.

09:05 **AAS 05 - 152** **Satellite Stationkeeping of the ORBCOMM Constellation via Active Control of Atmospheric Drag: Operations, Constraints, and Performance**

Timothy D. Maclay, ORBCOMM, Inc

ORBCOMM is one of the few low Earth orbit constellations to succeed in fully deploying its proposed satellite fleet. Through its operational network of 30 satellites distributed across six orbital planes, ORBCOMM provides global coverage for a wide variety of narrowband data communications applications. While there is a small, gaseous nitrogen propulsion system onboard for initial orbit injection, no fuel was allocated for orbit maintenance. Intra-plane stationkeeping is accomplished by actively varying the cross-sectional area of the spacecraft to create a differential in the drag forces experienced by individuals within the plane. This paper reviews the stationkeeping techniques employed in managing the constellation, the operational constraints that impact the original implementation concept, and the performance realized over the last seven years of stationkeeping flight operations.

09:30 **AAS 05 - 153** **Strategy for Satisfying Distance Constraints for the NASA Benchmark Tetrahedron Constellation**

Pedro A. Capó-Lugo and Peter M. Bainum, Howard University

The formation flying is a wide research area involving multiple satellites which provide different measurements from various points at the same time. The tetrahedron is one of the constellations proposed to be launched in the year 2009. An analysis of this constellation is performed without an active control scheme to observe how the constellation will interact in the orbit. The proposed strategy is based on the propagation of the initial orbital elements to predict subsequent motion of the constellation. To develop this analysis, the Satellite Tool Kit (STK) software is used. This software has different propagators that, numerically, supply approximate data to understand how the satellites will orbit. Different perturbations are analyzed to determine when the satellites violate the separation distance requirements. In conclusion, this constellation is analyzed in different ways to obtain the appropriate techniques which could satisfy the separation distance criteria for the constellation.

09:55 **AAS 05 - 150** **Parallel computing of the optimal geometry of a constellation performing radio-occultation measurements**

Dario Izzo, Isabelle Nann, Mihaly Csaba Markot, ESA

Evidence on the possibility to perform useful measurements of some planet atmospheric properties by means of inter-satellite links was first given in 1995 when a LEO-GNSS occultation measurements campaign was used to improve the existing numerical modelsof the Earth atmosphere. The problem of the optimal orbital geometry of a constellation that has to perform radio-occultation measurements is here faced by considering both the occultation numbers and their spatial distribution as parameters. A simple network architecture able to perform a global search and refine the solutions is proposed, the architecture makes use of parallel computing and its concept may be extended to larger networks and to different algorithms and problems.

Session 10: Formation Flying II
Chair: Bob Glover
AT&T

16:00 **AAS 05 - 160** **Optimal Formation Control for Imaging and Fuel Usage**

Islam I. Hussein, Daniel J. Scheeres, University of Michigan, and David C. Hyland, Texas A&M

In this paper we derive an expression relating the Modulation Transfer Function (MTF) and the trajectory of a sparse system of N telescopes. This formulation includes a noise model to represent contamination of the optical signal and is used to define a cost function for an optimal control problem including imaging and fuel performance measures. We derive the necessary optimality conditions for a generic multi-spacecraft formation and specialize them to a two-spacecraft formation. We show that the optimal solution must be symmetric about the origin of the coordinate system and that its center of mass must be fixed in space. Simulation results are provided to further investigate this control law. This work is fundamental to current and future work related to motion path planning.

16:25 **AAS 05 - 159** **On the Fuel Optimality of Maneuvers for Multi-Spaceraft Interferometric Imaging Systems**

Suman Chakravorty, Texas A&M University

In this paper, we study the design of minimum fuel maneuvers for multi-spacecraft interferometric imaging systems. We show that the underlying theoretical problem is NP-hard and it is necessary to resort to heuristics in order to solve the minimum fuel problem. We consider the design of minimum fuel spiral maneuvers and obtain the “minimum fuel double pantograph problem”. The optimization problem reduces to minimizing the fuel expenditure of the multi-spacecraft system while satisfying the imaging constraints: a set of bilinear constraints in the design parameters of the spiral, the geometric rate and the angular rate, called the “double pantograph constraints”. We show that the optimal solution is obtained by solving a set of convex programming problems.

16:50 **AAS 05 - 156** **Formation Flying Concept for Close Remote Sensing Satellites**

Simone D’Amico, Christian Arbinger, and Oliver Montenbruck, German Space Operations Center (GSOC)

Synthetic aperture radar (SAR) interferometry is a well-established technique based on the stereoscopic effect induced by matching SAR images obtained from slightly different orbital positions. The image resolution of present SAR interferometers may be improved by means of spacecrafts flying in close formation. In the framework of the TanDEM-X Phase-A Study, this paper discusses a suitable formation flying concept able to realize the demanding baselines for SAR interferometry, while minimizing the collision hazard associated with proximity operations. This study introduces the method, presents and validates an appropriate orbit control strategy and proposes an effective implementation of the distributed satellite concept.

17:15 **Break**

17:40 **AAS 05 - 158** **A Direct Approach for Minimum Fuel Maneuvers of Distributed Spacecraft in Multiple Flight Regimes**

Steven P. Hughes, D.S. Cooley, Jose J. Guzman, NASA Goddard Space Flight Center

In this work we present a method to solve the impulsive minimum fuel maneuver problem for a distributed set of spacecraft. We develop the method assuming a fully non-linear dynamics model and parameterize the problem to allow the method to be applicable to any flight regime. Furthermore, the approach is not limited by the inter-spacecraft separation distances and is applicable to both small formations as well as constellations.

18:05 **AAS 05 - 157** **On-Orbit Satellite Inspection: A Concept Study and Design**

David Woffinden, David Geller, Todd Mosher, Quinn Young, and Jeff Kwong, Utah State University

As a larger number of military, commercial, and scientific assets are placed in orbit, there arises a growing need to visually monitor particular details of these space vehicles. A small inspection satellite could serve as a practical solution. By performing various relative maneuvers close to the desired target, it could track the object of interest and provide high resolution images and other critical data concerning the status of the vehicle. In this paper, a small inspection satellite concept is developed and then verified using a high-fidelity 6 degree-of-freedom simulation. An actual satellite design is proposed along with the platform architecture applicable to a variety of similar type missions.

18:30 **AAS 05 - 155** **A Comparison of Various Relative Motion Models with Application to Close Proximity Missions**

Rebecca L. Johnson, T. Alan Lovell, and Frank R. Chavez, Air Force Research Laboratory

In this paper several existing models for relative satellite motion dynamics are compared to the familiar linear time-invariant form of the Clohessy- Wiltshire-Hill’s equations, with the goal of providing a formulation useful to mission planning specialists for satellite relative motion trajectories. The initial aspect of the comparison involves assessing the accuracy of each model against "truth" data for several candidate trajectories. Next, an impulsive-burn guidance algorithm is developed for each model, and the resulting maneuvers calculated to achieve several desired trajectories are simulated via a “truth” propagator and compared.

Session 11: Identification and Controls

Chair: Jean de Lafontaine
NGC Aerospace

16:00 **AAS 05 - 164** **Experiment Design Using Iterative Learning Control for Improved Identification of Linear Systems**

Richard W. Longman, Columbia University, and Minh Q. Phan, Dartmouth College

There is a field of optimal experiment design. Much of the theory is based on stochastic models and probability theory. This paper develops a procedure for creating a series of experiments, each one based on the results of the previous one. Use is made of iterative learning control which is a relatively new field that develops iterative methods to adjust the input to a system aiming to converge on zero error in the output of the system following a desired trajectory.

16:25 **AAS 05 - 163** **A Robust Nonlinear System Identification Algorithm Using Orthogonal Polynomial Network**

Puneet Singla, Troy Henderson, John L. Junkins, Johnny Hurtado, Texas A&M University

A robust system identification algorithm is presented which makes use of an orthogonal polynomial based artificial neural network. Adaptive learning laws are derived by thorough Lyapunov analysis to adjust different parameters of the neural network based model. The learning algorithm proposed in this paper is inspired by the recent development in adaptive control. Algorithm presented here is validated by thorough analysis and simulating different test examples mainly concerned with space applications. A detailed comparative study is performed to show the performance of the purposed algorithm with respect to some existing identification algorithms like Eigensystem Realization Algorithm (ERA).

16:50 **AAS 05 - 166** **Results of Generating Classical Compensators via Linear Quadratic Design with a Minimum Realization of the Compensator**

D. L. Mackison, University of Colorado

We have shown in a previous paper that the result of computing classical (lead, lag, quadratic) compensators via loop transmission recovery is, in the limit, a transfer function with a real zero and a complex conjugate pair of poles in the left half plane. By increasing the recovery gain in the loop transmission recovery process, the transient effects of not using a measured state to drive the controller disappear. However, the physical result of this process can make the controller essentially unrealizable, because of a large real pole.

17:15 **Break**

17:40 **AAS 05 - 165** **Inverse Dynamics Approach to NMPC Based Real-Time Optimal Feedback Control of Robots**

Jie Zhao and Richard W. Longman, Columbia University, and Hans Georg Bock, University of Heidelberg

This paper is one in a series of papers investigating optimal control of robots. References develop an understanding of the nature of time optimal solutions for different types of robots such as elbow robots, polar coordinate robots, and SCARA robots. References address issues of how to formulate an appropriate cost functional for near time optimal transfers and at the same time avoid excitation of vibrations. Also treated is how to make an existing feedback controller actually produce the computed optimal trajectory. Iterative learning control is used for that purpose.

18:05 **AAS 05 - 161** **Modeling and Control of Interferometric Formations in the Vicinity of the Collinear Libration Points**

Prasenjit Sengupta and Srinivas R. Vadali, Texas A&M University

The modeling and control of a Fizeau-type interferometer in the elliptic, restricted three body problem of the Sun and Earth-Moon Barycenter system, is the subject of this paper. The interferometer is in a quasi-periodic (lissajous) orbit about the trans-terrestrial libration point. Control laws are derived for effective station-keeping, inertial and local pointing, and slewing maneuvers, as well as attitude maintenance of the spacecraft in the formation. These control laws are derived from candidate Lyapunov functions, each of which is proven to be globally and asymptotically stable. The approach in this paper couples the translational and attitude kinematics of the spacecraft.

18:30 **AAS 05 - 162** **Refinements to the Q-law for Low-Thrust Orbit Transfers**

Anastassios E. Petropoulos, Jet Propulsion Laboratory

The Q-law is a Lyapunov feedback control law for performing low-thrust orbit transfers around a central body. Specified, arbitrarily large changes can be effected in all orbit elements other than true anomaly, provided the eccentricity remains below unity. The control law includes a simple mechanism for judiciously introducing coast arcs. Here we present a refinement to the proximity quotient, Q, which is a candidate Lyapunov function quantifying the proximity of the osculating orbit to the target orbit; specifically we better quantify the proximity to the target argument of periapsis by better quantifying the usefulness of out-of-plane thrust. We also introduce a new definition for the effectivity of the thrust, which simplifies the quantification of the trade-off between propellant mass and flight time.

Session 12: Propagation
Chair: Paul Schumacher
Naval Network and Space Operations Command

16:00 **AAS 05 - 167** **A Special Perturbation Method in Orbital Dynamics**
J. Pelaez, J. M. Hedo and P. Rodriguez de Andres, Technical University of Madrid

In dynamical simulations, a tether is discretized using several beads distributed along its length (bead models). The requirements -tens of particles, long integration periods and complex physical interactions- invite us to optimize orbit propagators both in runtime and accuracy. The special perturbation method presented conjugates ease of computer implementation, speediness and accuracy. It provides the evolution of some orbital elements, constants in a non-perturbed problem, but which evolve in the perturbation time scale. It can be used for any orbit, it is free of singularities related to small inclination or eccentricity and the use of Euler's parameter makes it robust.

16:25 **AAS 05 - 172** **Speed and Accuracy Tests of the Variable-Step Stoermer-Cowell Integrator**
Matt Berry, Analytical Graphics Incorporated and Liam Healy, Naval Research Laboratory

The variable-step Stoermer-Cowell integrator is a non-summed, double-integration multi-step integrator derived in variable-step form. The method has been implemented with a Shampine-Gordon style error control algorithm that uses an approximation of the local error at each step to choose the step size for the subsequent step. In this paper, the variable-step Stoermer-Cowell method is compared to several other multi-step integrators, including the fixed-step Gauss-Jackson method, the Gauss-Jackson method with s-integration, and the variable-step single-integration Shampine-Gordon method, in both orbit propagation and orbit determination. The results show the variable-step Stoermer-Cowell method is comparable with s-integration, except in high drag cases where the variable-step Stoermer-Cowell method is advantageous.

16:50 **AAS 05 - 171** **Secular Motion around TriAxial Planetary Satellites: Application to Europa**
Martin Lara, Real Observatorio de la Armada, and Juan F. San-Juan, Universidad de La Rioja

We investigate the secular motion of a spacecraft around the Jovian moon Europa. Our model takes into account the gravitational potential of Europa up to the second order, and the third body perturbation in Hill’s approximation. In a close vicinity of Europa the ratio of the rotation rate of Europa to the mean motion of the orbiter is small. We consider this ratio as a small parameter and found that the Coriolis effect is a first order perturbation, the third body tidal attraction is of second order, the ellipticity perturbation is of third order, and the oblateness effect remains between the second and third orders. Then, we apply perturbation theory and find that a third order approach is enough to manifest the influence.

17:15 **Break**

17:40 **AAS 05 - 170** **Nonlinear Mapping of Gaussian State Covariance and Orbit Uncertainties**
Ryan S. Park and Daniel J. Scheeres, The University of Michigan

We define and evaluate a theory of nonlinear phase flow and uncertainty propagation. Using this theory, the phase volume and statistics of the spacecraft state are mapped both linearly and nonlinearly to analyze the effect of dynamical instability on the spacecraft uncertainty distribution. The nonlinear model is constructed by incorporating the higher order terms of a Taylor series in the dynamics, propagated forward in time. We compare the linear and nonlinear flow of the phase volume and its statistical properties. We then show when and why the linear model fails to represent the valid probability model of the system.

18:05 **AAS 05 - 168** **Density Corrections for the NRLMSIS-00 Atmosphere Model**

Vasiliy S. Yurasov, Space Informatics Analytical Systems (KIA Systems), Andrey I. Nazarenko, Space Observation Center, Paul J. Cefola, Consultant in Aerospace Systems, Spaceflight Mechanics, and Astrodynamics, and Kyle T. Alfriend, Texas A&M University

Abstract Unavailable

18:30 **AAS 05 - 169** **Drag Coefficient Computation Results for Spacecraft and Simple Shapes in Low Earth Orbits Using Finite Plate Elements**

Charles Martin Reynerson, The Boeing Company

This paper describes a method for determining the drag coefficient of spacecraft in Low Earth Orbits (LEOs). A spacecraft configuration and mission orbit is required for this method to be useful. An effective drag coefficient is determined that can be useful for orbital mechanics perturbation force models. By using finite plate elements, complex shapes can be readily modeled. This model is validated using experimental data for hypersonic molecular beams and DSMC methods. The drag coefficient (CD) is a key parameter for LEO spacecraft when determining lifetime propellant consumption and predicting deorbit maneuvers. The drag coefficient for complex shapes is difficult to compute analytically, so a method was developed to determine satellite drag coefficients using finite plate elements.

Session 13: Interplanetary II
Chair: Paul Penzo
Global Aerospace Corporation

07:00 **AAS 05 - 173** **Trajectory Design and Maneuver Strategy for the MESSENGER Mission to Mercury**

James V. McAdams, The Johns Hopkins University Applied Physics Laboratory, Tony Taylor and Bobby G. Williams, KinetX, Inc., and David W. Dunham and Robert W. Farquhar, The Johns Hopkins University Applied Physics Laboratory

MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) will be the first spacecraft to orbit the planet Mercury when it begins its one-year Mercury orbit phase in 2011. Designed and operated by The Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland, MESSENGER draws leadership from the Carnegie Institution of Washington with key flight operation contributions from KinetX, Inc., NASA's Jet Propulsion Laboratory (JPL), Goddard Space Flight Center, and numerous universities, research institutions, and subcontractors. Supported by NASA's Discovery Program, the spacecraft successfully launched from Cape Canaveral, Florida, aboard a Delta II 7925H-9.5 launch vehicle on 3 August 2004. The spacecraft will utilize one Earth gravity assist, two Venus gravity assists, and three Mercury gravity assists during its 6.6-year ballistic trajectory to Mercury.

07:25 **AAS 05 - 174** **Constrained Parameter Optimization by the Method of Explicit Functions: Messenger Mission to Mercury Application**

James K. Miller, Kinetx Inc.

The solution of a nonlinear system of equations subject to constraints that involves minimizing a scalar performance index is required for many applications, particularly trajectory optimization. Numerical solutions are obtained on a computer by searching the space of independent parameters until the equations of constraint and condition of optimality are satisfied. A constrained parameter search and optimization algorithm based on the method of explicit functions is described. A fundamental equation describing parameter optimization subject to constraints is developed. This equation is used to show the relationship of the method of explicit functions to other optimization methods including the methods of Lagrange multipliers and gradient projection. A second order gradient search alogorithm is described.

07:50 **AAS 05 - 175** **An Internet-based Trajectory Database for the MESSENGER Mission to Mercury**

James V. McAdams, The Johns Hopkins University Applied Physics Laboratory, Legand L. Burge and Joseph Gill, Howard University

An Internet-based trajectory database was developed for the MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) mission to reduce the time required to answer trajectory-specific requests from lead engineers, scientists, and public relations professionals (those providing information to educators, the media, and the public). This diverse user community accesses the MESSENGER Trajectory Database (MESSWEB) at their convenience to obtain data rapidly to facilitate mission evaluation, data analysis, and observation planning. While the information retrieved from MESSWEB does not reveal the orientation of any spacecraft component, the database could be modified to add items of interest such as solar panel orientation and science instrument boresight direction. After a discussion of the capability, function, and architecture of the database, some suggestions are offered.

08:15 **Break**

08:40 **AAS 05 - 176** **Early Navigation Results for NASAs Messenger Mission to Mercury**

B. Williams, A. Taylor, E. Carranza, J. Miller, D. Stanbridge, B. Page, D. Cotter, and L. Efron, KinetX, Inc., R. Farquhar, J. McAdams, and D. Dunham, The Johns Hopkins University Applied Physics Laboratory

The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission is being flown as the seventh mission in NASA's Discovery Program. The MESSENGER mission is led by the principal investigator, Sean C. Solomon, of the Carnegie Institution of Washington. The project is managed by and the spacecraft was built and is operated by The Johns Hopkins University Applied Physics Laboratory. Navigation for the spacecraft is provided by the Space Navigation and Flight Dynamics Practice of KinetX,Inc., a private corporation. Navigation for launch and interplanetary cruise makes use of radio metric tracking data from NASA's Deep Space Network in addition to optical navigation from on-board images of planet flybys. The spacecraft was launched August 3, 2004, to begin its six and one-half year interplanetary cruise.

09:05 **AAS 05 - 177** **Recovery from a Period of Missed Thrust During a Low Thrust Mission to Jupiter**

John E. Weglian, Ohio Aerospace Institute, and Kurt Hack, NASA Glenn Research Center

Vehicles that fly on low-thrust trajectories may spend months or years continuously thrusting in order to reach their destination. If a malfunction occurs that causes a loss of propulsion during a period of planned thrust, the vehicle must change something from the baseline trajectory in order to reach the target. The options available to recover the mission vary depending on the vehicle and its systems. This analysis looked at the requirements to complete an Earth to Jupiter mission, if a malfunction caused a brief loss of propulsion at various points in the mission.

09:30 **AAS 05 - 178** **Lyapunov Control Functions for Low Thrust OTV Guidance: Gain Structures and Applications to Solar Sailing**

Jeremy S. Neubauer and Michael A. Swartwout, Washington University

Lyapunov control functions (LCFs) for low thrust vehicle guidance can offer simple, robust, and efficient orbit transfers. However, performance is tied to a user-specified, mission specific gain structure, requiring timely trial-and-error gain searches. This paper pursues a generalized state-based gain structure, comparing performance to constant gain LCF and time-optimal methods across multiple missions. Though the state-based method shows select promise, divergences from minimum transfer times often exceed 10%. Thus, LCF methods are applied to solar sailing, where time constraints are relaxed in favor of added robustness. Results show that numerically evolved constant gain structures outperform the investigated state-based gain structures.

Session 14: Optimization II
Chair: David Spencer
Penn State University

07:00 **AAS 05 - 182** **Optimal Finite-Time Feedback Controllers for Nonlinear Systems with Terminal Constraints**

S. R. Vadali and R. Sharma, Texas A&M University

This paper presents a novel power series solution method for developing feedback controllers for finite-time, nonlinear optimal control problems with terminal constraints. A general methodology is proposed for feedback control with time-dependent gains that operate on state variables and powers of the same. These gains are obtained from backward integration of differential equations with terminal boundary conditions. The differential equations for the gains are independent of the states. Terminal constraints on the state variables are handled using Lagrange multipliers. Numerical examples are considered to demonstrate the applications of this methodology. The results are compared with those obtained by using open-loop solutions to the respective problems.

07:25 **AAS 05 - 181** **Development of SAMURAI - Simulation and Animation Model Used for Rockets with Adjustable Isp**

Tadashi Sakai, John R. Olds, and Kristina Alemany, Georgia Institute of Technology

An interplanetary trajectory calculation application SAMURAI – Simulation and Animation Model Used for Rockets with Adjustable Isp – has been developed. SAMURAI calculates transfer trajectories with variable thrust, variable Isp (VASIMR type) engines as well as conventional constant low thrust, constant Isp engines and high thrust engines. Thrust history that minimizes the fuel consumption is computed. A 3D animation of the resulting transfer trajectory is created and can be viewed on the web browser using VRML. As an example of trajectory simulation, a round trip from Earth to Mars has been analyzed. The results show that modulating Isp reduces the fuel consumption.

07:50 **AAS 05 - 184** **Reconnaissance Problem Using Genetic Algorithms**

Ossama Abdelkhalik, Daniele Mortari, Texas A&M University

Reconnaissance mission requires that a satellite visits a given set of sites within a given time frame. This mission is investigated for a passive solution without thrusters. The goal is to find the optimal orbit so that all the assigned sites will be crossed by the ground track of that orbit within a given time frame. Two optimality definitions are considered based on the objective of the mission. The first considers optimizing the resolution for an imaging mission. The second maximizes the observation time over the sites. Genetic algorithms are used to search the minimum for the above two cost functions. As a final improvement step, the solution obtained by the Genetic Algorithms is used as initial guess in a gradient optimization method for a final refinement.

08:15 **Break**

08:40 **AAS 05 - 180** **Design Optimization Method for Libration Point Mission Trajectories**

Samantha Infeld and Walter Murray, Stanford University

Past libration point missions did not optimize the design. We present a method for optimizing the trajectory design and control strategy concurrently. Rather than controlling a particular orbit in minimum fuel, we explore the mission-length trajectory design space to find minimum-fuel solutions. We present the results from applying the approach to a simple force model with restrictions only on the final distance from the libration point. The solutions found in this space require no fuel and are therefore global optimizers. Different global minimizers are found by varying initial estimates used by the optimization algorithm.

09:05 AAS 05 - 179 6-DOF Simulation & Modeling of the Optimal Method of Ejection for the Orbital Express Launch Interface Ring

Michael W. Weeks, The Boeing Company

In September 2006, DARPA will launch its Orbital Express Advanced Technology Demonstrator consisting of a prototype servicing satellite, ASTRO, and a surrogate serviceable satellite, NEXTSat. The goal of the Orbital Express Space Operations Architecture program is to demonstrate the technical feasibility of robotic, autonomous on-orbit refueling and reconfiguration of satellites on orbit. After orbit insertion of the OE package, one of the early tasks is to safely eject an interface ring that supports the two vehicles during ascent, and ensure that recontact with the ring doesn't occur. This paper discusses the detailed analysis, simulation results, and perturbation & propagation methods.

09:30 AAS 05 - 183 Primer Vector Optimization: Force Model Considerations

Jose J. Guzman, The Johns Hopkins University Applied Physics Laboratory

Primer vector theory can be considered as a byproduct of applying Calculus of Variations (COV) techniques to the problem of minimizing the fuel usage of impulsive trajectories. A generalized form of the primer vector equations is used to study some of thedifferent formulations of the primer vector (dependent on the frame employed and on the force model). For the cost function variations, it is of interest to understand what quantities are continuous across an impulse. The following force models are considered: two-body problem, Clohessy-Wiltshire linearized model and restricted problems.

Session 15: Orbit Mechanics

Chair: Jose Guzman

Johns Hopkins University Applied Physics Laboratory

07:00 **AAS 05 - 186** **Bounded, Periodic Relative Motion using Canonical Epicyclic Orbital Elements**

N. Jeremy Kasdin and Egemen Kolemen, Princeton University

In this paper, we use a Hamiltonian approach to derive the equations of motion for an object relative to a circular reference orbit. By solving the Hamilton- Jacobi equation we develop constants of the relative motion called epicyclic elements. A perturbation Hamiltonian is formulated in order to derive variational equations for the "constants" via Hamilton's equations. We use this formalism to derive bounded, periodic orbits in the presence of various perturbations. In particular, we show a simple no-drift condition that allows for bounded orbits in the presence of J2 forces. We also derive the relative motion deviations due to eccentricity, second-order terms, and co-orbiting objects.

07:25 **AAS 05 - 187** **Dynamic Stability and Gravitational Balancing of Multiple Extended Bodies**

Marco B. Quadrelli, Jet Propulsion Laboratory

LISA is a three-spacecraft gravitational wave detector forming the vertices of an equilateral triangle with a side of 5 million km in length. Inside each spacecraft an optical bench monitors the motion of two independent proof masses, which reflect the laser light from the adjacent spacecraft, and sense the gravitational wave signal with unprecedented sensitivity. This paper considers a non-invasive compensation scheme for precise positioning of a massive extended body in free fall using gravitational forces caused by surrounding source masses. A feedback plus feed-forward control scheme demonstrates effective control of the sensitive proof mass within the specified requirements.

07:50 **AAS 05 - 188** **Mapping Long-term Stability Regions with Application to Distant Retrograde Orbits**

B.F. Villac, California Institute of Technology, and J. Aiello, Jet Propulsion Laboratory

The determination and characterization of long-term stability regions around periodic orbits (i.e. small, bounded variations in the state of a spacecraft for several hundred to a thousand years) is addressed using a modern numerical tool for the detection of chaotic motion: the Fast Lyapunov Indicator (FLI). Long-term stability regions are important for spacecraft applications as they can be used as disposal regions for end of mission requirements. The method is applied to the case of distant retrograde orbits around Jupiter's moon Europa. It is shown that the extent of the stability region decreases with the stability index of the periodic orbit family, reducing to an empty set in a neighborhood of the colinear libration point regions. The method is compared with long term trajectory integration.

08:15 **Break**

08:40 **AAS 05 - 190** **Orbit Mechanics about Planetary Satellites Including Higher Order Gravity Fields**

M.E. Paskowitz and D.J. Scheeres, University of Michigan

This paper explores orbit mechanics about a planetary satellite in the Hill 3-body problem. The Jupiter Icy Moons Orbiter (JIMO) mission is used to motivate our analysis, in particular we consider motion about Europa. The model used includes the tidal force and the J2 and J3 gravity effects. We develop an approximate theory of motion using an averaging approach and find orbits that have constant orbital element values on average. The stability of these orbits is investigated and their viability in the unaveraged system is studied. An analytic theory using the nonlinear manifolds of unstable frozen orbits is developed which can significantly extend the lifetime of these orbits.

09:05 AAS 05 - 185 An Orbit Analysis for Performing Remote Sensing from the International Space Station

Megan Mitchell and Todd J. Mosher, Utah State University

The International Space Station (ISS) offers a suitable orbit for remote Earth sensing. The structure of the station combined with the effects of drag cause 10 to 20 kilometer variations in the ISS altitude daily. To better grasp the consequences of the erratic orbit, this paper will investigate the astrodynamics of the ISS and analyze NASA trajectory predictions. A program is used to model the orbit of the ISS while taking into account viewing restrictions including lighting conditions, docking events, and station maneuvers. Comparisons between the actual orbit and the predictions are reviewed for mission planning and feasibility purposes.

Session 16: Formation Flying III
Chair: James Gearhart
Lockheed Martin Technical Operations Co.

16:00 **AAS 05 – 192** **Guidance and Control Results Obtained Using Different Linear Models for Spacecraft Relative Motion**

J. E. Cochran, Jr., D. Lee, and J. H. Jo, Auburn University and T. Alan Lovell, Air Force Research Laboratory

Guidance and control of the relative motion of two or more spacecraft that are orbiting a natural body, for example, the Earth, is an important part of space operations. As a result, the problem of modeling such relative motion has been of interest for almost fifty years. Models obtained by linearization of the equations of motion of the spacecraft have been used as the basis for guidance and control algorithms for rendezvous, station keeping, and intercept. This paper presents the results of a study of the relative merits of using several of these linear relative motion models, including inertial, circular restricted and elliptic restricted in guidance and control algorithms.

16:25 **AAS 05 – 191** **A Study of the Control Strategy of Low-Thrust Formation-Keeping**

Zhong-Sheng Wang, Embry-Riddle Aeronautical University

Satellite formation flight mission takes a long time, so long-term perturbation effects (such as the J2 effect) should be countered to maintain the formation. Our previous study led to a full dynamic model for the relative motion of formation flight and some stability conditions. In this study the model and stability conditions are applied to formation-keeping problems using small thrusters. The simulation results are compared with the results from the previous study, in which a device that collects solar radiation pressure is used as the control actuator. The paper also addresses propellant consumption issue of the proposed control strategy.

16:50 **AAS 05 – 194** **Discrete Maeuver Formationkeeping at Libration Points L1 and L2**

H.J. Pernicka, B.A. Carlson, and S.N. Balakrishnan, University of Missouri-Rolla

With the development of technologies that make Distributed Space Systems (DSS) a realistic option for incorporation into mission design, many new mission concepts have been proposed and will be proposed in the future which make use of this technology. Many of the features that make geocentric DSS architectures desirable are equally valid near libration points, such as increased sensor resolution, lower cost, and simplified development of smaller individual spacecraft. The effort described in this paper focuses on the development and analysis of discrete maneuvering techniques for maintaining a two satellite formation within required error tolerances. In particular, formation sizes and control tolerances are sought for which impulsive maneuvering becomes a practical option.

17:15 **Break**

17:40 **AAS 05 – 195** **Formationkeeping for Sun-Earth Libration Point Formations by Using Solar Radiation Pressure**

Hongming Li and Trevor Williams, University of Cincinnati

In this paper, we develop a novel method for applying solar radiation pressure to achieve the formationkeeping of satellite formations at one of the collinear Sun-Earth libration points. This method utilizes solar radiation pressure, which is one of the main perturbations acting on libration point satellites, to cancel the well-known natural instability of libration point orbits. Furthermore, this method can make the frequency of out-of-plane motion equal to that of in-plane motion and thus provides more flexibility for mission design. This concept, when compared with conventional approaches, can save considerable propellant. In addition, it also will avoid the technical difficulty of realizing the small propulsive forces needed for formationkeeping, since solar radiation pressure naturally produces control forces of this magnitude.

18:05 **AAS 05 – 196** **Coordinated Stationkeeping Strategies for Collocated Geosynchronous Satellites**

Chia-Chun Chao and Glenn E. Peterson, The Aerospace Corporation

This paper summarizes the design and development of an effective coordinated stationkeeping strategy for multiple geosynchronous spacecraft occupying the same longitude with different control boxes and mission objectives. The study focuses on examining the relative motion between two to three uncoordinated geosynchronous spacecraft and developing an effective maneuver procedure to maximize closest approach distances with minimized mission impacts. It is assumed that those uncoordinated geosynchronous missions control their spacecraft with conventional north/south and east/west stationkeeping methods. The satellites are not constrained to have the same tolerance limits. Their stationkeeping methods may or may not adopt the sun-pointing strategy and the area-to-mass ratios can be very different due to spacecraft designs and mission objectives. "The concept of isolating radial and cross-track separations at longitude crossing can avoid the prediction of intrack separation, which is always difficult to estimate with good accuracy after several days. A simplified analytic representation is derived which helps in understanding the relative motion between spacecraft. Numerical examples demonstrate the effectiveness of this method."

Session 17: Special-Session

Astrodynamics: How can we better meet tomorrow's requirements?

Chair: Felix Hoots
AT&T

16:00 **AAS 05 - 201** **Transforming Space Surveillance to Meet Todays Space Superiority Needs**

Dave Desrocher, Situational Awareness Solutions, Inc.

Transformation of national defense is more than just the buzz word of the day. With the fall of the Soviet Union, the rise of a more distributed threat that we fight in the Global War on Terrorism and the advances of technology, it is imperative that our operations and the capabilities that they employ meet these changing needs. This is no less true in the military space domain. With our dependence on space assets and capability higher than ever and still on the rise, the need for enhanced Space Situation Awareness (SSA) and the means to act swiftly and effectively on that SSA has become a predominant concern.

16:25 **AAS 05 - 200** **An Independent Technical Review Process for Government Developed Models: HASDM as a Case Study**

Michael J. Gabor

The Joint Astrodynamics Working Group (JAWG) was established by U.S. Space Command with the intention of overcoming the chasms between organizations that do Astrodynamics related research and development. In 2001, the JAWG sought to apply independent technical evaluations to new models prior to operational implementation. This process was applied to the Air Force Space Command implementation of the High Accuracy Satellite Drag Model (HASDM) to aid in the determination of atmospheric drag effects on low satellite orbits. The JAWG conducted an independent technical review of the HASDM theory, using many experts in the field. Lessons learned from the review process are captured and provide a foundation for developing a future process to implement and integrate new concepts into the operational military space architecture.

16:50 **AAS 05 - 199** **An Analysis of State Vector Propagation using Differing Flight Dynamics Programs**

David A. Vallado, Analytcal Graphics Inc., Center for Space Standards Improvement

The considerable growth in numerical techniques as applied to satellite flight dynamics operations in recent years is generating some unique challenges. While some of these challenges have been examined a long time ago, there is renewed interest in how organizations efficiently interact with and use orbital data from programs outside their direct control. While a few historical operations used analytically generated datasets for a majority of their calculations, most satellite operations use numerical techniques. The analytical approaches required strict adherence to a specific mathematical technique. Use of numerical techniques presents different challenges even though the underlying mathematical technique is the same. This paper provides results of an experiment of various initial state vectors that represent a cross-section of the existing satellite population.

17:15 **Break**

17:40 **AAS 05 - 202** **Trust, Risk & Aerospace Software: Balance and Optimization**

Sally J.F. Baron, Management Consulting Services

The ability to trust is often thought of as a subjective trait – subject to irrational assessments such as familiarity and name recognition. Trust, however is not completely subjective, nor completely bipolar; that is we do not necessarily either trust or distrust. Sometimes, we can trust a little, or trust a lot, or trust individuals or organizations in some aspects but not others. Trust, therefore, can more rationally and objectively be treated as a risk assessment, unique for each case. Software is one of the most important products used in aerospace, yet one of the most difficult to assess. Managers can be prone to trust organizations with whom they have had previous dealing or are familiar without a complete assessment of risk and other products.

18:05 **AAS 05 - 198** **Standards, Rules, Innovation, and Inhibition**

David Finkleman, Analytical Graphics Inc., Center for Space Standards Innovation

Cell phone users easily charge their devices across the country because standards regulate the process. However, international travelers discover the impact of differing standards. While standards can enable commerce, they can also inhibit innovation. They can assure sufficient levels of performance, interoperability, and performance, but this may be insufficient for many applications. Adopting standards can be voluntary, driven by market forces, or they may be imposed by statute. This paper examines several topics including how standards apply to space enterprises, which require sophisticated technology and which are characterized by engineering at the margin, exceptional weight constraints, and extremely expensive activities. Several legal, diplomatic, and societal impacts of space standards are examined. Finally, the role of the AIAA, industry, and Government is explored.

18:30 **AAS 05 - 197** **Q&A for All Papers in This Session**

Felix Hoots, AT&T

An opportunity to ask the authors in this session additional questions as well as an open discussion of issues related to the session theme.

Session 18: Tethers I
Chair: Michael Zedd
Naval Research Laboratory

16:00 **AAS 05 - 204** **Stability Analysis of Coulomb Tether Formation**

Arun Natarajan and Hanspeter Schaub, Virginia Polytechnic Institute

The stability analysis of a Coulomb tether formation is investigated. Here the relative distance between two satellites is controlled using Coulomb forces and held near a constant value. The gravity gradient will be exploited to stabilize the attitude of this Coulomb tether formation about an orbit nadir direction. The Coulomb tether will be modeled as a massless, elastic component. The elastic strength of this connection is controlled through a spacecraft charge control law.

16:25 **AAS 05 - 205** **Generator Regime of Self Balanced Electrodynamic Bare Tethers**

J. Pelaez and M. Sanjurjo, Technical University of Madrid

The generator regime of electrodynamic bare tethers working at inclined orbits is analyzed. These tethers are unstable without damping or any other kind of control. However, the instability disappears, or reduces drastically, when the tether is self balanced. The aim of the paper is to describe in detail the influence of the main parameters that should be considered in this kind of tethers in the balance condition. In addition a strategy will be proposed to balance the tether taking into account the whole trajectory followed by the system during the deorbiting process.

16:50 **AAS 05 - 206** **Optimal Orbital Maneuvers Using Electrodynamic Tethers**

Paul Williams, RMIT University

Electrodynamic tethers provide a means for propellantless orbital transfers. Electrodynamically driven tethered spacecraft differ from conventional low-thrust spacecraft because the propulsive forces depend on the local direction of the tether, the direction and magnitude of the Earth’s magnetic field, and the density of the surrounding ionospheric plasma. The electric current must be controlled in an optimal manner to affect the desired changes to the spacecraft’s orbit. In this work, the motion of the system center of mass, together with the tether librational motion, is used to derive the necessary conditions for optimality via Pontryagin’s Maximum Principle. Optimal orbital maneuvers under restricted current levels are determined using a combination of shooting and homotopy.

17:15 **Break**

17:40 **AAS 05 - 207** **Optimal Control of the Deployment of a Spinning Tethered Formation**

Paul Williams, RMIT University

The deployment of a spinning three mass tether constellation is considered. The tethered constellation is modeled using point masses connected via inelastic tethers. Optimal deployment trajectories using only tension control are determined using direct transcription. It is shown through numerical studies that minimizing the deployment acceleration gives better trajectories than minimizing other performance functionals, such as the work done by the tether reels. Deployment trajectories are obtained that maintain the tether spin at the desired rate and keep the system in the desired physical arrangement at the end of deployment. Parametric studies of the effect of system mass distribution and spin rate are performed.

Thursday, Jan 27, 2005 Bighorn C1

Session 19: Rendezvous and Relative Motion

Chair: T. Alan Lovell

Air Force Research Laboratory

07:00 **AAS 05 - 209** **Comparison of Several Sollutions of Elliptic Rendezvous Problem**

Jung Hyun Jo, John E. Cochran, Jr., and Nammi Jo Choe, Auburn University

Several solutions of relative motion between neighboring elliptic satellite orbits are reviewed and compared. The performance of these solutions is compared with the Hill-Clohessy-Wiltshire solution and the direct integrated orbit using full size geopotential model in test cases.

07:25 **AAS 05 - 210** **Guidance and Control for Highly Constrained Rendezvous**

Craig J. Van Beusekom and Piero Miotto, Draper Laboratory

A robust guidance and control system is developed for a spacecraft that has the objective of precise rendezvous with a point in space at a particular time. The timeline is a fraction of an orbit and terminal velocity is unconstrained. The spacecraft has a fixed impulse delta-V. An additional constraint is that all stages of the spacecraft must de-orbit in less than one orbit. The guidance solution is a modified Lambert general energy management steering algorithm. Traditional control algorithms are applied to a plausible set of hardware, and the whole system is simulated and performance is evaluated.

07:50 **AAS 05 - 211** **Guidance for Autonomous Rendezvous in a Circular Orbit**

Rafael Yanushevsky, Technology Service Corporation

An algorithm for autonomous guidance of a spacecraft to a target vehicle in a circular orbit is considered. The guidance law components are determined based on the model described by linear Clohessy-Wiltshire equations. The multipulse terminal control problem is formulated and the terminal control law is analyzed. The optimal rendezvous problem is presented with chaser acceleration components as multipulse guidance controls. Additional limits on a chaser's trajectory are considered. An algorithm of the solution of the optimal problem is discussed.

08:15 **AAS 05 - 212** **Safe or Emergency Fault Protection Approaches for Spacecraft**

Kenny Epstein, Chris Randall, Dan Reasbeck, and Kathy Fox, Ball Aerospace & Technologies Corp.

This paper gives a description of a simple and robust approach to the fault protection of spacecraft. Often on modern spacecraft, fairly sophisticated methods of fault protection are developed. These fault protection systems, while having excellent capabilities to keep spacecraft safe with a minimum of ground interaction, can often become a risk to the spacecraft in their own right. One approach to mitigate these kinds of risks is to have a simple and easily verifiable hardware based fault protection which can be placed at the lowest level. Our approach utilizes normally existing avionics hardware, with a simplified command and control architecture to provide a robust way of safing a spacecraft. Safing a spacecraft is defined herein to mean orientating the spacecraft in a power positive.

09:05 **Break**

Session 20: Mars Missions
Chair: Jay Middour
Naval Research Laboratory

07:00 **AAS 05 - 213** **A nuclear powered Cycler to Mars**

A. Davighi, A.Finzi, E. Finzi, G.Hanninen, A.Mafficini, Politecnico di Milano

The development of a sustained human presence on Mars is a reasonable goal in the foreseeable future, as space exploration advances into the 21st century. As a manned base will be built on the red planet resupply missions will be realized. The aim of this work is to resupply this human base through an Earth-Mars Cycler. Cycler orbits are resonant or near resonant trajectories between celestial bodies. Cyclers can be designed to enable sustained interplanetary transportation through regular encounters with Earth and the target planet.

07:25 **AAS 05 - 214** **An Analysis Plan for the Mars Telecommunications Orbiter Rendezvous and Autonomous Navigation Flight Experiment**

David K. Geller, Utah State University, and Andrew Vaughan, Jet Propulsion Laboratory

Orbital rendezvous and capture of an Orbiting Sample (OS) will be a likely element of a Mars Sample Return (MSR) mission. As such, NASA's Mars Program will be keenly interested in the currently proposed Rendezvous and Autonomous Navigation (RAN) flight experiment that will launch with the Mars Telecommunications Orbiter (MTO) in 2009. Thus it will be important to provide MTO with a thorough and detailed analysis of the rendezvous trajectory design and the overall GN&C system including all the rendezvous flight software. This paper presents a comprehensive analysis plan along with a set of analysis tools that will help ensure the success of what is going to be a carefully watched flight experiment.

07:50 **AAS 05 - 217** **Simulation Capabilities for Mars Reconnaissance Orbiter**

Jill L. Hanna Prince and Scott A. Striepe, NASA Langley Research Center

Mars Reconnaissance Orbiter will launch in August 2005 and will achieve Mars Orbit Insertion in March of 2006. It will then take approximately six months to use the process of aerobraking to shape its orbit into the desired science mapping orbit. This six-month period is arguably the phase of the mission with the highest risk to the spacecraft, dipping to within 100 km of the planet. Many flight simulations exist that predict MRO mission runout statistics and aerobraking progress. This paper will address simulation techniques and capabilities at NASA Langley Research Center with the simulation tool, Program to Optimize Simulated Trajectories II, POST2.

08:15 **AAS 05 - 216** **Mars Aerodynamic Entry Control Using Static Output Feedback and LPV Techniques**

Aymeric Kron, Jean de Lafontaine, NGC Aerospace Ltd, Catherine LePeuvédic, Alcatel Space

This paper addresses the 6 degrees-of-freedom control of a Mars Lander Module during its aerodynamic entry phase. The design methodology, the performance assessment and the comparison of two classes of attitude controllers are presented: a dynamic Linear-ParameterVarying (LPV) controller and a static output feedback controller designed with eigenstructure assignment. The former is attractive for its inherent robustness to parameter variations, which are large during atmospheric entry, whereas the latter is convenient for its simplicity in design and implementation. Both attitude controllers are compared using the same trajectory controller. The latter is designed using a Nonlinear-Dynamic-Inversion control technique coupled with a guidance law computed on-line using an Analytic Predictor-Corrector technique. During validation tests using a realistic nonlinear model of the dynamics, both attitude controllers provide satisfactory performance and meet the mission requirements. This study illustrates that the trade-off becomes one between controller simplicity and controller a priori robustness.

08:40 **AAS 05 - 215** **Atmospheric Variability at Mars Reconnaissance Orbiter Science Orbit Altitudes Based on Mars Express Reconstructions**

Dolan Highsmith, Tung-Han You, Allen Halsell, Moriba Jah, Stacia Long, Stuart Demcak, and Earl Higa, Jet Propulsion Laboratory

This paper describes the orbit reconstruction of Mars Express (MEX) with the specific goal of estimating the atmospheric density near periapsis and evaluating its variability and predictability. The desired outcome is to validate the covariance analysis assumption of atmospheric variability for the 2005 NASA Mars Reconnaissance Orbiter (MRO), as well as evaluate the accuracy of the density estimates output from the atmosphere model used by MRO. Topics covered include the MRO atmosphere model, MEX orbit determination and post-fit Doppler residuals, and atmosphere trending statistics gleaned from the orbit reconstructions.

09:05 **Break**

Session 21: 3-Body
Chair: Hank Pernicka
University of Missouri-Rolla

07:00 **AAS 05 - 219** **Solar Sail Transfer Trajectory Design and Stationkeeping Control for Missions to the Sub-L1 Equilibrium Region**

Mike Lisano, Jet Propulsion Laboratory, and Dale Lawrence, University of Colorado

In this paper, the design of a solar sail trajectory is treated, along with the associated thrust vector control history that transfers a solar-sail-propelled spacecraft, or sailcraft, from the Earth/Sun L1 libration point to a sub-L1 region nearer the Sun. A novel combination of trajectory optimization and new sailcraft trajectory control methods are employed to produce minimum time transfers and robust trajectory tracking and stationkeeping. First, a trajectory to sub-L1 region is targeted, where solar pressure and gravitational forces approximately balance. The nominal thrust vector control sequence that minimizes time-of-flight is generated using a gradient-search optimization tool. Then, feedback control is applied to reduce trajectory tracking errors along the transfer trajectory and to stabilize the (normally unstable) motion in the sub-L1 region.

07:25 **AAS 05 - 220** **Virtual Exploration by Computing Global Families of Trajectories with Supercomputers**

Rodney L. Anderson, University of Colorado at Boulder, and Martin W. Lo, Jet Propulsion Laboratory

The fact that no comprehensive set of solutions, such as has been found for the two-body problem, exists for the three-body problem makes finding trajectories for particular mission design applications difficult. Previous research has had success in locating useful trajectories by utilizing known quasi-periodic orbits and their invariant manifolds. It is certain that other desirable trajectories exist that are associated with unknown quasi-periodic orbits, or in regimes that have simply not yet been analyzed. Therefore, it is desirable to search the design space in a systematic way while focusing on particular regions that may be useful to mission design. One simple way to do this is by selecting many initial conditions in some region of interest and integrating the resulting trajectories using a supercomputer.

07:50 **AAS 05 - 221** **Trajectories Leaving a Sphere in the Restricted Three Body Problem**

C. von Kirchbach, H. Zheng, J. Aristoff, and J. Kavanagh, University of California at Los Angeles, B.F Villac, California Institute of Technology, and M.W.Lo, Jet Propulsion Laboratory

The set of trajectories leaving/impacting the surface of the Galilean satellites of Jupiter is analyzed from theoretical and computational viewpoints in order to characterize the sensitive impact regions for spacecraft trajectory applications, as well as the main dynamical structures influencing this set of trajectories. Several dynamical criteria, such as the number of revolution around each primary and the impact locations (in the event of impact), are used to compute maps of the escape/impact dynamics and assess the importance of different dynamical regimes. In particular, the relation between a two body dynamics approximation, the stable/unstable manifolds associated with the colinear libration point dynamics and these impact/escape maps are analyzed in more details.

08:15 **AAS 05 - 222** **Shoot the Moon 3D**

Jeffrey S. Parker, Colorado Center for Astrodynamics Research, and Martin W. Lo, Jet Propulsion Laboratory

Many efforts have been made to reduce the cost of a mission to the moon. One of the earliest was by Charles Connely where he used a low energy transfer based on the dynamics of the 3-body problem. However, since the transfer time required several months, it was unsuitable for human missions to the Moon and it was almost forgotten. Connely's foundational work on the 3-body problem is fundamental to the methods described in this paper. In 1991, the Japanese Hiten mission implemented a low-energy transfer trajectory to the moon, which allowed the spacecraft to become captured by the moon using less energy than that required by a standard Hohmann transfer.

08:40 **AAS 05 - 218** **An Investigation of Near Periodic Orbits about L4 in the Sun Perturbed Earth-Moon System**

Jean-Philippe Munoz and Bob E. Schutz, University of Texas at Austin

The purpose of this study is to find periodic and/or stable orbits around L4 in the Earth-Moon system under the perturbation of the Sun. First, the bicircular problem is considered, in which the Moon and the Sun are in a circular orbit around the center of mass of the Earth and the Moon. Then the eccentricity of the Moon's orbit and the inclination of the Sun's orbit are added to the model. Periodic orbits will be sought by using a targeting algorithm that would find orbits that match their initial position and velocity after a given time.

09:05 **Break**

Session 22: Genesis II
Chair: Prasun Desai
NASA Langley Research Center

09:30 **AAS 05 - 223** **Human Safety Analysis for the Genesis Sample Return Mission**

Geoffrey Wawrzyniak and Tom Wahl, Jet Propulsion Laboratory

In order to certify that the risks of the Genesis Sample Return were acceptable to NASA and the Utah Test and Training Range (the target site), a thorough analysis of collective and individual risk for the public and mission personnel was performed. This analysis was performed by finding the probability of landing in an inhabited area based on a Gaussian distribution multiplied by the uniform probability of casualty in that area. This process was repeated for all areas in two different data sets. Both nominal and off-nominal scenarios had to be considered, so contour analyses based on a grid of representative ellipses were performed to satisfy the entire Northwest Utah and Northeast Nevada region.

09:55 **AAS 05 - 224** **Public Risk Assessment of Off-Nominal Genesis Entries**

Gavin Mendeck and Binaifer Kadwa, NASA Johnson Space Center

Public risk estimations were among the preparations for the Genesis sample return capsule entry. Personnel at the Johnson Space Center were requested to provide estimates of the public risk to the Jet Propulsion Laboratory for off-nominal entries. These scenarios dealt with incomplete trajectory maneuvers that would result in the capsule landing outside of the controlled Utah Test and Training Range. Using a conservative approach to the inputs and assumptions, the off-nominal entries were demonstrated to fall within the project risk limits.

10:20 **AAS 05 - 225** **Genesis Backup Orbit Contingency Analysis**

Robert Haw, Michael Wilson, Roby Wilson, Ken Williams, Jet Propulsion Laboratory

The Genesis spacecraft returned its sample return capsule (SRC) to Earth on Sept 8, 2004. Before releasing the capsule however, the spacecraft was uniquely positioned to be able to offer an alternate, backup return-strategy (subsequent to the first attempt) should the initial sequence of commands be unsatisfactory in establishing the requisite conditions for SRC release. So as part of the preparation for the SRC return, Genesis planners also designed a delayed Earth-return trajectory as a contingent strategy in case of a possible SRC-release abort.

10:45 **AAS 05 - 226** **Genesis Extended Mission Trajectory Design**

Roby S. Wilson, Jet Propulsion Laboratory

As the fifth Discovery mission, the Genesis spacecraft was launched on August 8, 2001 with a science objective to collect solar wind samples for a period of approximately two and a half years while in orbit in the vicinity of the Sun-Earth L1 Libration point. On September 8, 2004, the Genesis sample return capsule returned to Earth with its collection of solar wind samples. Although the capsule did not get captured in the intended manner, from a navigational perspective the mission was a complete success. Now that the samples have been delivered, the remaining portion of the spacecraft is still fully functional, and has a generous amount of maneuver capability remaining.

Session 23: Tethers II

Chair: TS Kelso

Analtyical Graphics Inc. / CSSI

09:30 **AAS 05 - 227** **Evaluation of Command Generation Techniques for Tethered Satellite Retrieval**

Michael Robertson, Andrew Timm, and William Singhose, Georgia Institute of Technology

This paper describes the implementation of the command generation technique called input shaping to the retrieval of tethered satellite systems. It will quantify the percent reduction in retrieval time achieved when using command generation techniques and the ability of command generation to reduce the in-plane swing angle. Results are shown for both a simple tether model and one that accounts for the tether's flexibility. Combining command generation and feedback control can lead to the reduction of tether retrieval time, while keeping in-plane swing angles within acceptable limits.

09:55 **AAS 05 - 228** **Preliminary Orbit Determination of a Tethered Satellite Using Angles-Only Measurements**

Cherish Qualls and David A. Cicci, Auburn University

The presence of a tether force creates perturbations on a satellite's motion. Classical preliminary orbit determination (POD) methods are unable to account for this modified Keplerian motion and result in inaccurate orbital elements. Modifications have been made to two classical angles-only POD methods to allow for the identification of a tethered satellite. The performance of these methods was evaluated through scenarios of differing tether lengths, observation noise levels, and libration angles. For comparison purposes, a modified POD technique utilizing range measurements in addition to angular observations was used. Real-world data was also used to validate the modified angles-only methods.

10:20 **AAS 05 - 229** **Tethered Satellite Identification with Mixed Observation Data**

Mark Faulstich, Air Force Space Command 17th Test Squadron, and Steve Tragesser, University of Colorado

Tethered satellite systems present a challenge to tracking systems and software, because the end bodies do not follow Keplerian motion. A robust and efficient algorithm is warranted that can identify if a satellite is tethered. This research develops an approach that estimates the tether length in order to minimize an objective function of the residuals. Tethered satellite identification is then based on the estimated tether length. A unique feature of the filter is that is permits mixed observations of either end mass, but there is no a priori knowledge of which body is associated with any given data point.

Session 24: Attitude II
Chair: Richard Longman
Columbia University

09:30 **AAS 05 - 230** **Performance Analysis and Compensator Design in Higher Order Repetitive Control**

Chun-ping Lo and Richard W. Longman, Columbia University

Repetitive control (RC) has been shown to be effective in eliminating periodic disturbances in many dynamic systems. It is done by learning from the error in previous periods of the disturbance, to adjust the command to a feedback control system in the present period. An important spacecraft application for RC is to cancel the effects of slight imbalances in momentum wheels, reaction wheels, control moment gyros, or cryo pumps on board. Imbalances in such system create vibrations of the spacecraft structure, and disturb fine pointing experiments or microgravity experiments.

09:55 **AAS 05 - 231** **Cancellation of Unknown Periodic Disturbance by PLL/Adaptive Matched Basis Function Repetitive Control**

Masaki Nagashima and Richard W. Longman, Columbia University

Various spacecraft have a dominant source of vibrations, such as a momentum wheel or a cryo pump. Other spacecraft have multiple unrelated sources of vibrations with frequencies that can evolve with time. When there is some fine pointing equipment on board, one needs to have a way to isolate the equipment from such sources. Passive methods are limited in their ability to isolate equipment, and typical feedback control methods are also limited unless they are designed specifically to address a specific disturbance frequency. Repetitive control is one form of control that addresses all frequencies of a certain period.

10:20 **AAS 05 - 232** **Comparison of Methods for Rejecting Multiple Frequency Disturbance with Frequency Tracking**

Masaki Nagashima and Richard W. Longman, Columbia University

Spacecraft often have multiple rotating parts, and slight imbalances in these cause vibrations that disturb fine pointing equipment. It is very typical to have three reaction wheels, one for each principal axis. To avoid going through zero velocity, these have a nominal spin rate. And their speed is changed up or down to cancel the effects of torque disturbances to the attitude of the spacecraft. In addition, secular perturbations can cause the speed to increase over time. With fine pointing equipment onboard, one needs some way to isolate the equipment from these vibrations.

10:45 **AAS 05 - 233** **Time-Optimal Magnetic Attitude Control Toward Real-time Applications**

Hui Yan, Texas A&M University, I. Michael Ross, Naval Postgraduate School, and Kyle T. Alfriend, Texas A&M University

Magnetic actuators for momentum dumping have been used in many spacecraft. Of late, magnetic actuators have also been proposed as a sole means for attitude control, particularly for small inexpensive spacecraft. In this paper, we investigate the use of magnetic torque for the time-optimal slew maneuver using DIDO. The parameters of the numerical example correspond to that of NPSAT1, a small satellite being built at the Naval Postgraduate School, and due to launch in January 2006. The numerical experiments reveal that real-time optimal solutions can be obtained.

AUTHOR INDEX

Author	Session #
Abdelkhalik, Ossama	9, 14
Aiello, J.	15
Akins, Keith	5
Alemany, Kristina	14
Alfano, Salvatore	5
Alfriend, Kyle T.	12, 24
Anderson, Rodney	21
Antreasian, Peter	3
Arbinger, Christian	10
Aristoff, J.	21
Bae, Sungkoo	2
Bainum, Peter	9
Baird, Darren	4
Balakrishnan, S.N.	16
Baron, Sally	17
Berry, Matt	12
Berryman, Johnathan	1
Bhaskaran, Shyamkumar	4
Bishop, Robert	6
Bock, Hans Georg	11
Bruccoleri, Christian	9
Brunet, Charles-Antoine	8
Burge, Legand	13
Cangahuala, L. Alberto	8
Capo-Lugo, Pedro	9
Carlson, Brian	16
Carranza, E.	13
Cefola, Paul	7, 12
Chakravorty, Suman	10
Chao, Chia-Chun	16
Chavez, Frank	1, 10
Choe, Nammi Jo	19
Cicci, David	23
Cochran, John	16, 19
Coffey, Shannon	5
Cooley, D.	10
Cotter, D.	13
Cox, Timothy	5
Craig, Diane	4
Criddle, Kevin	3
Dahlke, Scott	7
D'Amico, Simone	10
Davighi, A.	20
Davis, Mark	5
de Lafontaine, Jean	2, 8, 20
Demcak, Stuart	20
Desai, Prasun	4
Desrocher, Dave	17
Dunham, David	8, 13

Author	Session #
Efron, L.	13
Eller, Thomas	5
Epstein, Kenny	19
Erwin, R. Scott	9
Fahnestock, Eugene	9
Farquhar, Robert	13
Faulstich, Mark	23
Finkleman, David	17
Finzi, A.	20
Finzi, Elvina	20
Folcik, Zachary	7
Ford, Lester	5
Fox, Kathy	19
Fuller-Rowell, T.J.	6
Gabor, Michael	7, 17
Galvez, Andres	8
Geller, David	10, 20
Gill, Joseph	13
Gollu, Narendra	2
Graat, Eric	4
Gromov, Konstantin	3
Guzman, Jose	10, 14
Hack, Kurt	13
Hadley, Hugh	5
Halsell, Allen	20
Han, Dongsuk	4
Hanna Prince, Jill	20
Hanninen, G.	20
Haw, Robert	22
Healy, Liam	12
Hedo, Jose Manuel	12
Helfrich, Clifford	4
Henderson, Troy	11
Higa, Earl	20
Highsmith, Dolan	20
Hollm, Richard	5
Hoots, Felix	5, 17
Howell, Dale	4
Hughes, Steven	1, 10
Hujsak, Richard	7
Huntington, Geoffrey	1
Hurtado, Johnny	6, 11
Hussein, Islam	10
Hyland, David	10
Infeld, Samantha	14
Ionasescu, Rodica	3
Izzo, Dario	8, 9
Jah, Moriba	20
Jo, J.H.	16
Jo, Jung Hyun	19
Johnson, Rebecca	10

Junkins, John 6, 11
Kadwa, Binaifer 22
Kasdin, N. Jeremy 15
Kavanagh, J. 21
Kelm, Bernie 5
Kelso, T.S. 5
Kim, Yuchan 7
Kim, Yuri 2
Koleman, Egemen 15
Kopke, Kenneth 5
Kron, Aymeric 20
Kulkarni, Tapan 3
Kwong, Jeff 10
Lam, Try 3
Lang, Thomas 9
Langmaier, Jerry 3
Lara, Martin 12
Lawrence, Dale 21
Lebel, Karina 8
Lee, D. 16
Lemay, Charles-Etienne 8
LePeuvedic, Catherine 2, 20
Lewis, George 4
Li, Hongming 16
Lisano, Mike 21
Lo, Chun-ping 24
Lo, Martin 21
Long, Stacia 20
Longman, Richard 11, 24
Lovell, T. Allan 1, 10, 16
Lyon, Richard 7
Lyons, Dan 4
Mackison, Don 11
Maclay, Timothy 9
Mafficini, A. 20
Markot, Mihaly Csaba 9
McAdams, James 13
McAllister, J. Greg 4
McElrath, Tim 4
McLaughlin, Timothy 5
Meek, M. Cameron 3
Mendeck, Gavin 22
Mettler, Edward 3
Miller, James 13
Minter, Cliff 6
Miotto, Pierre 19
Mitchell, Megan 15
Mitchell, Scott 8
Montenbruck, Oliver 10
Mortari, Daniele 3, 9, 14
Mosher, Todd 10, 15
Muhonen, Daniel 8
Munoz, Jean-Philippe 21
Murray, Walter 14
Nagashima, Masaki 24
Nann, Isabelle 9
Natarajan, Arun 18
Nazarenko, Andrey 12
Neubauer, Jeremy 13
Neveu, David 8
Ocampo, Cesar 6
Olds, John 14
Ongaro, Franco 8
Page, B. 13
Parcher, Daniel 3
Park, Keun 9
Park, Ryan 12
Parker, Jeffrey 21
Paskowitz, M.E. 15
Patel, Prashant 6
Pelaez, J. 12, 18
Pernicka, Henry 16
Peterson, Glenn 5, 16
Petropoulos, Anastassios 11
Phan, Minh 11
Pierce, Geoffrey 5, 5
Pittelkau, Mark 2
Potts, Christopher 4
Quadrelli, Marco 3, 15
Qualls, Cherish 23
Quick, Megan 7
Randall, Chris 19
Rao, Anil 1
Reasbeck, Dan 19
Reynerson, Charles 12
Rim, Hyung-Jin 7
Robertson, Michael 23
Rodriguez de Andres, P. 12
Ross, I. Michael 24
Roundhill, Ian 3
Sabol, Chris 7
Sakai, Tadashi 14
San-Juan, Juan 12
Sanjurjo, M. 18
Schaub, Hanspeter 1, 18
Scheeres, Daniel 6, 10, 12, 15
Schutz, Bob 2, 7, 21
Scott, Christopher 1
Seago, John 5
Segerman, Alan 5
Sengupta, Prasenjit 11
Sharma, R. 14
Sims, Jon 3
Sinclair, Andrew 6

Singhose, William 23
Singla, Puneet 11
Six, Stephen 5
Smith IV, Walter 5
Sousa, Mark 5
Spencer, David 1
Stanbridge, D. 13
Stauch, Jason 3
Striepe, Scott 20
Subbarao, Kamesh 16
Summers, Byron 5
Swartwout, Michael 13
Taylor, A. 13
Taylor, Tony 13
Timm, Andrew 23
Tollefson, Mark 1
Tragesser, Steve 23
Vadali, Srinivas 14, 11
Vallado, David 17
Van Beusekom, Craig 19
Van Cleve, Jeffrey 8
Vaughan, Andrew 20
Villac, B.F. 15, 21
Visser, Benjamin 7
von Kirchbach, C. 21
Voth, Christopher 4
Wahl, Tom 22
Walker, Roger 8
Wang, Zhong-Sheng 16
Wawrzyniak, Geoffrey 4, 22
Weeks, Michael 14
Weglian, John 13
Welsh, Sam 16
Wiese, David 7
Williams, Bobby 13
Williams, Kenneth 4, 22
Williams, Paul 6, 18
Williams, Trevor 16
Wilson, Michael 22
Wilson, Roby 4, 22
Woffinden, David 10
Yan, Hui 24
Yanushevsky, Rafael 19
Yoon, SungPil 2, 7
You, Tung-Han 20
Young, Quinn 10
Yurasov, Vasiliy 12
Zedd, Michael 5
Zhao, Jie 11
Zheng, H. 21
Zimmer, Scott 6
Zurbuchen, Thomas 6

RECORD OF MEETING EXPENSES

15th AAS/AIAA Space Flight Mechanics Meeting

Copper Mountain Conference Center
Copper Mountain, Colorado
23-27 January 2005

Name:________________________________ Organization: ______________________
Last   First

Registration Fee: AAS or AIAA Member @ $300 ______________________
Non-Member @ $385 ______________________
Student @ $100 ______________________

Conference Proceedings ___ @ ______________________

Technical Paper Sales @ $1/paper ______________________

TOTAL: ______________________

Technical Paper Purchases:

# of Papers	Cost	Date
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Copper Mountain Conference Planner

		Sunday				
R	P					
		4:00 - 5:00 PM	Registration, Kokopelli			
		5:00 - 6:00 PM		Reception, Kokopelli		
		6:00 - 7:00 PM				
		7:00 - 8:00 PM				
		8:00 - 9:00 PM	AIAA COS, Hasty's			

Copper Mountain Conference Planner

Monday

Time	Bighorn C1	Ptarmigan A2	Ptarmigan C2
6:30 - 7:00 AM	Speakers Breakfast, Hasty's		
	1 Bighorn C1 Formation Flying (I)	2 Ptarmigan A2 Attitude (I)	3 Ptarmigan C2 Interplanetary (I)
7:00 - 7:25 AM			
7:25 - 7:50 AM			
7:50 - 8:15 AM			
8:15 - 8:40 AM	Morning Break		
8:40 - 9:05 AM			
9:05 - 9:30 AM			
9:30 - 9:55 AM			
10:00 AM - Noon	AIAA TC Hasty's		
12:00 - 1:30 PM	Committee Luncheon, Bighorn CCC		
1:30 - 3:30 PM	AAS TC Hasty's		
	4 Bighorn C1 Genesis (I)	5 Ptarmigan A2 Space Surveillance	6 Ptarmigan C2 Optimization (I)
4:00 - 4:25 PM			
4:25 - 4:50 PM			
4:50 - 5:15 PM			
5:15 - 5:40 PM	Afternoon Break		
5:40 - 6:05 PM			
6:05 - 6:30 PM			
6:30 - 6:55 PM			
7:45 - 9:15 PM	Brouwer Award, Bighorn C1		

Tuesday

Time	Bighorn C1	Ptarmigan A2	Ptarmigan C2
6:30 - 7:00 AM	Speakers Breakfast, Hasty's		
	7 Bighorn C1 Orbit Determination	8 Ptarmigan A2 Near Earth Objects	9 Ptarmigan C2 Constellations
7:00 - 7:25 AM			
7:25 - 7:50 AM			
7:50 - 8:15 AM			
8:15 - 8:40 AM	Morning Break		
8:40 - 9:05 AM			
9:05 - 9:30 AM			
9:30 - 9:55 AM			
9:55 - 10:20 AM			
	10 Bighorn C1 Formation Flying (II)	11 Ptarmigan A2 Identification Controls	12 Ptarmigan C2 Propagation
4:00 - 4:25 PM			
4:25 - 4:50 PM			
4:50 - 5:15 PM			
5:15 - 5:40 PM	Afternoon Break		
5:40 - 6:05 PM			
6:05 - 6:30 PM			
6:30 - 6:55 PM			
7:15 - 9:30 PM	Evening Social, South Hall		

Wednesday

Time	Bighorn C1	Ptarmigan A2	Ptarmigan C2
6:30 - 7:00 AM	Speakers Breakfast, Hasty's		
	13 Bighorn C1 Interplanetary (II)	14 Ptarmigan A2 Optimization (II)	15 Ptarmigan C2 Orbital Mechanics
7:00 - 7:25 AM			
7:25 - 7:50 AM			
7:50 - 8:15 AM			
8:15 - 8:40 AM	Morning Break		
8:40 - 9:05 AM			
9:05 - 9:30 AM			
9:30 - 9:55 AM			
	16 Bighorn C1 Formation Flying (II)	17 Ptarmigan A2 Open Astrodynamics	18 Ptarmigan C2 Tethers (I)
4:00 - 4:25 PM			
4:25 - 4:50 PM			
4:50 - 5:15 PM			
5:15 - 5:40 PM	Afternoon Break		
5:40 - 6:05 PM			
6:05 - 6:30 PM			
6:30 - 6:55 PM			

Thursday

Time	Bighorn C1	Ptarmigan A2	Ptarmigan C2
6:30 - 7:00 AM	Speakers Breakfast, Hasty's		
	19 Bighorn C1 Rendezvous	20 Ptarmigan A2 Mars Missions	21 Ptarmigan C2 3-Body
7:00 - 7:25 AM			
7:25 - 7:50 AM			
7:50 - 8:15 AM			
8:15 - 8:40 AM			
8:40 - 9:05 AM			
9:05 - 9:30 AM	Morning Break		
	22 Bighorn C1 Genesis (II)	23 Ptarmigan A2 Tethers (II)	24 Ptarmigan C2 Attitude (II)
9:30 - 9:55 AM			
9:55 - 10:20 AM			
10:20 - 10:45 AM			
10:45 - 11:15 AM			
12:00 PM		Conference Ends	