Conference Program

AAS/AIAA Astrodynamics Specialists Conference

August 7-11, 2005
Lake Tahoe, California

American Astronautical Society

AIAA

AAS General Chair
Kathleen Howell
Purdue University

AAS Technical Chair
Bobby Williams
KinetX, Inc

AIAA General Chair
Felix Hoots
AT&T

AIAA Technical Chair
Louis D'Amario
Jet Propulsion Laboratory

Program cover design & printing costs sponsored by:

KINETX

Space Navigation and Flight Dynamics Practice

Systems & Software Engineering

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General Information

Registration

The following registration fees are in effect for this conference:

- AAS or AIAA Members **$290**
- Nonmembers (includes one year membership in the AAS) **$375**
- Full-time Students **$90***
- Retired Professionals **$90***

* Does not include ticket to Monday social event.

The registration desk will be open at the following times:

• Sunday Aug 7	4:00 – 7:00 PM	
• Monday Aug 8	7:00 – 11:30 AM	1:30 – 5:30 PM
• Tuesday Aug 9	7:00 – 11:30 AM	1:30 – 5:30 PM
• Wednesday Aug 11	7:00 – 11:30 AM	1:30 – 5:30 PM
• Thursday Aug 12	7:00 – 11:30 AM	

Conference Proceedings

The proceedings are available for purchase at a reduced pre-publication 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 as follows:

- Conference Rate **$240**
- Post-published List Price **$500 (approximate)**
- List Price with Author Discount **$250 (approximate)**

Local Information

South Lake Tahoe, California
"Where the sun shines over 300 days a year!"

As America's largest alpine lake, 12 miles wide and 22 miles long, it's easy to see that summertime is fun time at Tahoe. The recreation at this mountain vacation paradise is virtually unlimited. Hiking and biking, world class golf, water sports, paddlewheel boat cruises, trail riding and so much more.

Lake Tahoe Facts

Lake Tahoe is the largest alpine lake in North America. It is 12 miles wide, 22 miles long, and has 72 miles of shoreline.

Lake Tahoe's surface elevation is 6,223 feet above sea level.

Lake Tahoe has a dry and comfortable climate with an 80 percent chance of sunshine throughout the year. The area averages 409 inches of snowfall per year.

Visit the **South Lake Tahoe Chamber of Commerce** website **www.tahoeinfo.com** to find visitor and travel information, all about South Lake Tahoe, and a myriad of great links. This community at the lake features an array of accommodations, shopping, restaurants, attractions, entertainment, museums, art galleries, and more!

Embassy Suites Hotel Lake Tahoe Resort

Embassy Suites Hotel Lake Tahoe Resort offers first-rate luxury in the heart of South Lake Tahoe. All reservations include a two-room suite, complimentary cooked-to-order breakfast, and evening reception with your favorite beverages. Embassy Suites is proud to be the largest all-suite resort in beautiful Lake Tahoe. Located only minutes from endless Tahoe recreation (including walking distance from the Gondola at Heavenly Ski Resort), world-class nightlife and gaming, and family adventures, Embassy Suites is a home away from home.

The staff at the hotel is on-site and ready to do all they can to ensure an enjoyable time at Embassy Suites. Once here, every guest is encouraged make the staff aware of additional assistance that can be provided to ensure a more comfortable stay. The 24-hour manager-on-duty is happy to assist every visitor and handle all requests.

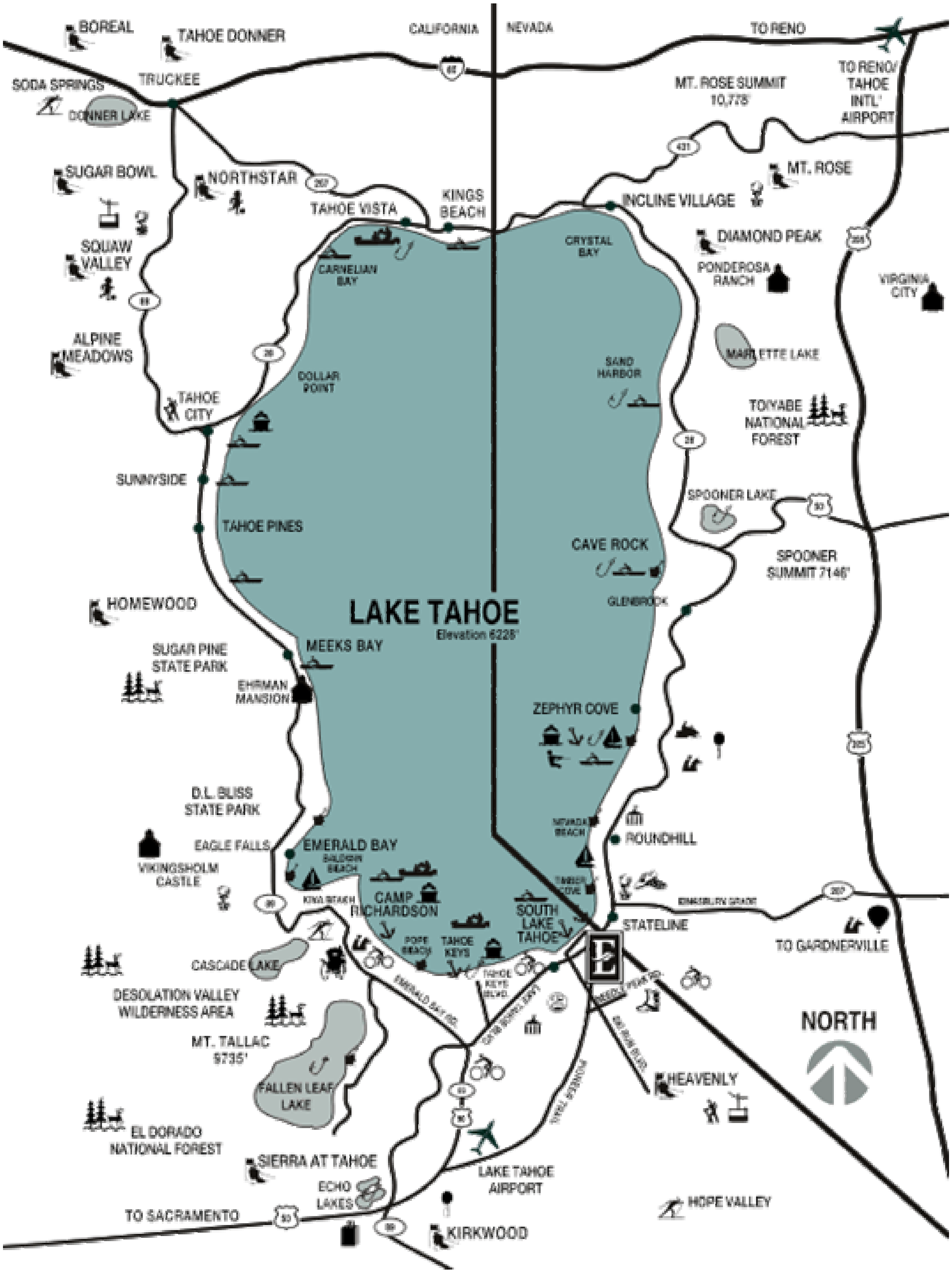
Please take a look at the resort website **www.embassytahoe.com** prior to arrival for additional information. Contact the hotel via phone 530-544-5400 / 877-497-8483 or email **info@embassytahoe.com** if questions arise in connection with the hotel.

Getting to South Lake Tahoe

Getting to South Lake Tahoe by car is a relatively short drive from major cities in California and Nevada. The drive promises beautiful scenery along the way, and culminates with the incredible expanse of Lake Tahoe.

One can fly into Reno/Tahoe International Airport to get to the hotel. With 25 flights out of Northern California and 19 out of Southern California, Reno/Tahoe International Airport has a total of 252 flights daily. Flying non-stop from 24 destinations and direct (one stop) from 17 destinations, getting to South lake Tahoe is easy.

South Tahoe Express provides worry-free year-round transportation, with non-stop service from Reno/Tahoe International Airport to South Lake Tahoe. There are 14 regular departures daily to Embassy Suites from the departure lounge located in the Baggage Claim area at the Reno/Tahoe International Airport. For information, call 1-866-89TAHOE (1-866-898-2463).



Getting Around

Casinos along Tahoe's South Shore operate convenient complimentary shuttles. Other free shuttles will take you to the Tahoe Queen and M.S. Dixie II paddle-wheelers for day and evening cruises on the lake. In winter, the ski shuttle is an easy way to get to and from area resorts. For information regarding shuttles, ask your concierge or front desk staff.

For sightseers and information seekers, the "Nifty 50" trolleys are an interesting option. Geared to visitor's interests, the open trolleys operate June through Labor Day, ferrying passengers from Harvey's to Kiva Beach on one route and from the Heavenly Tram or Zephyr Cove on another. Drivers provide interpretive information and continuous narration about sites and scenes along each one-hour route.

Area Attractions

Art Galleries

Borg & Night
Phone: 530.541.8438

Eagle Valley Frames & Art Gallery
Phone: 530.544.4099

Hanifin's Art and Antiques
Phone: 530.542.4663

Lake Tahoe Community College
Phone: 530.541.4660

Low Impact Wildlife Photography
Phone: 530.577.4101

Northstar
Phone: 530.562.1010

Paper & Gold Gallery
Phone: 775.588.4438

Sierra Galleries
Phone: 775.588.8500

Zephyr Cove Art Gallery
Phone: 775.588.0578

Balloon Rides

Balloons Over Lake Tahoe
Phone: 530.544.7008

Lake Tahoe Balloons
Phone: 800.872.9284

Mountain High Balloons
Phone: 530.587.6922

Beaches

Baldwin Beach

Cave Rock
Phone: 775.831.0494

Connolly Beach

El Dorado Beach

Emerald Bay Beach

Fallen Leaf Lake

Kiva Beach

Lakeside Beach

Nevada Beach

Pope Beach

Reagan Beach

Round Hill Pines Beach

Zephyr Cove Beach

Biking

Anderson Bicycle Rental
Phone: 530.541.0500

The City Bicycle Trail

Golf Courses

Bijou Municipal Course
Phone: 530.542.6097

Dayton Valley
Phone: 775.246.7888

Edgewood Tahoe Golf Course
Phone: 775.588.3566

Incline Village
Phone: 800.236.8753

Lake Tahoe Golf Corse
Phone: 530.577.0788

Sierra Nevada Golf Ranch
Phone: 775.782.7700

Squaw Creek
Phone: 530.583.6300

Tahoe Paradise Golf Course
Phone: 530.583.6300

The Golf Club at Genoa Lakes
Phone: 775.782.4653

Miscellaneous

National Embassy Suites Hotels
www.embassysuites.com
Embassy Suites Hotels Corporate Site, a proud member of the Hilton family of fine hotels.

Ski Resorts

Heavenly Ski Resort
Phone: 775.586.7000

Kirkwood Mountain Resort
Phone: 209.258.6000

Wellness

An Association of Massage Therapist
www.massagetherapylaketahoe.com

Hiking Information

HIKING AROUND THE LAKE

ANGORA LAKES TRAIL — EASY — 1/2 MILE
Take 89 north approximately 3 miles from South Lake Tahoe to Fallen Leaf Road and turn left. Turn left at the first paved road. Continue to Forest Service Road 12N14 and turn right. Continue past Angora Lookout to the road's end at the parking lot.

BAYVIEW TRAIL — STRENUOUS — 1-5 MILES
Take 89 north from South Lake Tahoe approximately 8 miles to the Bayview Campground across from Inspiration Point. Parking is located at the far end of the campground.
WILDERNESS PERMIT REQUIRED
1 mile to Granite
4 miles to Azure
5 miles to Dick

BIG MEADOW — 2 MILES
Off 89 about 8 miles south of Meyers

CASCADE CREEK FALL TRAIL — EASY — 1 MILE
Take 89 north from South Lake Tahoe approximately 8 miles to the Bayview Campground across from Inspiration Point. Parking is located at the far end of the campground.

CLARK TRAIL — STRENUOUS — 1.6 MILES
Take Hwy 89 north from South Lake Tahoe to Fallen Leaf Lake Road. Parking is located at the Glen Alpine Trailhead. From the parking lot, walk back down the road to the junction of Fallen Leaf Lake Road. Look for the small church to your right. A little post located behind the church marks the hard to find trailhead.

DESOLATION WILDERNESS
This is the most heavily used wilderness area per acre in the United States. It contains 63,475 acres of sub-Alpine forests, granite peaks, and glacial lakes and valleys. Portions of the Pacific Crest National Scenic Trail and Tahoe Rim Trail pass through this area. Travel is limited to hikers and pack animals. Mountain bikes are not allowed. All persons entering Desolation Wilderness must obtain a wilderness permit and pay camping fees. Day-hikers may self-register at the trailheads, but overnight users must obtain a permit and pay fees in person. Since this spot is so popular, a wilderness permit quota system is in place for overnight campers from June 15th to Labor Day. Reservations for overnight permits are available only at the El Dorado National Forest Information Center. Campfires are prohibited at all times and you may only use portable stoves.

DONNER PASS-PACIFIC CREST TRAIL — VARIABLE
Less than 2 miles off 89 west of Truckee.

EAGLE FALLS TRAIL — MOD-STRENUOUS — 4.5-5 MILES
Take 89 north approximately 8 miles from South Lake Tahoe to Eagle Falls Picnic Area on the left. WILDERNESS PERMIT REQUIRED

Moderate: 4.5 miles to Dicks, Upper and Middle Velmas
Strenuous: 5 miles to Fontanills

ECHO LAKES TRAIL **MODERATE** **4-6 MILES**
US 50 to Echo Summit and turn onto Johnson Pass Road. Stay left and the road will lead you to the parking area by lower Echo Lake. WILDERNESS PERMIT REQUIRED.
2.5 Miles to NW corner of Upper Echo
4 miles to Tamarack
5 miles to Lucille and Margery
5 miles to Lake of the Woods
6 miles to Aloha

GLEN ALPINE TRAIL **MOD-STRENUOUS** **2-6 MILES**
Hwy 89 north approximately 3 miles from South Lake Tahoe to Fallen Leaf Road. Continue until you see the Glen Alpine trailhead sign and turn left. Trailhead parking is across from Lilly Lake. WILDERNESS PERMIT REQUIRED
2 miles to Grass Lake
4 miles to Susie
5 miles to Heather
6 miles to Aloha
4.5 miles to Half Moon
5.2 miles to Alta Morris
6 miles to Tallac - Strenuous

GRANITE CHIEF WILDERNESS
This wilderness area overlooks the northwest portion of the Lake Tahoe Basin and is adjacent to the Alpine Meadows and Squaw Valley Ski resorts. Not as crowded as Desolation, hikers are not required to have permits but campfire permits are required.

FROG & WINNEMUCCA LAKES **2 MILES**
Hwy 88 south of the Carson Pass

MARLETTE LAKE **5 MILES**
Off Hwy 28 at Spooner Lake north to the sign

MEEKS BAY TRAIL **MODERATE** **4.5-8 MILES**
Take 89 to the Meeks Bay Resort. Parking is located across the highway from the resort at a small dirt parking lot. WILDERNESS PERMIT REQUIRED
4.5 miles to Genevieve
5 miles to Craig
5.7 miles to Hidden
5.9 miles to Stony Ridge
8 miles to Rubicon

MEISS COUNTY WILDERNESS
This is another spectacular area for exploring. Though not designated wilderness by Congress, this 20 square mile area between Luther Pass (89) and Carson Pass (28) contains 6 major lakes in a glacial sub-Alpine zone. Hikers, equestrians, and mountain bikers are allowed. However, mountain bikers are not allowed in the Pacific Crest National Scenic Trail. Campfire permits are required.

MOKELUMNE WILDERNESS
Located between 88 and 4 just south of the Lake Tahoe Basin, this 105,165 acre wilderness is managed by the El Dorado, Stanislaus and Toiyabe National Forests. Wilderness permits are required for overnight visits between April1 and November 30. Wood fires are prohibited in the Carson Pass area of Frog, Winnemucca, Round Top, Fourth of July, and Emigrant Lakes.

MORAINE TRAIL **EASY** **1 MILE**
Take Hwy 89 north to Fallen Leaf Lake Road. Continue approximately 3 miles from South Lake Tahoe. Continue approximately two-thirds of a mile to Fallen Leaf Campground. Drive through the campground and park just before campsite #75 on the right. Look for trailhead.

MT. ROSE **6 MILES**
West off 89 at the Squaw Valley turnoff.

MOUNT ROSE WILDERNESS
This wilderness is one of the nation's newest designated wilderness areas and is located in the extreme northeastern portion of the Basin. Access to this scenic area can be obtained from the Mt Rose Highway (431). Permits are not required.

MT. TALLAC TRAIL **STRENUOUS** **1.7-5 MILES**
The trailhead is located approximately 3.5 miles north of South Lake Tahoe on 89. Look for the Mt. Tallac Trailhead sign directly across from the entrance to Baldwin beach and turn left down the dirt road. Continue to the trailhead parking lot. WILDERNESS PERMIT REQUIRED
1.7 miles to Floating Isle
2.5 miles to Cathedral
5 miles to Tallac

RUBICON TRAIL **MODERATE** **3-4 MILES**
Take 89 north 10 miles from South Lake Tahoe to D. L. Bliss State Park. There is a fee for day use parking.

TALLAC HISTORIC SITE **EASY** **VARIABLE**
0.3 miles on Lake of the Sky Trail at the Lake Tahoe Visitors Center or trail begins at Kiva Beach Area.

VIKINGSHOLM CASTLE **EASY** **1 MILE**
Take Hwy 89 north from South Lake Tahoe for approximately 9 miles to the parking lot on the right. Tours of Castle daily for a nominal fee.

PREY MEADOWS/SKUNK HARBOR **EASY** **1.5 MILES**
Take 28 from 50 north for approximately 2 miles. Look for an iron pipe gate on the west side of the highway. Park in one of the turnouts but do not block the gate. Walk to fork in the road. Left fork leads to Prey meadows. Right fork leads to Skunk Harbor.

MARLETTE LAKE **MODERATE** **5 MILES**
Park at the Spooner Lake Trailhead, located in Lake Tahoe Nevada State Park, just northwest of Hwy 50 and 28 junction. Parking fee required.

MT. ROSE **STRENUOUS** **6 MILES**
Take 431 (Mt. Rose Hwy) north of Incline Village. Park at the trailhead located one mile south of the summit.

RIM TRAIL NORTH **MODERATE** **5-13 MILES**
Take 50 east approximately ½ mile from the junction of 50 and 28. Parking is located just beyond the summit along the north side of the highway.
5 miles to Marlette Lake
13 miles to Tunnel Creek

RIM TRAIL SOUTH **MODERATE** **2-4 MILES**
Park at the Spooner Summit Rest Area located along US 50. The trail begins behind the Nevada Department of Transportation building.
2 miles to Duane Bliss Peak
3 miles to South Camp Peak
4 miles to Genoa Peak
2 miles to Kingsbury Grade

STATELINE LOOKOUT **EASY** **0.5 MILES**
From 28 on the north shore of Lake Tahoe, turn north on Reservoir Drive, just east of the Old Tahoe Biltmore Casino. Turn right on Lakeshore Avenue and left on Forest Service Road 1601, by the iron pipe gate. Park in the lot just below the lookout.

POPULAR SHORT HIKES

EAGLE FALLS -EAGLE LAKE: Trail starts at the Eagle Picnic Area, on Highway 89, across from Emerald Bay. It's only two miles round trip to Eagle Lake (only about one third mile to the falls): the trail varies from steep to flat and crosses over beautiful Eagle Falls on a wooden foot bridge.

RUBICON TRAIL: This shoreline route starts in D. L. Bliss State Park, about 13 miles south of Tahoe City on Highway 89. There is paved parking. The trail has moderate ups and downs, following an underdeveloped portion of Lake Tahoe's shoreline about 3 miles to the mouth of Emerald Bay. From there it follows the Bay shoreline another 1.5-2 miles to Vikingsholm. (NOTE: Vikingsholm up to Highway 89 is a steep mile, but the hearty can return along the highway instead of doubling back on the trail.) State Park fee: $3.

TUNNEL CREEK STATION: Trail road starts at Nevada Highway 28, across from Hidden Beach, about one mile past Ponderosa Ranch (no sign, look for gate). A steep trail road, about 1.5 miles each way, at the ruins of the western portal of the old log flume tunnel. Limited parking along Highway 28.

LOCH LEVON LAKES: Three beautiful glacial tarns make up the Lock Levon group. A well graded trail climbs two miles to the first lake, and reaches two more in its next mile. The island-dotted lakes are beautiful and excellent for swimming. Trailhead: Big Bend exit off Interstate 80. Look for the sign "Private Road, Public Trail" across from Big Bend Ranger Station, west of Rainbow Tavern (a good hike if you're headed for Sacramento or the Bay Area at the day's end).

MARLETTE LAKE: via North canyon. Trail starts near Spooner Lake Picnic Area, at the junction of Highway 28 and 50 (green metal gate on east side of 28). It's about five miles each way to the lake but it's mostly mild terrain (one full day will do it). Marlette is a good-sized high altitude lake. Years ago, its water was diverted to Incline Village via flume, and used to shoot logs through a tunnel to Washoe Valley for use in the Virginia City mines.

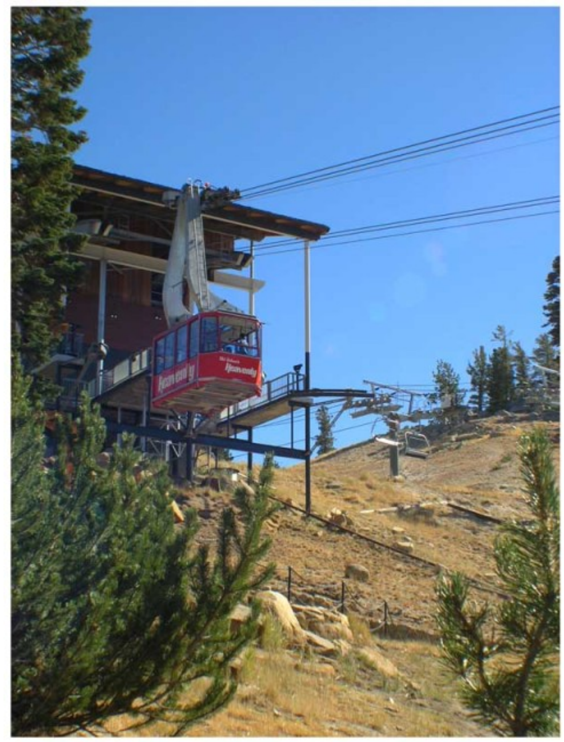
BARKER PASS TO TWIN PEAKS: From Highway 89 on West Shore, take Blackwood Canyon Road to Barker Pass. From there the road is called Forest Service Road #3. One third of a mile further is the Pacific Crest Trailhead and parking area. Traveling north approximately three miles takes you to Twin Peaks. The trail has gentle grades and offers excellent views of Lake Tahoe and nice displays of wildflowers.

SUMMIT LAKE: From I-80 take the Castle Peak exit to the south side of the freeway, then travel east about ¼ mile to the Pacific Crest Trailhead parking area. The trail travels in an easterly direction, then veers north passing through a tunnel under I-80. Shortly after the underpass, is the intersection with the Summit Lake Trail, which is clearly marked.

Special Events

Sunday, August 7
Cocktail Reception, 6:30 – 8:30 PM, Tallac/Patio

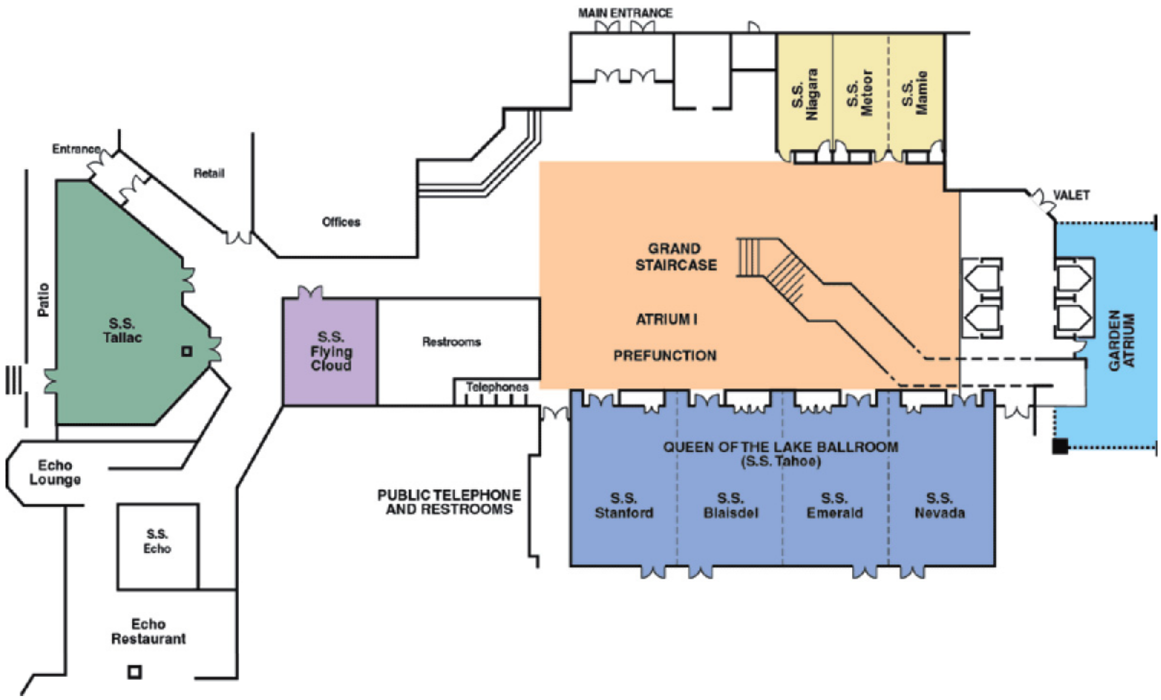
Monday, August 8
Social event, 6:30 – 9:30 PM, Lakeview Lodge, Top of the Ski Heavenly Tram (not included in price of student or retired registration)



Tuesday, August 9
Star and satellite viewing organized by Dave Vallado and T. S. Kelso. Time and location information will be available at the registration desk.

Wednesday, August 10
Cocktail Reception, 6:30 – 8:30 PM, Tallac/Patio

Conference Center Floor Plan



Technical Program

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

Technical Sessions

- This conference presents about 177 papers on space flight mechanics and related topics in 24 sessions, of which four are special invited sessions described below. Three sessions run in parallel each morning and afternoon of the conference for four days.
- Morning sessions start at 8:00 AM and usually end by 11:40 AM.
- Afternoon sessions commence at 1:30 PM and usually conclude by 5:10 PM.
- The sessions break for 20 minutes each morning (9:40 AM) and afternoon (3;10 PM). Refreshments are served in the pre-function area on the Atrium I level of the Conference Center.
- The meeting rooms are on the Atrium I level of the Conference Center.

Special Sessions

- There will be three special invited sessions as part of the technical program.
- **Neutral Density and Satellite Drag** will be examined on Monday morning.
- The operation of the **Earth Sciences Afternoon Constellation** will be discussed Wednesday afternoon.
- **Atmospheric Entry/Reentry Breakup Analysis** will be presented on Thursday morning.

Awards

- The **John V. Breakwell Student Travel Award** is presented to encourage and promote research activity in spaceflight mechanics and astrodynamics by providing financial support to one or more students presenting papers at each AAS/AIAA Spaceflight Mechanics Meetings and Astrodynamics Conferences.
- The **Best Paper Award** from the 2005 AAS/AIAA Spaceflight Mechanics Meeting in Copper Mountain Colorado, January 23-27, 2005.
- These awards will be presented at the social event on Monday evening at Lakeview Lodge, Top of the Ski Heavenly Tram.

Presentations

- Each presentation is allocated 25 minutes total time: 20 minutes for the presentation and 5 minutes for questions. Session chairs will maintain this pace to assure that presentations proceed according to the posted schedule, so that attendees may schedule their time between parallel sessions.
- Each room will be equipped with a computer with CD-ROM drive and a LCD projector. Authors should contact their session chairs at the Speaker's Briefing to get their presentations loaded if using the computer projection system.

- The **NO PAPER / NO PODIUM** rule will be enforced – i.e., speakers will not be allowed to present their paper if they have not provided 40 copies of the written paper. The session chairs will verify the delivery of a reproducible original hard copy and electronic version (PDF) for the conference proceedings plus 40 copies for every presentation in their sessions by the end of the applicable Speakers Briefing (see below). Lack of such timely delivery will constitute withdrawal of the paper.

Speakers Briefing

Authors who are making presentations and session chairs of the day will meet in the Meteor/Mamie Room for a short briefing at 7:30 AM on the morning of their session. Since breakfast is included for you at the Embassy Suites, there will be no breakfast served at this meeting.

Paper Preprints and Conference Proceedings

Authors are required to bring 40 copies of their paper to the conference. The preprints will be on sale for $1.00 per paper in the Stanford Room adjacent to the meeting rooms. Bound copies of the conference proceedings may be ordered at the registration desk at a reduced prepublication cost. Orders for the conference proceedings will be accepted at the time of registration. After the conference, the proceedings will approximately double in cost.

Committee Meetings

Committee meetings will be held according to the following schedule in the Meteor/Mamie Room:

Joint AAS/AIAA TC Meeting	Monday	12:00 – 1:30 PM
AAS Space Flight Mechanics TC	Tuesday	12:00 – 1:30 PM
AIAA Astrodynamics TC	Wednesday	12:00 – 1:30 PM
AIAA Committee on Standards	Thursday	12:00 – 1:30 PM

Reminder for Winter 2006 Meeting

16th AAS/AIAA Space Flight Mechanics Meeting

January 22-26, 2006

Westin Innisbruck Golf Resort – Tampa, Florida

Abstract Deadline: October 1, 2005

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

Schedule of Events

Date/Time	Event	Location
Sunday, August 7		
1600–1900	Registration	Atrium I
1830–2000	Cocktail Reception	Tallac/Patio
Monday, August 8		
0700–1130	Registration	Atrium I
0730–0755	Speakers Briefing	Meteor/Mamie
0800–1130	Paper Sales	Stanford
0800–1140	Neutral Density & Satellite Drag **(Invited)**	Blaisdel
0800–1140	Attitude Dynamics & Control I	Emerald
0800–1140	Mission Design	Nevada
0940–1000	Morning Break	Atrium I
1200–1330	Joint AAS/AIAA TC Meeting	Meteor/Mamie
1330–1730	Registration	Atrium I
1330–1730	Paper Sales	Stanford
1330–1710	Satellite Constellations & Formation Flying I	Blaisdel
1330–1710	Guidance Navigation & Control I	Emerald
1330–1710	Orbital Dynamics I	Nevada
1510–1530	Afternoon Break	Atrium I
1830–2130	Social at Lakeview Lodge	Top of the Sky Tram
Tuesday, August 9		
0700–1130	Registration	Atrium I
0730–0755	Speakers Briefing	Meteor/Mamie
0800–1130	Paper Sales	Stanford
0800–1140	Space Debris & Collision Probability	Emerald
0800–1140	Orbit Determination I	Nevada
0940–1000	Morning Break	Atrium I
1200–1330	AAS Space Flight Mechanics TC Meeting	Meteor/Mamie
1330–1730	Registration	Atrium I
1330–1730	Paper Sales	Stanford
1330–1710	Tethers and Large Space Structures	Blaisdel
1330–1710	Attitude Dynamics & Control II	Emerald
1330–1710	Trajectory Design & Optimization I	Nevada
1510–1530	Afternoon Break	Atrium I
TBD	Star & Satellite Viewing	TBD

Schedule of Events (cont.)

Date/Time	Event	Location
Wednesday, August 10		
0700–1130	Registration	Atrium I
0730–0755	Speakers Briefing	Meteor/Mamie
0800–1130	Paper Sales	Stanford
0800–1140	Satellite Constellations & Formation Flying II	Blaisdel
0800–1140	Guidance Navigation & Control II	Emerald
0800–1140	Orbital Dynamics II	Nevada
0940–1000	Morning Break	Atrium I
1200–1330	AIAA Astrodynamics TC Meeting	Meteor/Mamie
1330–1730	Registration	Atrium I
1330–1730	Paper Sales	Stanford
1330–1710	Earth Science Afternoon Constellation Ops **(Invited)**	Blaisdel
1330–1710	Trajectory Design & Optimization II	Emerald
1330–1710	Dynamical Systems Theory & Applications	Nevada
1510–1530	Afternoon Break	Atrium I
1830–2030	Cocktail Reception	Tallac/Patio
Thursday, August 11		
0700–1130	Registration	Atrium I
0730–0755	Speakers Briefing	Meteor/Mamie
0800–1130	Paper Sales	Stanford
0800–1140	Atmospheric Entry/Reentry Breakup Analysis **(Invited)**	Blaisdel
0800–1140	Low Thrust Mission & Trajectory Design	Emerald
0800–1140	Orbit Determination II	Nevada
0940–1000	Morning Break	Atrium I
1200–1330	AIAA Committee on Standards	Meteor/Mamie
1330–1730	Paper Sales	Stanford
1330–1710	Trajectory Design and Optimization III	Blaisdel
1330–1710	Attitude Dynamics & Control II	Emerald
1330–1710	Libration Point Trajectories	Nevada
1510–1530	Afternoon Break	Atrium I

Session 1: Neutral Density & Satellite Drag (Invited)

Chair: Frank Marcos
Air Force Research Laboratory

08:00 **AAS 05 - 251** **New Measurements of Thermospheric Neutral Density: A Review**
Frank A. Marcos, US Air Force Research Laboratory, Hanscom AFB

Uncertainties in neutral density variations continue to be the major source of satellite drag errors. Accurate thermospheric density measurements are critical to the development of future satellite drag forecast models. Data sets that have become available in this century include those from routine ground-based radar tracking of satellite orbital decay and from satellite-borne accelerometers, mass spectrometers and remote sensors. These measurements provide global coverage over a wide range of thermospheric altitudes and have complementary spatial and temporal capabilities. The new data provide constraints on physical model thermospheric driver estimation processes and support advanced operational assimilation forecast models.

08:25 **AAS 05 - 252** **Advances in Solar Inputs for Precision Orbit Determination**
W. Kent Tobiska, Space Environment Technologies

Three major improvements in solar irradiances for precision orbit determination in anomaly resolution and operational systems are reported. First, background solar extreme ultraviolet (EUV) irradiances are calibrated to TIMED/SEE data and we find integrated 1-40 nm bandpass energy rather than the full EUV spectrum provides better density correlations. Second, high-time resolution predictions of solar X-ray and EUV flare evolution are now being produced operationally. Flares contribute excess energy above background irradiances affecting satellite drag and attitude control. Third, researchers are studying whether additional thermospheric heating occurs from far ultraviolet wavelengths, i.e., energy not previously captured by the EUV proxies.

08:50 **AAS 05 - 253** **Long and Short Term Variations in Thermospheric Heating Sources**
Delores J. Knipp, US Air Force Academy

The Sun is the primary heating agent for the upper atmosphere. Temporal and spatial variations of solar power produce temperature changes that drive local and global circulations. On a practical level the temperature changes create density perturbations that strongly influence the dynamics of orbiting bodies in the Earth's atmosphere. This paper provides an accounting of the range and variability of three key sources of atmospheric energy over the last three solar cycles: solar radiation, Joule dissipation, and kinetic energy deposition by low-energy particles (primarily electrons). Of these the Joule dissipation associated with geomagnetic activity is the most variable.

09:15 **AAS 05 - 254** **The Semiannual Thermospheric Density Variation at Altitudes of 160-300 km**
Bruce R. Bowman, US Air Force Space Command, Peterson AFB

The semiannual thermospheric density variation is characterized at low altitudes, covering the height range of 160 to 300 km. Approximately 70,000 very accurate daily density values were computed for 1993 through 2003 using 36 highly eccentric satellite orbits. As with previous analyses by this author, the semiannual variation has been found to be variable from year to year. The magnitude of the maximum yearly difference is used to characterize the yearly semiannual variability. A high correlation has been found between this maximum difference and solar EUV values. This correlation is a function of altitude, with the correlation reversing sign as the altitude decreases from 300 km to 160 km.

09:40 **Break**

10:00 **AAS 05 - 255** **Mapping the Global Structure of Neutral Mass Density Using Data Assimilation Techniques**

Tim Fuller-Rowell, Cliff Minter, Mihail Codrescu, CIRES University of Colorado and NOAA Space Environment Center

Thermospheric models are based on the "primitive" equations used routinely in lower atmosphere general circulation models for conventional weather forecasting. For the upper atmosphere, these equations are combined with the generalized diffusion equations to predict the total neutral mass density for satellite drag applications. Recently, the physical models have been combined with observations using data assimilation techniques in order to improve specification of density. The Kalman filter is well established but the challenge in the use of the physical model is in specifying the solar and geomagnetic driver. During the filter propagation step, incorrect drivers can push the state away from observations. The non-linear nature of the response renders the conventional linear methods inappropriate, more sophisticated tools are required including the Ensemble Kalman filter.

10:25 **AAS 05 - 256** **Application Of The ARIMA Model To Analyze And Forecast The Time Series Of Density Corrections For NRLMSIS-00**

V. S. Yurasov, Space Informatics Analytical Systems (KIA Systems), Russia; A. I. Nazarenko, Space Observation Center, Russia; P. J. Cefola, Consultant in Aerospace Systems, Spaceflight Mechanics, and Astrodynamics; K. T. Alfriend, Texas A&M University

The basic statistical properties of the observed density corrections for the NRLMSIS-00 atmosphere density model are investigated. Statistical distributions, correlations, autocorrelations, and cross correlations are provided. The results suggest that time series analysis techniques may be applied to identify the nature of the phenomena represented by the density correction estimate time series. The Autoregressive Integrated Moving Average (ARIMA) method is used to construct simple scalar models describing the time series of density corrections, to smooth them, and to predict the future values of the time series using observations up to the current time. The ARIMA model represents the time series values observed at the given time instant as a linear combination of previous values of the series and a linear combination of moving averages.

10:50 **AAS 05 - 257** **Drag Coefficient Variability at 175-500 km from the Orbit Decay Analyses of Spheres**

Bruce R. Bowman, US Air Force Space Command, Peterson AFB; Kenneth Moe, Science and Technology Corp.

Drag coefficients were computed from the decay of the ODERACS spheres, the Starshine spheres, several radar calibration Calspheres, GFZ-1, and numerous Russian Taifun radar calibration spheres. Atmospheric temperature and density corrections were first determined on a daily basis using selected calibration satellites. These corrections were applied in orbit corrections, with the resulting ballistic coefficient values used to deduce the variation of the fitted drag coefficient values during the last hundred days of decay. The observed values are compared with theoretically computed physical drag coefficients. This comparison enables the determination of the bias originally introduced into the Jacchia 70 atmospheric model.

11:15 **AAS 05 - 258** **The Effects of Surface Composition and Treatment on Drag Coefficients of Spherical Satellites**

Kenneth Moe, Science and Technology Corp.; Bruce R. Bowman, Air Force Space Command, Peterson AFB

The Space Analysis Division's atmospheric density analysis project has been used to derive fitted drag coefficients for several sets of spherical satellites having different surface materials and different surface treatments. We find that the effect of surface material on the drag coefficients of smooth spheres is masked by the adsorption of atomic oxygen at altitudes near 200 km; but the effect becomes apparent at higher altitudes, where there is less atomic oxygen adsorbed on the satellite surfaces. When the spherical surfaces are interrupted by flat mirrors or solar cells the drag coefficients are measurably increased.

Session 2: Attitude Dynamics & Control I

Chair: Hanspeter Schaub
Virginia Tech

08:00 **AAS 05 - 259** **ICESat Off-Nadir Laser Targeting: Theory and Practice**
Charles E. Webb, Robert E. Harpold, Bob E. Schutz, University of Texas at Austin; Jason R. Stauch, Jet Propulsion Laboratory; Kurt M. Lorhammer, George H. Born, University of Colorado at Boulder

In January 2003, NASA's Ice, Cloud and land Elevation Satellite (ICESat) began its mission to quantify the spatial and temporal variations in ice-sheet topography. To obtain the required elevation measurements, the satellite must be rolled by up to 0.1 degree to point a laser in the on-board Geoscience Laser Altimeter System (GLAS) at reference ground tracks in the polar regions. Additional targets of opportunity can also be surveyed at roll angles as large as 5 degrees. This study evaluates the performance of the ground-based and on-board systems in planning and executing this off-nadir targeting during two of the mapping campaigns.

08:25 **AAS 05 - 260** **Precision Attitude Determination Using Gyro and Star Tracker Data With A Batch Least Squares Estimation**
Sungkoo Bae, Bob E. Schutz, The University of Texas at Austin

An extended Kalman filter (EKF) has been used for the precision attitude determination (PAD) in the ICESat mission. Some features of the real star tracker data have been sources of accuracy degradation in the PAD. Those systematic error sources should be handled by independent methods from the EKF to achieve the PAD accuracy goal. A batch method has been developed using the least squares estimation scheme. The systematic error sources associated with the star tracker data would be effectively reduced or removed in the attitude determination procedure when the batch method is used instead of the EKF.

08:50 **AAS 05 - 261** **Velocity Solution for a Spinning-Up Rigid Body Subject To Constant Body-Fixed Moments and Forces**
Mohammad A. Ayoubi, James M. Longuski, Purdue University

A spinning-up rigid body is subjected to constant transverse body-fixed forces and body-fixed torques. Because of constant torque in the spin-axis direction, the spin rate increases linearly with time. By assuming small deviations of the spin axis (with respect to an inertially fixed direction), an approximate closed-form analytical solution is obtained for the axial and transverse velocities. Numerical simulations confirm that the solutions are highly accurate when applied to typical motion of a spacecraft (such as the Galileo spacecraft).

09:15 **AAS 05 - 262** **Improved Methods to Cancel Multiple Periodic Disturbances by Repetitive Control**
Richard Longman, Columbia University; Joe W. Yeol, Polytechnic University; Yeong S. Ryu, New York City College of Technology

Fine pointing equipment such as a telescope must be isolated from vibration sources when mounted on a satellite. Slight imbalance in rotating parts produce vibrations. There can be 3 or more periods to the vibrations, and sometimes these periods are very close as in three identical control moment gyros, and sometimes the periods can cross as they evolve, as in reaction wheels. Repetitive control is an active control method that aims for zero error in the presence of a periodic disturbance. This paper develops an improved method for designing repetitive controllers to handle multiple unrelated periods, and studies their effectiveness.

09:40 **Break**

10:00 **AAS 05 - 263** **Frequency Based Optimal Design of FIR Compensators and Zero-Phase Filters for Robust Repetitive Control**
B. Panomruttanarug, R. W. Longman, Columbia University

Spacecraft often have control moment gyros or reaction wheels, and any slight imbalance impairs the performance of fine pointing equipment. Repetitive control systems learn to cancel resulting vibrations at the location of fine pointing equipment on board, by using the error in previous periods. In a previous paper, a very effective and easy to use frequency based optimization method was developed to design the compensators needed to stabilize the learning process based on a system model. This paper uses similar methods making a frequency based optimization to design zero-phase low-pass filters to robustify the design to unmodeled modes, or parasitic poles. And then the two methods are integrated to produce a practical and effective approach to creating robust repetitive control systems.

10:25 **AAS 05 - 264** **Observability and Calibration of a Redundant Inertial Measurement Unit: Illustrative Results**
Mark E. Pittelkau, Swales Aerospace

A redundant inertial measurement unit (RIMU) has $n > 3$ angular rate sensing axes. The body-to-gyro mapping matrix G and its left null space N determine observability of the calibration parameters in attitude and in a null-space rate measurement. When scale factors and misalignments are estimated, these parameters are observable in two distinct subspaces, one in attitude and one in the null-space. If only scale factors or only misalignments are estimated, then there is overlap of observablility in the measurements. It is shown that this feature can be exploited to partially maintain calibration accuracy in the absence of attitude measurements.

10:50 **AAS 05 - 265** **Sequential Attitude Estimation using Particle Filters**
Deok-Jin Lee, Kyle T. Alfriend, Keun-Joo Park, Daniele Mortari, Texas A&M University

This paper provides efficient methods for spacecraft attitude estimation by utilizing a novel simulation-based method called the particle filter for nonlinear/non-Gaussian estimation problems. The flexible nature of the particle filter renders it often being more adaptive to some features of the complex attitude systems. This work investigates a number of improvements on particle filters that are developed independently in various engineering fields. Several variants of the particle filter include the sampling important resampling, regularized particle filter, and unscented particle filter. The performance of the particle filters is compared with the extended Kalman filter and the unscented Kalman filter.

11:15 **AAS 05 - 266** **Sigma Particle Filtering for Spacecraft Attitude Estimation**
Deok-Jin Lee, Kyle T. Alfriend, Texas A&M University

In this paper an efficient particle filtering algorithm is derived for the spacecraft attitude estimation. The new particle filter is formulated by combining a sigma-point sampling method and the sequential weight update from the particle filtering. It draws sigma-point particles deterministically from various sigma boundaries instead of making random samples. The sequential weight updates are carried out by combing the measurement likelihood function used in the particle filter. The new particle filter has advantages over the standard particle filters in that it not only mitigates the computational load, but also provides results as accurate as those obtained by the standard particle filters.

Session 3: Mission Design

Chair: Jon Sims
Jet Propulsion Laboratory

08:00 **AAS 05 - 267** **Adventures in Parallel Processing: Entry, Descent and Landing Simulation for the Genesis and Stardust Missions**
Daniel T. Lyons, Jet Propulsion Laboratory; Prasun N. Desai, NASA Langley Research Center

Both Genesis and Stardust are sample return missions. Genesis has already returned to Earth and Stardust is scheduled to return on January 15, 2006. This paper will describe the Entry, Descent and Landing simulation tradeoffs and techniques that were used to provide the Monte Carlo data required to approve entry during a critical period just before entry. Only one hour was available for the simulation which propagated 2000 dispersed entry states to the ground. Creative simulation tradeoffs combined with parallel processing were needed to provide the landing footprint statistics that were an essential part of the Go/NoGo decision.

08:25 **AAS 05 - 268** **Ramifications of Communication During the Entry, Descent, and Landing Phase of the 2009 Mars Science Laboratory Mission**
Angela L. Bowes, P. Dan Burkhart, Stuart J. Kerridge, Joseph G. Neelon, William D. Strauss, Michael M. Watkins, Charles W. Whetsel, Aron A. Wolf, Jet Propulsion Laboratory

This paper addresses the assumptions, constraints, analysis, and selection of the Mars Science Laboratory launch / arrival periods and entry, descent, and landing communication strategy. The discussion details the complexity of satisfying EDL communication in the 2009 Earth-Mars opportunity while maintaining a wide landing site latitude range, remaining within the capability of the spacecraft and mission cost, and sharing the 2009 opportunity with the MTO Project. The extent and type of communication available to MSL during EDL is presented, as well how the availability of communication during EDL drove the selection of launch / arrival periods for the MSL Project.

08:50 **AAS 05 - 269** **Mars Exploration Via Earth-Mars Semi-Cyclers**
Damon Landau, James M. Longuski, Purdue University

We present an architecture for the human exploration of Mars. This architecture is characterized by the use of parking orbits at Earth and gravity assists at Mars. An interplanetary transfer vehicle cycles from Earth orbit to Mars flyby and back, eliminating the need to launch transfer vehicles off of the surface of Earth and Mars. Necessary developments for an Earth-Mars semi-cycler mission (beyond traditional architectures) include reusable transfer vehicles and rendezvous during planetary flyby. When compared to scenarios similar to NASA's Design Reference Mission, the Earth-Mars semi-cycler requires 10%–33% less injected mass to low-Earth orbit.

09:15 **AAS 05 - 270** **Addition of a Low Altitude Tethys Flyby to the Nominal Cassini Tour**
Brent Buffington, Nathan Strange, Rodica Ionasescu, Jet Propulsion Laboratory

Of the eight Saturnian icy satellites, all but Mimas and Tethys have low altitude targeted flybys during the 4-year nominal Cassini spacecraft tour. In November 2004, the existence of a potential low-altitude Tethys flyby was discovered; this low-altitude Tethys flyby, added to the nominal tour in March 2005, corresponds to a 1500 km non-targeted periapsis altitude and requires a delta-v cost of 8 m/s. This paper details the methods used to determine the Tethys flyby altitude, driven by navigational requirements and operational constraints, in addition to several trajectory modifications implemented to reduce total delta-v costs, while simultaneously increasing scientific return.

09:40 **Break**

10:00 **AAS 05 - 271** **Finding Acceptable James Webb Space Telescope Mission Orbits from a Fixed Ariane Flight Profile**

Mark Beckman, Leigh Janes, NASA Goddard Space Flight Center

The James Webb Space Telescope (JWST) will be launched into orbit about the Sun/Earth L2 libration point. Trajectory design was recently completed which included expected separation states from the Ariane launch vehicle, constraints such as eclipses, maximum orbit size, maximum Sun-Vehicle-Earth/Moon angles, and launch opportunities. The results of this trajectory design give a set of possible trajectories for JWST with bounded stray light zones and provide a complete launch window. This data is also used to design the initial trajectory correction maneuver such that a maneuver towards the Sun is not possible.

10:25 **AAS 05 - 272** **Collision Risk Assessment During Launch, LEOP and On-Orbit Phases**

Beatrice Deguine, CNES French National Space Agency; Laurent Dagnac, Laurence Lorda, ATOS ORIGIN

As CNES operates satellites and participates to launches, CNES has developed a collision risk assessment tool named ARC to assess the collision risk between primary objects as launcher/satellite and secondary objects as catalogued objects during launch, LEOP or on-orbit phases. All these phases may include propulsive periods. Robust and efficient algorithms have been designed in order to quickly assess the collision risk between primary objects and all catalogued secondary objects. The main interesting and original methods are presented. This tool has been applied on launch, LEOP, and on-orbit primary object trajectories to be compared with all catalogued objects. Some interesting results are presented to demonstrate the efficiency of the filtering methods and their robustness and some benchmarks are addressed to illustrate its CPU time performances.

10:50 **AAS 05 - 273** **Enabling Exploration Missions Now: Applications of On-Orbit Staging**

David C. Folta, Frank Vaughn, Paul Westmeyer, NASA Goddard Space Flight Center; Gary Rawitscher, NASA Headquarters; Francesco Bordi, The Aerospace Corporation

Future NASA Exploration goals are difficult to meet using current launch vehicle implementations and techniques. We introduce a concept of On-Orbit Staging (OOS) using multiple launches into a Low Earth orbit (LEO) staging area to increase payload mass and reduce overall cost for exploration initiative missions. This concept is a forward-looking implementation of ideas put forth by Oberht and Von Braun to address the total mission design. Applying staging throughout the mission and utilizing technological advances in propulsion efficiency and architecture enable us to show that exploration goals can be met in the next decade.

11:15 **AAS 05 - 274** **Uni-Flower: A Novel Proposal for University-Built Nanosatellites in Flower Constellations**

Troy Henderson, Daniele Mortari, Helen Reed, John Junkins, Texas A&M University

The basic outline for a novel research project is proposed which makes use of nanosatellites-built solely by universities-in a flower constellation determined by the mission of the satellites. One specific scenario is descried in detail, with options left open for new mission ideas. The project described is a FC orbiting the Earth for scientific data collection. For this mission, the orbit design, satellite design, educational possibilities, and university collaboration prospects are thoroughly discussed. One should quickly realize that any such research project would be a massive undertaking, so preliminary concepts on the management of such a research project are presented.

Session 4: Satellite Constellations & Formation Flying I

Chair: Jay Middour
Naval Research Laboratory

13:30 **AAS 05 - 275** **Structural Analogy for Control of Satellite Formations**

Giulio Avanzini, Politecnico di Torino; Guido de Matteis, Valerio Tarantini, University of Rome La Sapienza, Italy

In this work, the application of a structural analogy to the control of a formation of satellites is discussed and a novel control system architecture is presented. The main contribution of the paper is the integration of two techniques for control of systems of multiple agents/vehicles, namely, the formation feedback control and the node augmentation technique. Formation feedback allows for an efficient design of maneuvers by assigning a prescribed state for each vehicle in terms of desired position and attitude that are defined as place holders and satisfy some structural constraint, e.g. a rigid formation. At the same time, the node augmentation technique, developed in the framework of the application of graph theory to formation flight, allows one to easily design formations.

13:55 **AAS 05 - 276** **Control of an Orbiting Formation of Satellites using the Virtual Structure Approach**

Giulio Avanzini, Politecnico di Torino, Italy; Guido de Matteis and Valerio Tarantini, Universita di Roma La Sapienza, Italy

In this paper, control of satellite formations in orbit is realized using the structural analogy. The proposed approach exploits the concepts of virtual structure and formation feedback in order to efficiently determine place--holders during formation maneuvers, when the assumption of a rigid formation is made. At the same time, the formation feedback greatly simplifies the task of coordinating the control action on each agent even in those cases where a decentralized architecture is implemented. The control system is validated in a nonlinear model of the individual agents of the formation where circular or elliptic orbit dynamics, including the effect of Earth's oblateness, are taken into consideration.

14:20 **AAS 05 - 277** **Guidance Law for the Reconfiguration of Satellite Formation in the Presence of Measurement Errors**

David Mishne, RAFAEL Ltd., Israel

The paper addresses the issue of reconfiguration maneuver of satellite formation, in the presence of measurement errors of the states. An optimal guidance law is developed here to maneuver the satellite to specified terminal conditions, while minimizing a performance criterion which is a weighted sum of the fuel consumption and the sensitivity of the terminal constraints to initial state errors. The paper includes analysis and general formulation of the method. The method is applied to a reconfiguration maneuver of N satellites toward a projected circular formation. A numerical example for two satellites demonstrates that the sensitivities of the terminal constraints to initial state uncertainties can be greatly reduced, with only slight increase in the fuel consumption.

14:45 **AAS 05 - 278** **Static Equilibrium Configurations In GEO Coulomb Spacecraft Formations**

John Berryman, Hanspeter Schaub, Virginia Tech

The benefits of Coulomb control for spacecraft formations 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 the proposed paper is to compare previous analytically determined stationary formations with numerically determined stationary formations. The comparison will serve as impetus for a reparameterization of the equations of motion so that the possibilities of stationary Coulomb formations can be more completely understood. The focus will be placed upon two and three craft formations.

15:10 **Break**

15:30 **AAS 05 - 279** **Paper Withdrawn**

15:55 **AAS 05 - 280** **Satellite Constellation Design Optimization via Multiple-objective Evolutionary Computation**

Matthew Ferringer, The Aerospace Corporation / Pennsylvania State University; David Spencer, Pennsylvania State University

Multiple-objective evolutionary computation provides the satellite constellation designer with an essential optimization tool due to the discontinuous, temporal, and/or nonlinear characteristics of the metrics that architectures are evaluated against. In this work, the Non-Dominated Sorting Genetic Algorithm II (NSGA-II) is utilized to find the set of optimal constellation designs (Pareto-fronts) for two pairs of conflicting metrics. The first pair replicates a previously published sparse-coverage trade to establish a baseline for tool development, while the second characterizes the conflict between temporal (revisit time) and spatial (image quality) resolution.

16:20 **AAS 05 - 281** **Geometric Diversity and Directional Access Analysis for Satellite and Constellation Trade Studies**

William Todd Cerven, The Aerospace Corporation

The problem of directional access to a satellite and the geometric diversity of those accesses is a key factor in many constellation designs. In this paper, mathematical tools are presented which model and provide conservative bounds for these quantities for use in circular orbit trade studies. Such tools include access time bounds for given fields of view, field of view regions over which a drifting satellite will never pass, and bounds on the density of over flight tracks. Results are a sampling of direct circular orbits from LEO to GEO and wide variety of field of views.

16:45 **AAS 05 - 282** **Low Thrust Control Law in Equinoctial Elements Applied to Maintenance of "Teardrop" Elliptical Orbit Constellations**

Benjamin E. Joseph, Dr. Paul J. Cefola, Massachusetts Institute of Technology

Repeat-ground track elliptic constellations present a viable way to provide coverage of mid to high latitude locales for broadband data communications. However, using electric propulsion for station keeping on these types of constellations is not yet well characterized. An automated technique formulated in equinoctial elements for determining a station keeping profile for any circular or elliptical orbit is presented. Its implementation in the Goddard Trajectory Determination System (GTDS) is discussed, as well as the current state of GTDS in general. This station keeping analysis technique is applied to the six satellites in John Draim's elliptical “teardrop” constellation.

Monday, Aug 8, 2005 Emerald

Session 5: Guidance, Navigation, & Control I

Chair: Don Mackison
University of Colorado

13:30 **AAS 05 - 283** **Robust Stabilization of Uncertain, Unstable Halo Orbits**
Hiroaki Fukuzawa, Pierre T. Kabamba, University of Michigan

The problem of robust stabilization of uncertain, unstable Halo orbits is treated. These are periodic orbits in the vicinity of the colinear Lagrange libration points in the restricted circular 3-body problem. Halo orbits have the potential of being highly unstable and are also typically uncertain, in period and location, due to uncertainty in the parameters of the system, such as the masses of the bodies. The technical approach used here is to extend the method of Generalized Sampled-Data Hold Function control of linear periodic systems in two ways: a change in independent variable, and an adaptation strategy.

13:55 **AAS 05 - 284** **Navigation Models of Comet Outgassing Jets**
Sharyl M. Byram, Daniel J. Scheeres, Michael R. Combi, University of Michigan

An outgassing jet model is presented to support spacecraft navigation for future missions to comets. The model will also be an important tool for estimation of the physical outgassing properties of jets at and near the surface of a comet. If incorporated within a spacecraft's navigation system, the free parameters of this model can be estimated to fit navigation data from an orbiting spacecraft.

14:20 **AAS 05 - 285** **Flight Path Control Strategies and Preliminary Delta-V Requirements for the 2007 Mars Phoenix (PHX) Mission**
Behzad Raofi, Jet Propulsion Laboratory

In August 2007, the Phoenix (PHX) Project will launch a spacecraft to Mars whose objective is to deliver a stationary lander to a landing site in the latitude band from 65 N to 72 N. Instruments on the lander will perform in-situ and remote-sensing investigations to characterize the chemistry of materials at the local surface, subsurface, and atmosphere. Lander instruments will also identify the potential provenance of key indicator elements of significance to the biological potential of Mars, including potential organics within any accessible water ice. This paper describes the methods used to estimate the statistical Delta-V requirements for the propulsive maneuvers that will deliver the spacecraft to its target landing site while satisfying planetary protection requirements. The paper presents flight path control analysis results.

14:45 **AAS 05 - 286** **Cassini-Huygens Maneuver Experience: Cruise and Arrival at Saturn**
Troy D. Goodson, Brent Buffington, Yungsun Hahn, Nathan Strange, Sean Wagner, Mau Wong, Jet Propulsion Laboratory

The Cassini-Huygens mission to Saturn and Titan was launched in 1997. It is an international effort to study the Saturnian system. Cassini-Huygens' interplanetary cruise delivered the spacecraft to Saturn in 2004. It also made use of many propulsive maneuvers, both statistical and deterministic. Maneuver-related analysis and performance for latter half of cruise is reported. The system has performed more accurately than the pre-launch expectations and requirements. Additionally, some maneuvers have already been skipped, saving fuel and flight team effort. The analysis that led to the cancellation of these maneuvers and to improved modeling of statistical execution errors is presented.

15:10 **Break**

15:30 **AAS 05 - 287** **Cassini-Huygens Maneuver Experience: First Year of Saturn Tour**

Sean V. Wagner, Brent B. Buffington, Troy D. Goodson, Yungsun Hahn, Nathan J. Strange, Mau C. Wong, Jet Propulsion Laboratory

This paper documents the maneuvers performed by the Cassini-Huygens spacecraft in its first year of Saturn tour. Since Saturn arrival, Cassini-Huygens has made several flybys of Saturn's satellites and has delivered the Huygens probe to Titan. Of the 20+ maneuvers performed since Saturn orbit insertion, the Periapsis Raise Maneuver, the Probe Targeting Maneuver, and the Orbiter Deflection Maneuver were the most unique. Typically, three maneuvers are executed between satellite encounters: a cleanup and two targeting maneuvers. A chained-maneuver optimization strategy is incorporated to minimize fuel cost. In its first year orbiting Saturn, Cassini-Huygens has been navigated with tremendous success.

15:55 **AAS 05 - 288** **Paper Withdrawn**

16:20 **AAS 05 - 289** **Landmark Navigation and Target Characterization in a Simulated Itokawa Encounter**

Robert W. Gaskell, Jet Propulsion Laboratory

A simulated asteroid Itokawa was constructed from Ostro's latest radar model by adding craters, rocks and fractal surfacing. Images were constructed from this model with known spacecraft positions and orientations, and asteroid pole and shape as "groundtruth", using available values for the Hayabusa camera parameters, and following the proposed encounter scenario. The nominal values of these quantities were given realistic errors. The images were analyzed with landmark navigation and target characterization software to determine how well ground truth could be reproduced. Calculated spacecraft locations during approach to the surface agreed with the true values to less than a meter.

Session 6: Orbital Dynamics I

Chair: Kim Luu
Air Force Research Laboratory

13:30 **AAS 05 - 290** **Global Search for Planar and Three-Dimensional Periodic Orbits near Europa**
Ryan P. Russell, Jet Propulsion Laboratory

A global grid search is performed to find simply- and doubly-symmetric periodic orbits in the Restricted Three Body Problem using the dimensioned parameters associated with the Jupiter-Europa system. Local differential correctors are derived and applied to regions of the initial condition phase space that appear to be near solutions. Families of direct and retrograde solutions, both new and previously published, are found and discussed. Stability is analyzed for each solution and general regions of stability are noted. The global database of solutions is a practical reference for preliminary design of missions to Europa.

13:55 **AAS 05 - 291** **Analytical Ephemerides for the Satellites of Neptune**
A. M. Segerman, AT&T Government Solutions, Inc.; L. A. Policastri, Analytical Graphics, Inc.; D. L. Richardson, University of Cincinnati

Analytical ephemerides for the motion of Neptune's satellites Triton and Nereid, with their unusual orbital characteristics, present challenges which require sophisticated perturbation methods. Such methods were earlier used to develop a theory for Triton and Nereid, intended to be accurate to approximately 0.01 arc seconds over 300 years. In this paper, the full ephemerides are presented, with the lengthy analytical solutions made available via FORTRAN driver. Additionally, lower-precision time series are provided, valid over shorter time spans. Using Satellite Tool Kit (STK), an investigation has been performed into the solution accuracy, the results of which are presented.

14:20 **AAS 05 - 292** **Epicycles and Oscillations: the Dynamics of the LISA Orbits**
Theodore H. Sweetser, Jet Propulsion Laboratory

This paper presents a modern treatment of epicycle theory, which is an exact series representation of Keplerian motion, and uses that theory to develop the first analytic method for analyzing the higher order dynamics of the LISA orbits. LISA, the Laser Interferometer Space Antenna mission, uses a constellation of three spacecraft in heliocentric space and takes advantage of particular solutions of the Clohessy-Wiltshire equations, a first-order approximation of gravitational dynamics, to keep the constellation an equilateral triangle. The higher-order analysis presented here suggests a modification of the basic LISA orbit architecture which may improve the stability of the constellation.

14:45 **AAS 05 - 293** **Comparison of Several Solutions of Elliptic Rendezvous Problem**
Jung Hyun Jo, John E. Cochran, Jr., 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 a geopotential model in test cases.

15:10 **Break**

15:30 **AAS 05 - 294** **Solutions to the Variational Equations for Relative Motion of Satellites**
John E. Cochran, Jr. , Daero Lee, and J. H. Jo, Auburn University

Although the basis for classical investigations, closely connected to Lagrange's planetary equations, fundamental in certain guidance schemes, and recently used to obtain accurate relative motion models, the general importance of the use of integrals of the reference motion has been somewhat ignored. The relative motion of orbiting satellites is considered for two purposes. First, methods used to obtain several different solutions to the linear differential equations (the "variational equations") that govern the motion of a satellite relative to a point moving in an elliptic two-body orbit (the "reference orbit") are reviewed and compared. Second, the accuracies of the solutions are compared.

15:55 **AAS 05 - 295** **Periodic Orbits in the vicinity of the Equilateral Points of the Restricted Full Three Body Problem**
J. Bellerose, D. J. Scheeres, University of Michigan

The dynamics of a particle in the gravitational field of a binary system are studied. The bodies are modeled as a sphere and a constant density tri-axial ellipsoid. The system is not in synchronized motion. Periodic orbits in the vicinity of the analogueL4,5 points are investigated for values of the mass ratio, distance between the bodies, shape parameters of the ellipsoid and the ratio of the ellipsoid and orbit rotation rate. Numerical simulations show that stable periodic orbits exist for low values of the mass ratio. Stability is reduced from the R3BP and the synchronized case of the RF3BP.

16:20 **AAS 05 - 296** **A Numerical Approach to High Precision Numerical Relative Orbit Propagation**
Egemen Imre and Phil Palmer, Surrey Space Center, United Kingdom

A novel method for relative orbit propagation is presented. The usual approach is to model the relative motion analytically, making a lot of simplifications and taking into account only J2 and/or eccentricity effects. This study outlines a symplectic numerical integration scheme which can accommodate a very detailed geopotential model (up to 36 terms in zonal and tesseral harmonics) without any restrictions for eccentricity. The forces are computed via a novel implementation of Hamilton's equations. This high accuracy model will potentially require significantly less sensor input for relative
navigation, decreasing computational load and saving power.

16:45 **AAS 05 - 297** **A Numerical Study of Orbit Lifetime**
James Woodburn and Shannon Lynch, Analytical Graphics, Inc.

The computation of orbit lifetime is extremely challenging. The abundance of uncertainty makes the results of any one analysis suspect. In this study, we examine how the issues of uncertain atmospheric behavior, variations in atmospheric density models and the selection of a computational technique affect orbit lifetime predictions. Key to this effort is the development of a stochastic sequence to generate realistic time series of solar weather to drive the atmospheric density models. We hope the results of this study can serve as a guide to analysts making modeling decisions and provide recommendations for qualifying orbit lifetime predictions.

Session 7

Session 7 has been canceled.

Session 8: Space Debris & Collision Probability

Chair: Alan Jenkin
The Aerospace Corporation

08:00 **AAS 05 - 303** **The ESA-MASTER 2005 Debris Environment Model**

M. Oswald, S. Stabroth, C. Wiedemann, P. Vörsmann, Technische Universität Braunschweig, Germany; P. Wegener, Wegener Aerospace Consult; H. Klinkrad, ESA/ESOC, Darmstadt

The Meteoroid and Space Debris Terrestrial Environment Reference Model of the European Space Agency, ESA-MASTER, is currently being developed to its next release, MASTER-2005. In this paper, the upgrades of the model and the associated software will be described. The upgrades include all tools involved. POEM, the MASTER population generation tools has undergone significant changes for all debris sources. PROOF, the validation tool, has been extended to also support the validation of MASTER against observations from bistatic radars. MASTER-2005 is currently being developed by a consortium led by the Institute of Aerospace Systems under ESA contract.

08:25 **AAS 05 - 304** **Modelling of Surface Degradation Particle Releases in ESA MASTER**

Sebastian Stabroth, Michael Oswald, Carsten Wiedemann, Peter Vörsmann, Technische Universität Braunschweig, Germany; Peter Wegener, Wegener Aerospace Consult; Heiner Klinkrad, ESA/ESOC Darmstadt

Surface degradation particles are known to significantly contribute to the LEO small debris object environment. The driving factors for the particle generation are atomic oxygen, thermal cycling, and ultraviolet radiation. The paper describes the approach to the problem that is used in ESA's MASTER space debris model to account for surface degradation particles. It closes with a description of the particle release rate and the orbital distribution of the resulting particle population in orbit with time.

08:50 **AAS 05 - 305** **The Efficient Analytic Computation of Fractional Reentering Debris from an Idealized Isotropic Explosion in General Elliptic Orbit**

Jean A. Kechichian, Marlon E. Sorge, The Aerospace Corporation

The efficient computation of the fraction of debris from an isotropic explosion in general elliptic orbit, which would fly in orbits whose perigees are below a certain given altitude that usually corresponds to the atmosphere interface is presented. Given an explosion velocity, a spacecraft idealized as a sphere breaks up into small fragments that either stay in earth orbit or intersect the atmosphere interface resulting in reentry. The locus of points on the surface of the sphere that separates the two groups of debris is obtained analytically in the form of a quartic, and the corresponding areas are evaluated by Gaussian quadrature for accurate percentage counts.

09:15 **AAS 05 - 306** **A Meaningful Relative Motion Coordinate System For Generic Use**

Daniel R. Adamo, United Space Alliance, LLC

The concept of "meaningful" relative motion between two orbiting objects is defined for generic application to rendezvous, conjunction, and formation flying scenarios requiring continuous trajectory situation awareness. The Local Vertical Curvilinear (LVC) relative motion coordinate system in use by the Space Shuttle Program is reviewed, and limitations confining its meaningful use to nearly co-planar relative motion are cited. A new Local Vertical Spherical (LVS) relative motion coordinate system removing these
limitations is then documented. Example plots are provided comparing LVC to LVS relative motion. An LVS implementation specification accompanied by numeric test data is also included.

09:40 **Break**

10:00 AAS 05 - 307 Determining Object Sizes from Radar Cross Section for Collision Avoidance
Glenn E. Peterson, The Aerospace Corporation

In collision avoidance analysis, conjunctions are found and probabilities of collision are computed based upon the relative state vector, sizes, and the error ellipsoids of the primary and secondary objects. While the customer typically supplies the primary's size as input, the size of the secondary is often not known and there is reliance upon the radar cross-section (RCS) information. Since the RCS values are often very noisy, direct reliance upon the raw values is not recommended. This study examines a method for extracting useful size information from radar cross-sectional values.

10:25 AAS 05 - 308 CAM Planning Tool
Dr. Salvatore Alfano, Analytical Graphics, Inc.

Satellite Collision Avoidance Maneuver (CAM) planning must take into account many factors. This work describes the development of a MATLAB analysis tool that can perform parametric studies of single-axis and dual-axes maneuvers. The tool reads the object pair's positions, velocities, covariances and physical sizes from Satellite Tool Kit (STK) and allows the user to modify the covariances and sizes. The tool is used to determine a maneuver time and velocity change to reduce collision probability to an acceptable level. These are then fed back into STK where further analysis can be performed to address other maneuver concerns.

10:50 AAS 05 - 309 Collision Probability for Large Bodies Having Non-Linear Relative Motion
Russell P. Patera, The Aerospace Corporation

A method to evaluate satellite collision probability for space objects having non-linear relative motion was developed several years ago. The method is valid for cases where the probability density is fairly uniform over the combined hardbody volume. This condition is satisfied in nearly all real cases, since hardbody sizes range in meters and the standard deviation of the symmetrized position uncertainty range in hundreds or thousands of meters. The current work extends the validity of the method to larger hardbody sizes. This is achieved by more accurately evaluating the probability integral for such cases. The improved method is validated with cases having known results.

11:15 AAS 05 - 310 Spacecraft Edge Extraction by Wavelet Transformation
Hirohisa Kojima, Yutaka Usuda, and Takashi Kobayashi, Tokyo Metropolitan Institute of Technology, Japan

Astronauts assisted by the space shuttle manipulator work to eliminate debris from orbit. This task is, however, dangerous for astronauts, and automated and unmanned methods are desired. If a vision system is used to sense the attitude of space debris, light conditions in space should be considered, because the conditions vary in accordance the direction of debris relative to the debris capture satellite and the Sun. In this paper, an in-space light environment simulator is constructed and a capability of wavelet transformation to extract edges of a spacecraft is studied, compare to other edge extraction methods, using the constructed simulator.

Session 9: Orbit Determination I

Chair: L. Alberto Cangahuala
Jet Propulsion Laboratory

08:00 **AAS 05 - 311** **Cassini Orbit Reconstruction from Jupiter to Saturn**

Duane Roth, Robert Jacobson, Peter Antreasian, Jeremy Jones, John Bordi, M. Cameron Meek, Kevin Criddle, Ian Roundhill, Rodica Ionasescu, Jason Stauch, Jet Propulsion Laboratory

After nearly seven years of interplanetary cruise and four planetary gravity assists, the Cassini spacecraft was successfully captured into orbit around Saturn on 1 July 2004. For the first time during the Cassini mission, optical navigation images were obtained and integrated with radio-metric data. Navigators contended with optical navigation images that were potentially biased by Titan's dense atmosphere and Iapetus' albedo variations. Radio-metric data quality was degraded because of small Sun-Earth-probe angles near orbit insertion. The Jupiter to Saturn leg of the spacecraft's trajectory has been reconstructed and is used to provide a metric on navigation performance and maneuver execution errors. In particular, the reconstructed trajectory is compared to trajectory predictions at closest approach to Phoebe, the largest of Saturn's known irregular moons.

08:25 **AAS 05 - 312** **CASSINI Orbit Determination Performance During the First Seven Orbits of the Satellite Tour**

P. G. Antreasian, J. J. Bordi, K. E. Criddle, R. A. Ionasescu, R. A. Jacobson, J. B. Jones, R. A. Mackenzie, M. C. Meek, F. J. Pelletier, D. C. Roth, I. M. Roundhill, J. Stauch, Jet Propulsion Laboratory

From June 2004 through July 2005, the Cassini/Huygens spacecraft will have made nine successful close-targeted encounters by three of the major satellites (Phoebe, Titan, and Enceladus) in the Saturnian system. During the third orbit the Huygens probe was precisely targeted for a successful landing on Titan's surface. Current results show that orbit determination has met design requirements for targeting encounters, Huygens landing, and predicting science instrument pointing for targeted satellite encounters. This paper compares actual target dispersions against the predicted tour covariance analyses. To assess orbit determination performance, post-flyby results are compared to OD predictions. Prediction accuracy of the satellite ephemeris is a key challenge for successful navigation. The improvement of this ephemeris through the orbit determination process is discussed.

08:50 **AAS 05 - 313** **A Stochastic Parameter Solution for Outgassing Accelerations Experienced by a Spacecraft After Launch**

Connie Weeks, Loyola Marymount University; James K. Miller, KinetX, Inc. Space Navigation and Flight Dynamics Practice

For a month after the launch of the MESSENGER mission to Mercury, the spacecraft was perturbed by nongravitational accelerations that resulted in a migration of several thousand kilometers in the target B-plane. It is speculated that the accelerations were due to outgassing of water trapped in the composite materials of the spacecraft. Nongravitational accelerations are difficult to model, leading to inconsistent solutions for the spacecraft state from Doppler and range data. A method is proposed for modelling nongravitational accelerations as a sum of exponentially decaying stochastic vectors with different correlation times. The acceleration time history after launch of the MESSENGER mission is used as an example.

09:15 **AAS 05 - 314** **Covariance Analysis for Deep-Space Satellites with Radar and Optical Tracking Data**
James G. Miller, The MITRE Corporation

Covariance analysis for the special perturbations orbit determination problem for deep-space satellites is considered to determine the relative merit of radar and optical tracking data. Deep-space radars provide very accurate range measurements, but less accurate angle measurements. Optical sensors provide very accurate angle measurements, but make no range measurements since they are passive systems. The relationship of the size of the spatial part of the covariance to the relative track density of radar and optical tracks in the orbit determination fit interval is illustrated for various satellite orbits, including geosynchronous, circular semi-synchronous, and highly eccentric semi-synchronous.

09:40 **Break**

10:00 **AAS 05 - 315** **Upper Atmospheric Phenomena and Satellite Drag**
Craig A. McLaughlin, University of North Dakota

Astrodynamicists with experience in operational orbit determination of low Earth orbit satellites during periods of high solar activity are familiar with the difficulty of accurately predicting satellite positions even a few days or hours in advance. This paper examines the relationship between upper atmospheric phenomena and their effects on satellite drag. This is an initial effort to correlate known or theorized thermospheric and exospheric density variations that will have a measurable effect on satellite drag, but are not included in current density models used in orbit propagation. Hopefully this will stimulate cooperation between the orbital mechanics and aeronomy research communities.

10:25 **AAS 05 - 316** **Effect of Atmospheric Density Correction on Precision Orbit Determination**
Hyung-Jin Rim, Yuchan Kim, Bob E. Schutz, The University of Texas at Austin; Paul J. Cefola, Consultant in Aerospace Systems, MIT

Atmospheric drag is one of the most significant non-gravitational forces acting on Low-Earth-Orbiting satellites. In Precision Orbit Determination (POD), the atmospheric density is modeled using a chosen density model. However, the model density usually does not represent the actual atmospheric density. To minimize the effect of this model deficiency on POD, drag related parameters and empirical parameters are adjusted in the POD process. One approach to improve the density model accuracy is to provide corrections to the modeled atmospheric density by estimating the fluctuations between the actual density and a chosen density model. In this paper, the effect of atmospheric density correction on GRACE and ICESat POD is evaluated.

10:50 **AAS 05 - 317** **Effects of Orbital Uncertainty on Handover and Breakup Processing**
Thomas J. Eller, Kenneth D. Kopke, Mark W. Sousa, Omitron, Inc.; Richard L. Hollm, USAF ESC/NDWA; Timothy McLaughlin, Northrop Grumman

Breakups, handovers, UCTs, and small objects have marginal viewing conditions, sparse data, uncertain ELSET quality, older ELSETs, etc. Surveillance operations must occur much faster than is commonly believed. Computations, tasking, messaging, and analysis must take place in minutes if objects are to be cataloged and repeatedly viewable--or, the uncertainty box may extend thousands of kilometers, giving searching for an object little likelihood of success. Two-body analysis of sensitivity to initial condition errors, simulated breakups/handovers using STK-OD, and real data illustrate the growth in position uncertainty and its effect on a sensor's efforts to detect and track an object.

Session 10: Tethers & Large Space Structures

Chair: Paul Penzo
Global Aerospace Corporation

13:30 **AAS 05 - 318** **Libration Control of an Electrodynamic Tethered System through Electric Current Switching**

Noboru Takeichi, Institute of Space Technology and Aeronautics, Japan Aerospace Exploration Agency, Japan

The libration of an electrodynamic tether (EDT) is inherently orbitally unstable during its descent phase. The dynamic characteristics of an EDT basically depends on the state of the electric current of the tether. Therefore, it is possible to control the libration by turning on/off the electric current. In this paper, a current switching law for the libration control will be presented, and numerical simulations show that the amplitude of libration is successfully limited within a certain bound.

13:55 **AAS 05 - 319** **Orbit Boosting of an Electrodynamic Tethered Satellite with Input-Shaped Current**

Arun Banerjee, Lockheed Martin Advanced Technology Center; William Singhose, Georgia Institute of Technology

We develop the dynamical model of a tethered satellite with a two-stage tether, one half carrying current and the other half not. When the current carrying segment moves in the magnetic field of the earth, a force perpendicular to the tether is developed. This force can be used in boosting the orbit of the satellite. An undesirable effect of this force is the onset of librations and vibrations of the tether. Input shaping of the current can be done to reduce these undesired vibrations. We show by simulation the effectiveness and robustness of this approach.

14:20 **AAS 05 - 320** **Real-Time Computation of Optimal Trajectories for Tethered Satellite Systems**

Paul Williams, RMIT University, Australia

The real-time optimal control of tethered satellite systems is considered using a pseudospectral discretization. A sampled data feedback implementation is demonstrated that can achieve over 50000 samples for a retrieval maneuver with good initial guesses. Even with poor guesses and cold starts, over 4600 samples can be achieved using current technology with algorithms implemented on a personal computer. Several issues, such as the time delay in updating the control and the effect of perturbations, are considered. For the most effective control, it is necessary to include most of the salient effects in the computation of the control law.

14:45 **AAS 05 - 321** **Study on Prolonged Rendezvous using Tethers**

Paul Williams, RMIT University; Chris Blanksby, Swinburne University, Australia

The problem of matching the position and velocity of a target payload in a significantly different orbit than the main spacecraft is considered. Many of the proposed scenarios for capturing such payloads using tethers involve instantaneous rendezvous. This paper examines the possibility of extending the proximity time of the capture device and the payload by utilizing an actuator mass that “crawls” along the tether. The prolonged rendezvous maneuver is studied using optimal control methodology, and the effect of various system parameters such as system mass ratios and rendezvous windows are examined.

15:10 **Break**

15:30 **AAS 05 - 322** **Deployment Control for the YES2 Tether-Assisted Re-Entry Mission**

Paul Williams, RMIT University, Australia; Andrew Hyslop, Delta-Utec SRC, The Netherlands

YES2 (launching October 2006) aims to demonstrate a tether-assisted re-entry concept, whereby payload will be returned to Earth using momentum provided from a swinging tether. This paper presents a methodology for solving the deployment and control problem for this mission. The two-phase deployment maneuver is first optimized to minimize the tether lateral oscillations and satisfy other important objectives. A feedback controller is designed to track the trajectory. The controller is tested for robustness in a flexible tether model under different environmental conditions and parameter uncertainties. A closed-loop hardware test using the actual deployer is used to complete the testing.

15:55 **AAS 05 - 323** **Investigation of Controls Structure Interaction on the Jupiter Icy Moons Orbiter**

Marco B. Quadrelli, Edward Mettler, Jet Propulsion Laboratory; Don Soloway, NASA Ames Research Center; Atul Kelkar, Iowa State University

The baseline Jupiter Icy Moons Orbiter (JIMO) spacecraft presents challenging controls-structure interactions caused by having to accurately and simultaneously point the existing multiple articulated payloads (high-gain antenna, scan platform) which are mounted on a large flexible base. Sensitivity analyses and simulation studies were carried out using complex finite element models describing the vehicle’s dynamics and control. The results of these studies indicate that: 1) the controller bandwidth must be less than 0.01 Hz for stable pointing control at the end of a slew with the fine RCS; 2) to achieve a 90 deg slew maneuver in two hours the controller bandwidth must be greater than 0.0001Hz with the coarse RCS; 3) the first natural frequency of the flexible vehicle should be 1 Hz.

Session 11: Attitude Dynamics & Control II

Chair: Mark Pittelkau
Swales Aerospace

13:30 **AAS 05 - 324** **Analysis of Thrust Vectoring Capabilities for the Jupiter Icy Moons Orbiter**
Marco B. Quadrelli, Konstantin Gromov, Emmanuell Murray, Jet Propulsion Laboratory

A strategy to mitigate the impact of the trajectory design of the baseline Jupiter Icy Moons Orbiter (JIMO) on the attitude control design is described in this paper. This paper shows how the thrust vectoring control torques, i.e. the torques required to steer the vehicle, depend on various parameters (thrust magnitude, thrust pod articulation angles, and thrust moment arms). Rather than using the entire reaction control system (RCS) system to steer the spacecraft, we investigate the potential utilization of only thrust vectoring of the main ion engines for the required attitude control to follow the representative trajectory. This study has identified mitigation strategies for trajectory segments where the required control torque may exceed the ion engine capability.

13:55 **AAS 05 - 325** **Long-Term Attitude Drift of Spinning Spacecraft under Solar Radiation Torques**
J. C. van der Ha, Consultant, Mission Design & Operations; V. J. Lappas, Surrey Space Centre, United Kingdom

Solar radiation forces have been utilized on-board satellites since more than 40 years. Certain control schemes have been previously developed to utilize the solar radiation forces with most applications focused on station-keeping strategies for communications satellites. The long-term effect of the Solar Radiation Pressure (SRP) can substantially alter the attitude and orbital behavior of spacecraft especially in long term missions (> 7 years). Furthermore, the effect of SRP is amplified for large area structures in space such as solar sails. This work analyzes the long term effect of the SRP disturbance on the spacecraft's spin axis.

14:20 **AAS 05 - 326** **Stabilizing Intersample Error in Discrete Time Iterative Learning Control**
Richard W. Longman, Tawkjoon Kwon, Columbia University

Iterative learning control (ILC) adjusting the command to control systems to produce zero error for a repeating trajectory. Applications include generating high speed, high precision mechanical motions, e.g. for spacecraft maneuvers. Previous work showed that zero error at sample times for most physical systems, produces errors tending to infinity between sample times. This paper shows that this problem is eliminated by letting the first few trajectory time steps be determined by a minimum input norm. Adaptive inverse ILC is reformulated to take advantage of this and now shown to be a practical approach, while other ILC laws are modified accordingly.

14:45 **AAS 05 - 327** **The Effect of Interpolation on Stability and Performance in Repetitive Control**
Wando Kang, Richard W. Longman, Columbia University

Repetitive control (RC) can potentially eliminate the influence of vibrations on fine pointing equipment caused by periodic disturbances such as from slight imbalance in a momentum wheel. Typical RC assumes that the disturbance period is an integer number of time steps, and this assumption introduced substantial error at higher frequencies. This paper studies the effect of introducing linear or cubic interpolation to address this issue. It is shown that such interpolation cannot destabilize an RC system. Methods are developed to know what influence interpolation has on the error level reached. And the influence on the waterbed effect are also studied.

15:10 **Break**

15:30 AAS 05 - 328 Frequency Response Analysis of Higher Order Repetitive Control
Chun-Ping Lo, Richard W. Longman, Columbia University

Spacecraft often have one major vibration source, e.g. a slight imbalance in a momentum wheel or cryo pump, that degrades performance of fine pointing equipment. Repetitive control (RC) learns to cancel periodic disturbances at the equipment location. Various publications suggest RC using error data from multiple periods to adjust the current command. A previous paper performs a root locus plot analysis of such higher order RC. This paper uses the frequency response approach. The effect of adjusting weights on different periods is studied, relative to the waterbed effect and to sensitivity to accurate knowledge of the disturbance period.

15:55 AAS 05 - 329 Modeling Albedo Effects in Coarse Sun-Sensor Data for a Spinning Nanosatellite
Timothy M. Meisenhelder, Robert G. Melton, Penn State University

This paper describes progress made on modeling the effect of Earth albedo and modifying the associated onboard Kalman filter for the Local IONospheric Measurements Satellite. LionSat must rely on magnetometer and coarse sun-sensor data (from body-mounted solar panels on all ten faces) for attitude determination. Using data from the Total Ozone Mapping Spectrometer, a simplified albedo model that averages reflectivity data across all longitudes (and across the 6-month mission lifetime) along with a geometric field-of-view model, one can model the albedo intensity at each panel on the satellite. The paper will present simulations of the performance of the attitude determination and control system.

16:20 AAS 05 - 330 Passive Attitude Control System for Nano-Satellite REFLECTOR
Anna D. Guerman, University of Beira Interior, Covilha, Portugal; M. Yu. Ovchinnikov, V. I. Pen'kov, S. A. Mirer, Russian Academy of Sciences; V. D. Shargorodsky, Research Institute for Precise Device Engineering, Russia

We present passive attitude control system of nano-satellite REFLECTOR. This satellite is used as an optical reference target for optical sensing, imaging and tracking experiments. The analysis of satellite dynamics showed that it is possible to guarantee gravity-gradient stabilization by use of additional masses and proper choice of hysteresis rods. This study permitted us to determine the mass distribution, as well as the parameters of damping system (such as the volume, number, and location of hysteresis rods), which guarantee the necessary characteristics of steady-state motion of the satellite and provide the acceptable time of response.

16:45 AAS 05 - 331 Optimal switching between agile targets using rate-limited slews
Sergei Tanygin, Analytical Graphics, Inc.

Scheduling imaging satellites takes into account various factors including how fast the satellite can slew from one target to another. This paper discusses minimization of slew duration considering slew rate limits as well as relative geometry and motion of the target vectors within specified time interval.

Session 12: Trajectory Design & Optimization I

Chair: T. Alan Lovell
Air Force Research Laboratory

13:30 **AAS 05 - 332** **A Historical Introduction to the Covector Mapping Principle**
I. Michael Ross, Naval Postgraduate School

The Covector Mapping Principle (CMP) represents a unification of several apparently disparate ideas in solving trajectory optimization problems. In recent years, the CMP has made possible a simple approach to solving complex problems. Although the CMP is modern in philosophy, its origins can be traced back to Euler's original idea that he abandoned in favor of Lagrange's variational approach. In combining approximation theory with the now classical ideas of Karush, Pontryagin and Bellman, this paper traces the origins of this approach while demonstrating how one can quickly solve problems that were considered difficult only about a decade ago.

13:55 **AAS 05 - 333** **Decreasing Semimajor Axis Uncertainty Through Trajectory Design**
Scott Zimmer, Cesar Ocampo, and Robert Bishop, The University of Texas at Austin

This paper presents a method to transfer a spacecraft with continuous thrust while minimizing a combination of fuel consumption and uncertainty of the spacecraft state in a frame other than the one in which the spacecraft equations of motion and covariance are expressed. The technique allows one to minimize the uncertainty in the spacecraft semimajor axis, flight path angle, or range without developing the equations of motion for the spacecraft or covariance in a non-Cartesian frame. Example problems demonstrate that the covariance associated with the semi-major axis can be reduced significantly with only a slight increase in fuel consumption.

14:20 **AAS 05 - 334** **Finite Burn Trajectory Optimization Including Observability with Discrete Measurements**
Scott Zimmer, Cesar Ocampo, and Robert Bishop, The University of Texas at Austin

This paper presents a method to solve a trajectory transfer problem for a spacecraft with continuous thrust while minimizing a combination of fuel consumption and spacecraft state uncertainty. This paper extends previous results to allow for the case where the observations are discrete measurements. Because the optimality conditions derived with the calculus of variations require that the covariance matrix be included in the spacecraft state, each discrete observation provides a discontinuity in the system state and consequently a discontinuity in the costates. The theory is developed to determine the required relationship between the costates before and after each discrete measurement.

14:45 **AAS 05 - 335** **Paper Withdrawn**

15:10 **Break**

15:30 **AAS 05 - 336** **A Multiple Encounter Targeting and Optimization Algorithm**
James K. Miller, KinetX, Inc. Space Navigation and Flight Dynamics Practice

A multiple encounter trajectory design algorithm is described. The solution of a highly nonlinear system of equations is obtained by adapting a conventional constrained parameter search and optimization algorithm. The problem of extreme sensitivity and nonlinearity is solved by breaking the trajectory into overlapping legs comprised of two successive encounters. The second partial derivatives, required for an efficient second order gradient search, are approximated in order to reduce the number of function evaluations per iteration. Since the second partial derivatives do not enter into computation of the optimization criterion, the final solution is exact for the entire trajectory. As an example, the trajectory design of the MESSENGER mission to Mercury is optimized to minimize propellant consumption.

15:55 **AAS 05 - 337** **Determination of Optimal Feedback Control Solutions for Trajectory Optimization using OCEA: An Operator Overloading Software**
Srinivas Rao Vadali, Rajnish Sharma, James D. Turner, Texas A&M University

Developing real-time optimal feedback control laws for nonlinear systems is a grand challenge problem. It has applications in trajectory optimization and real-time path planning. Hamilton-Jacobi-Bellman (HJB) equation, a nonlinear partial differential equation. The method of characteristics, which is typically implemented via shooting algorithms, results in open-loop solutions to the HJB equation. The feedback solution is determined by expressing costate vector as a function of the current time and current state. The required result essentially boils down to performing vector series reversion in near-real time. Generation of the higher order state transition matrix (tensor) differential equations and the implementation of the vector series reversion process can be accomplished through the program OCEA, a Fortran-based

16:20 **AAS 05 - 338** **Optimal Reconfiguration of a Tetrahedral Formation Via a Gauss Pseudospectral Method**
G. T. Huntington, A. V. Rao, Draper Laboratory

The problem of determining minimum-fuel maneuver sequences to reconfigure a four-spacecraft tetrahedral formation is addressed. The objective of this research is to develop a minimum-fuel reconfiguration strategy such that, after reconfiguration, the four spacecraft are able to maintain an acceptable tetrahedral configuration near apogee for a period of three weeks without any required propulsive maneuvers. In the design considered here, an acceptable tetrahedron is obtained by satisfying a constraint on a modified version of a tetrahedral quality factor called the Glassmeier quality metric. The optimal reconfiguration problem is posed as a nonlinear optimal control problem and is solved using the Gauss pseudospectral method. The results obtained in this study provide insight into the optimal reconfiguration strategy and the structure of the optimally controlled system.

16:45 **AAS 05 - 339** **Post-Optimality Evaluation and Analysis of a Formation Flying Problem Via The Gauss Pseudospectral Method**
G. T. Huntington, A. V. Rao, Draper Laboratory; D. A. Benson, Massachusetts Institute of Technology

The post-optimality analysis of a tetrahedral formation flying optimal control problem is considered. In particular, the Karush-Kuhn-Tucker (KKT) conditions from the Gauss pseudospectral method are applied to a four-spacecraft orbit insertion problem. These discrete optimality conditions are compared to the continuous-time optimality conditions found by applying the calculus of variations to this optimal control problem. It is found that optimal control resulting from the KKT conditions are in excellent agreement with the continuous-time optimal control. The results obtained here demonstrate the accuracy of the Gauss pseudospectral method. Furthermore, the results illustrate the usefulness of the Gauss pseudospectral method as a means of gaining insight into the structure of optimally controlled systems.

Session 13: Satellite Constellations & Formation Flying II

Chair: Ron Proulx
Draper Laboratory

08:00 AAS 05 - 340 **Perturbed Equations of Motion for Formation Flight Near the Sun-Earth L2 Point**

A. M. Segerman, AT&T Government Solutions; M. F. Zedd, Naval Research Laboratory

NASA is planning missions to the vicinity of the Sun-Earth L2 point, some involving a distributed system of telescope spacecraft, configured in a plane about a hub. Several sets of differential equations are written for the formation flight of such telescopes relative to the hub, with varying levels of fidelity. Effects are cast as additive perturbations to the circular restricted three-body problem, expanded in terms of the system distances, to an accuracy of 10-20 m. These include Earth's orbital eccentricity, lunar motion, solar radiation pressure, and small thrusting forces. Simulations validating the expanded differential equations are presented.

08:25 AAS 05 - 341 **Discrete Nonlinear Optimal Control of Spacecraft Formations Near the L1 and L2 Points of the Sun-Earth/Moon System**

B. G. Marchand, K. C. Howell, Purdue University; J. T. Betts, The Boeing Company

Spacecraft formations, near the libration points of the Sun-Earth/Moon system, represent one option currently under consideration for applications to space based interferometry. This type of mission often requires precision tracking from the vehicles in the formation. However, past studies reveal that the dynamically sensitive nature of this region of space presents a number of unique challenges in this respect. For instance, the addition of thrust constraints into the design problem can significantly limit the level of positional accuracy that is achievable. The focus of this investigation is the application of discrete nonlinear optimal control to the constrained formation keeping problem.

08:50 AAS 05 - 342 **Design of Nonlinear Formationkeeping Controller for Earth-Moon Libration Point**

Hongming Li, Trevor Williams, University of Cincinnati

Based on a set of nonlinear equations of relative motion for libration point mission, a nonlinear formationkeeping controller is designed to support the future formation flight missions near the Earth-Moon L2 libration point. To take advantage of the nice property of the nonlinear equations of relative motion, techniques of feedback linearization is used to design the nonlinear controller, which suppresses the natural instability of the formation motion and the disturbance caused by solar radiation pressure effectively. Furthermore, a scheme of applying solar radiation to formationkeeping is developed to reduce the fuel cost of formationkeeping. The properties of these two schemes are analyzed.

09:15 AAS 05 - 343 **Coverage and Control of Constellations of Elliptical Inclined Frozen Lunar Orbits**

Todd A. Ely, Jet Propulsion Laboratory

A great deal of scientific interest exists regarding the Moon’s South Pole, which has been proposed for extensive robotic and human exploration. Unfortunately, it is typically not in view of Earth, and would require some form of communication relay to facilitate exploration. Prior results have developed a methodology for selecting a long-lived constellation of 3 satellites that provides persistent, stable coverage to either the North or South Pole with no requirement for station keeping under the influence of only gravitational perturbations. In the present study, coverage statistics are examined to determine the extent of coverage at lower latitudes. The sensitivity of this coverage in the presence of non-gravitational forces is determined, and control strategies are formulated that minimize any potential sensitivity to these accelerations.

09:40 **Break**

10:00 **AAS 05 - 344** **Implementation of the Strategy for Satisfying Distance Constraints for the NASA Benchmark Tetrahedron Constellation**
Pedro A. Capo-Lugo, Peter M. Bainum, Howard University

The NASA benchmark tetrahedron constellation is a proposed formation scheduled to be launched in the year 2009. In a previous paper, the authors developed a strategy based on the orbital elements without the use of an active control scheme. This strategy for maintaining the separation distance constraints is based on selection of the combination of initial velocities for the four satellites. This technique was only studied for phase I (one specific size) of the NASA benchmark problem. For this phase, the constellation does not violate the separation distance constraints without perturbations, and, with perturbations, the constellation maintains the formation for a period of 6 days. Through this paper, the strategy is implemented for the other two phases to determine when the constellation violates the separation

10:25 **AAS 05 - 345** **A Bang-Off-Bang Control for Out-of-Plane Orbital Maneuvers**
Xiaodong Duan, P. M. Bainum, Howard University

A bang-off-bang control is proposed for out-of-plane orbital maneuvers. For the mission that requires minimum energy consumption with constant thrust, this control technique could be a potential candidate. The control can adapt to low-thrust type thrusters. It can be used to maintain the relative orbits for formation flying and constellation station keeping. Expressions for the first and second firing switching times are obtained. They are functions of the initial conditions, the velocity and the position, the total maneuver time, and the thrust level. This analytic solution makes the control flexible since different maneuver times and thrust levels are acceptable. The simulations are conducted to verify the algorithm.

10:50 **AAS 05 - 346** **Planar Dynamics of a Variable Length Multi-Tethered Satellite System Near the Sun-Earth Lagrangian Point**
Brian Wong, Arun Misra, McGill University, Canada

This paper will examine the planar dynamics of a Lagrangian point multi-tethered system, connected together by variable length tethers, in the vicinity of the second Lagrangian point of the Sun-Earth system. Equilibrium configurations of the system under different tether length laws are determined and small motions about these configurations are analyzed. A numerical analysis of the controlled planar tether motions under different tether length control law is carried out for a two end-masses case when the system is near L2. Control effort required to maintain the desired end mass motions and tether librations would be determined.

11:15 **AAS 05 - 347** **Natural Configurations and Control Strategies Suitable for Formation Flying**
G. Gomez, M. Marcote, IEEC & Universitat de Barcelona, Spain; J. J. Masdemont, IEEC & Universitat Politecnica de Catalunya, Spain; J. M. Mondelo, IEEC & Universitat Autonoma de Barcelona, Spain

The present paper is devoted to study natural configurations, and the controlled motions between them, suitable for formation flying. Most of the study is done in the model defined by the Restricted Three Body Problem equations of motion, although it can be extended to the general n-body problem, as is shown in the paper. Configurations related to libration point nominal and transfer orbits of the Restricted Three Body Problem (RTBP) have been considered. The concrete goals of the paper are the study of geometries around arbitrary nominal orbits of the n-body problem with good properties for formation flight; the study of controlled motions between the zero relative radial acceleration cones obtained in the preceding analysis; the application of the above results to spacecraft.

Wednesday, Aug 10, 2005 Emerald

Session 14: Guidance, Navigation, & Control II

Chair: David Spencer
Penn State University

08:00 **AAS 05 - 348** **Orbital Control of Satellite Systems Using Nonholonomic Control Theory**
Shinji Hokamoto, Kyushu University, Japan

This study deals with orbital control of a satellite system into a prescribed orbit defined as a set of orbital elements by using its inner force, while most of the previous works for orbital transfer aim at changing just orbital energy. By applying nonlinear control theory, it is shown that the system is controllable except its pericenter and its apocenter in the elliptic orbit. Then, this paper transforms the nonlinear governing equation into a chained form, and demonstrates that a specified orbit is accomplished by applying the control procedure explained here.

08:25 **AAS 05 - 349** **Receding Horizon Control using Gauss-Lobatto Quadrature Approximations**
Paul Williams, RMIT University, Australia

An efficient approach for providing time-varying feedback via receding horizon control is proposed. The state and control trajectories are discretized over a future prediction horizon using a Gauss-Lobatto quadrature discretization. The linearized system equations are converted into a set of algebraic equations and the optimal control problem can be solved analytically for the feedback control gains. The approach is compared to a traditional pseudospectral discretization and it is found that the proposed approach is better-conditioned for numerical implementation. Closed-loop control of an elastic tether, which has both rigid body and elastic instabilities, is demonstrated.

08:50 **AAS 05 - 350** **A New Guidance Strategy in Aerodynamic Ascent Path using Air-breathing Propulsion**
Takayuki Yamamoto, Jun'ichiro Kawaguchi, Japan Aerospace Exploration Agency, Japan

The paper proposes the new guidance strategy in the aerodynamic ascent path. This guidance form has only four parameters comprised of Linear and Logarithmic functions. And the paper presents the guidance results for the practical application cases with certain constraints. The results show the guidance is well performed and satisfies the terminal boundary conditions specified. This guidance strategy does not include the optimization process aboard but solves a simple two-by-two linear algebraic equations along with forward integration. This strategy does guarantee the robust and real-time solutions, excluding any optimization process, and it is concluded quite practical.

09:15 **AAS 05 - 351** **Planetary Aeromaneuvering for Precision Landing Using Parafoils**
Marco Quadrelli, Jet Propulsion Laboratory

This paper identifies some advantages of gliding decelerators for exploration of planets with tenuous atmospheres. A parametric study was conducted for a representative system descending on Mars from an 8 km altitude varying the lift over drag ratio from0 to 2.5, the bank angle from 1 deg to 90 degrees, and the wind drift from 1 m/s to 20 m/s along the –y axis direction. The results of the study point out that a decelerator system with a large lift over drag ratio not only succeeds in completing a 180 degree turn away from an adverse wind, but can also land within 8 kilometers of the target, with enough time to replan its trajectory.

09:40 **Break**

10:00 **AAS 05 - 352** **Relativistically Correct Celestial Reference Systems**
P. Kenneth Seidelmann, University of Virginia; John H. Seago, Honeywell Technolgy Solutions, Inc.

The International Astronomical Union has adopted the International Celestial Reference System as a barycentric system providing increased accuracy below the milliarcsecond level. This new system is a fixed, epoch-independent system, determined from extragalatic radio sources. A new, moving frame based on Earth kinematics has been introduced. It has a new, slowly moving, fiducial point, the Celestial Intermediate Origin, as an alternative for the equinox. Therefore, many of the conventional expressions and terminology for Earth orientation are changing. Furthermore, the Geocentric Celestial Reference System (primarily used by artificial satellites) is defined based on general relativity, such that small Coriolis forces appear.

10:25 **AAS 05 - 353** **Real-Time Outer and Inner Loop Optimal Control Using DIDO**
Hui Yan, Deok J. Lee, Texas A&M University; I. Michael Ross, Naval Postgraduate School; Kyle T. Alfriend, Texas A&M University

In this paper we design two levels of control structure, outer loop and inner loop control, to enhance the robustness of real-time optimal control. The optimal control is efficiently solved by DIDO. An extended Kalman filter is used to estimate states to simulate real-time optimal control. We use a classic inverted pendulum problem to demonstrate our control approach. The results show the inverted pendulum can be stabilized very well in real-time.

10:50 **AAS 05 - 354** **Orbital Motion Equations with Dynamic Models**
Douglas H. May, Embry-Riddle Aeronautical University

Two-body orbits analyzed with fundamental principles of classical mechanics apply force, power, and energy principles to derive time-displacement equations. New models provide both time-displacement and velocity vector relationships for each orbit type. Dynamic models validate the approach by demonstrating compliance with the principle of conservation of energy. These models show that three dimensions are necessary to represent all energy terms. Rectilinear motion is a special case of the general model for each orbit type. Equations are expressed as trigonometric functions of conformance displacement angles that result naturally from the integration, and all models are based on circles.

11:15 **AAS 05 - 302** **Multi-User Communication and Tracking using CDMA for Cislunar Missions**
Jason Soloff, NASA Goddard Space Flight Center

Integral to NASA's plans are the Robotic Lunar Exploration Program (RLEP) and Project Constellation. RLEP and Project Constellation are programs involving multiple missions and vehicles that combine during a mission. Existing communication and navigation infrastructure is unable to support the expected volume of users over the next two decades. A key issue is the lack of frequency spectrum available to provide simultaneous multi-mission communication and tracking. This paper explores the infrastructure to support the RLEP and exploration missions.

Session 15: Orbital Dynamics II

Chair: James Gearhart
Lockheed Martin Technical Operations Co.

08:00 **AAS 05 - 355** **Orbit Optimization for Regenerative Aerobraking at Mars**
Douglas Tolbert, University of Missouri-Rolla

The goal of this study is the optimization of the mission design of a Mars mission with regenerative aerobraking as the design focus. The concept of regenerative aerobraking is to utilize the energy that is lost during aerobraking to benefit the mission. At high velocities, the atmosphere of Mars will ionize around the spacecraft. During this time period electrons can be gathered and significant amounts of power generated. Also, oxygen can be extracted from CO2, once the oxygen is stripped from the hot CO2. This oxygen can be collected and used on the surface of Mars by astronauts.

08:25 **AAS 05 - 356** **Simulation And Analysis Of Binary Asteroid Dynamics Using Mutual Potential And Potential Derivatives Formulation**
Eugene G. Fahnestock, Daniel J. Scheeres, N. Harris McClamroch, University of Michigan; Robert A. Werner, Jet Propulsion Laboratory

We investigate the coupled orbital and rotational dynamics of two arbitrarily shaped bodies, modeled as uniform density polyhedra, under the influence of their mutual gravitational potential. A method of calculating the mutual potential's derivatives with respect to relative position and attitude is derived. Equations of motion for the binary system are presented and a dynamic simulation software package is described. Results obtained with the package are presented for four cases to validate the package and to describe the behavior of a fragmenting asteroid. This simulation capability is also useful for enabling spacecraft missions to binary asteroids.

08:50 **AAS 05 - 357** **Epicyclic Description of Resonant Satellite Motion: Absolute and Relative Orbit Analysis.**
K. A. O'Donnell, P. L. Palmer, Surrey Space Center, University of Surrey, United Kingdom

A novel analytical description is presented of near-circular satellite motion in resonance with a tesseral harmonic of a rotating primary. The model is sufficiently accurate for use in orbit determination yet, unlike conventional approaches, has a concise geometric interpretation and is therefore computationally efficient enough to be implemented on-board a small satellite. A full derivation of the model is presented and simulation results demonstrate its accuracy in comparison to highly accurate symplectic orbit integrations. Preliminary analyses are also presented concerning resonance effects on satellite formations and the applications of this model to a GEO orbit estimator.

09:15 **AAS 05 - 358** **Transient Behavior of Planetary Satellite Orbiters**
Marci E. Paskowitz, Daniel J. Scheeres, University of Michigan

The transient behavior of a planetary satellite orbiter is studied, motivated by the Jupiter Icy Moons Orbiter (JIMO) mission. The Hill 3-body problem with higher order gravity field effects for the central body is used together with averaging theory to better understand the dynamics governing the motion. In particular, we compare and contrast the singly and doubly averaged systems in a systematic manner in order to provide insight regarding how to obtain long lifetime orbits in the unaveraged system.

09:40 **Break**

10:00 **AAS 05 - 359** **High Order Analytical Solutions of Hill's Equations**

Gerard Gomez, Manuel Marcote, IEEC & Universitat de Barcelona, Spain

The purpose of this paper is the semi-analytical computation of the bounded orbits of Hill's (or Clohessy--Wiltshire) equations, describing the relative motion of two particles in their Keplerian motion around a central body. We mainly consider the case in which one of the particles moves along a circular reference orbit. The extension of the procedure in the case of an elliptic reference orbit is also given. The solutions obtained are the generalisation of the periodic orbits obtained for the linearized equations when including the non-linear terms. With the algorithm presented, those orbits can be computed in a fast and efficient way up to an arbitrary order.

10:25 **AAS 05 - 360** **Paper Withdrawn**

10:50 **AAS 05 - 361** **Closed-Form Solution of the Orbit Equation in the Vicinity of Near-Circular Arcs with Atmospheric Drag Models**

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

This paper considers the restricted two-body problem in the presence of drag that varies with a power of the magnitude of the velocity. In general the orbit equation for this problem is an integro-differential equation. For extreme cases in which the motion is mostly tangential (i.e. near a circular arc) and the drag varies with the square of the magnitude of the velocity, conditions are found in which the orbit equation can be transformed to an ordinary differential equation. Closed-form solutions of this equation are found for two atmospheric density models. One of these models demonstrates a significant improvement in accuracy over previous results.

11:15 **AAS 05 - 362** **Orbital Dynamics of Temperature-Constrained Solar Sails**

Hiroshi Yamakawa, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Japan

The orbital dynamics of solar sails are investigated considering the limit of the sail temperature. Firstly, the orbital property of a constant temperature solar sail is studied by varying the initial orbital conditions and optical/thermal properties of the non-perfect solar sail. Then an approximate solution for the constant temperature sail spiral trajectory is investigated . Finally, Sun-pointing solar sails, which is the case for large and/or Gossamer sails, are assumed to investigate its circular orbit existence and its stability.

Session 16: Earth Sciences Afternoon Constellation Operations (Invited)

Chair: Mark Vincent
Raytheon

13:30 **AAS 05 - 363** **EOS Aura Ascent Planning - Establishing the Earth Science Afternoon Constellation**

Richard J. McIntosh, A. I. Solutions, Inc.; Lauri Kraft Newman, NASA Goddard Space Flight Center

This paper describes the trajectory planning and operations efforts of the NASA GSFC Flight Dynamics team to place EOS Aura in its mission orbit to form the fundamental beginnings of the Earth Science Afternoon Constellation. Aura is required to fly in a particular location relative to the WRS path of EOS Aqua. Pre-mission analysis is discussed, including choice of launch window start and duration to meet constellation requirements, nominal ascent scenarios, and contingency plans. Actual as-flown orbit raising maneuvers are also documented, including operational maneuver constraints, maneuver calibration results, conjunction assessments for collision avoidance, and backup burn options.

13:55 **AAS 05 - 364** **Inclination Adjust Maneuver Planning and Execution for the Earth Science Afternoon Constellation**

David K. Rand, A. I. Solutions, Inc.; Lauri Kraft Newman, NASA Goddard Space Flight Center; Kevin T. Work, Lockheed Martin Space Operations

EOS Aura recently performed a series of inclination change maneuvers in concert with a similar series performed by EOS Aqua in order to prepare for several other missions to enter the Earth Science Afternoon Constellation. This paper details the Aura inclination maneuver planning, including leveraging Aqua lessons learned, examining various maneuver date options in concert with ascent planning, contingency planning, and collaboration with the Aqua Flight Operations Team to ensure that the maneuvers could be executed from the shared control center by shared personnel without issue. The actual maneuver operations and results are discussed along with lessons learned.

14:20 **AAS 05 - 365** **PARASOL Insertion in the A-Train**

Damien Delobette, Centre National D'Etudes Spatiales (CNES), France

This paper will present operational aspects of the second CNES microsatellite mission called Parasol. Parasol has been launched the 18 December 2005 by an Ariane 5 G+ from Europe's spaceport in Kourou, French Guiana, riding as a passenger among seven satellites. The A-train formation is composed of six satellites, taking identical measurement for clouds, aerosol and atmosphere study. The insertion of Parasol in the A-train was leaded by several operational or technological constraints. This presentation will cover different flight dynamics aspects, respecting those different constraints. And this, from injection until station keeping within A-train formation.

14:45 **AAS 05 - 366** **Calipso and Cloudsat Insertion in the Aqua Train Formation**

Corinne Salcedo, Centre National D'Etudes Spatiales (CNES), France

This paper will focus on the operational aspects of the Calipso and Cloudsat missions for obtaining their constellation and maintaining a short spacing, between these two satellites within the Aqua train formation. The Aqua train formation is composed of six satellites, taking coincident measurement for climate prediction. Trees of them are already in orbit. Calipso and Cloudsat will be launched in June 2005 in a dual launch with a Delta II rocket and will be separated in the same insertion orbit. After the separation, they will perform coordinated maneuvers to reach the Aqua train formation. For safety guarantees this station acquisition will requires close coordination between the two missions and the other members of the constellation.

15:10 **Break**

15:30 **AAS 05 - 367** **The "Playbook" for Inserting Cloudsat Into the A-Train Constellation**
Mark Vincent, Raytheon Company; Donald Keenan, The Aerospace Corporation; Ronald Boain, Jet Propulsion Laboratory

A playbook has been created which describes the maneuvers used to place the CloudSat satellite into the A-Train Constellation. This paper describes the analysis that went into determining the sequence and timing of the maneuvers. Factors that were included are the launch vehicle injection and separation errors and the errors in both the magnitude and direction of the maneuvers. Each possible scenario in a repetitive 16-day launch cycle was analyzed. The orbit raise maneuvers are used to place CloudSat between its formation flying partner, CALIPSO, and the Aqua satellite and to achieve a frozen orbit.

15:55 **AAS 05 - 368** **Analysis for Monitoring the Earth Science Afternoon Constellation**
Karen Richon, NASA Goddard Space Flight Center; Peter Demarest, Frank Wright, AI Solutions, Inc.

The coordination of flight dynamics activities between the 6 member satellites is critical to the safety and success of the Afternoon Constellation. This coordination is based on two main concepts, the "control box" and the "zone of exclusion." The control box defines the spacing of the satellites while the zone of exclusion (ZOE) represents the region where evasive maneuvers may be necessary to ensure the health and safety of the satellites. This paper discusses the coordination concepts of the control box and ZOE and will include a description of the software tools used to calculate these parameters.

16:20 **AAS 05 - 369** **Afternoon Constellation Contingency Procedures**
Karen Richon, NASA Goddard Space Flight Center; Warren Case, Stinger Ghaffarian Technology

The Afternoon Constellation (AC) is comprised of six satellites: Aqua, Aura and PARASOL (on-orbit) and CALIPSO, CloudSat and OCO (to be launched). The AC's common science goal is to provide coincident Earth observations. This paper describes the high-level procedures for maintaining the safety of the AC and includes defining the contingency situations, the pertinent parameters involved in the contingency analysis and establishing guidelines for the actions required, based on the results of the contingency analyses.

Session 17: Trajectory Design & Optimization II

Chair: John Lynch
NASA Goddard Space Flight Center

13:30 **AAS 05 - 370** **Near Real-time Optimization of Launch Trajectory**
Mingguang Wang, Jianping Yuan, Jianjun Luo, Northwestern Polytechnical University, China

Firstly, the dynamics and kinematics equations of motion is simplified according to the features of ascent trajectory of RLV. Secondly, the trajectory optimal control problem is converted into constraint nonlinear programming program by advanced method, and then this constraint nonlinear programming is transmuted into unconstraint nonlinear programming problem using an augmented-LaGrange multiplier method. Consequently, the BFGS method is used to solve this problem. At last, the ascent trajectory optimization of air-launch mode has been simulated numerically. Successful results show this methodology can generate a feasible ascent trajectory of about 1000 s flight time in 10-20 s on the desktop computer.

13:55 **AAS 05 - 371** **An Algorithm for Computing Near-Optimal, Many-Revolution Earth-Orbit Transfers**
Y. Gao, C. A. Kluever, University of Missouri-Columbia

A novel algorithm is developed for obtaining near-optimum, many-revolution Earth-orbit transfers for very low-thrust spacecraft. The thrust-direction control strategy employs a combination of tangential steering, inertial steering, and piecewise constant-yaw steering to simultaneously change the orbital energy, eccentricity, and inclination, respectively, within each orbital revolution. Orbital averaging techniques are used to significantly reduce the number of numerical integration steps, and simple approximations are utilized to obtain analytical integrals. The optimal steering profile is determined by a small number of free design parameters. Our method is demonstrated by obtaining optimal transfers from low-Earth and geostationary transfer orbit to geostationary orbit.

14:20 **AAS 05 - 372** **Indirect Optimization of Spiral Trajectories with Estimation Techniques Used for Initial Unknowns**
Chris Ranieri, Dr. Cesar Ocampo, University of Texas at Austin

Indirect optimization is used to compute minimum propellant spiral trajectories. Two estimation techniques allow the user to generate accurate initial estimates of the Lagrange multipliers. The first method uses the values of the initial multipliers from converged solutions of shorter, easier-to-find spirals, to extrapolate the values of the multipliers for longer spirals. Polar rather than Cartesian coordinates are used and in this frame, the multipliers evolve in a well-behaved fashion, allowing the extrapolation to accurately predict the multipliers. The second, an Adjoint Control Transformation, converts the thrust unit direction vector to the actual multipliers that control the trajectory.

14:45 **AAS 05 - 373** **Minimum Impulse Transfers to Rotate the Line of Apsides**
Connie Phong, Theodore H. Sweetser, Jet Propulsion Laboratory

While an optimal scenario for the general two-impulse transfer between coplanar orbits is not known, there are optimal scenarios for various special cases. In this paper we reconsider the special case of in-plane rotation of the line of apsides of an ellipse. Numerical comparisons with a trajectory optimization program support the claim that the optimal DV required by two impulses is about half that required by a single impulse, regardless of semi-major axes. We observe that this estimate becomes more conservative with larger angles of rotation and eccentricities, and thus also present a more accurate two-impulse rotation DV estimator.

15:10 **Break**

15:30 **AAS 05 - 374** **Low-Thrust Gravity Assist Trajectory Optimization Using Evolutionary Neurocontrollers**

Ian Carnelli, Massimiliano Vasile, Amalia Ercoli Finizi, Politecnico di Milano, Italy; Bernd Dachwald, Wolfgang Seboldt, German Aerospace Center, DLR, Germany

Combining low-thrust propulsion and gravity assists to enhance deep space missions has proven to be a formidable task. While trajectories generated by methods based on optimal control theory are typically close to the needed initial guess, recently investigated global evolutionary programming techniques often necessitate the successive use of different methods. In this paper, a new method based on evolutionary neurocontrollers is presented. The advantage lies in its ability to explore the solution space autonomously to find optimal trajectories, without an initial guess and without permanent attendance of an expert in astrodynamics. For a Mercury rendezvous problem with a Venus gravity assist, preliminary results are presented.

15:55 **AAS 05 - 375** **Optimization of Low-Thrust Gravity-Assist Trajectories with a Reduced Parameterization of the Thrust Vector**

Chit Hong Yam, James M. Longuski, Purdue University

Low-thrust trajectories can be modeled as a sequence of impulses (delta-Vs) connected by conic arcs. Each delta-V is described by at least three coordinates. We investigate new ways of parameterizing the delta-V coordinates when optimizing low-thrust gravity-assist trajectories. For the delta-V magnitude coordinate, we use a set of on/off times to control the thrusting and coasting period of the trajectory. For the delta-V angles, we use parametric functions of time (e.g. polynomials) to approximate the optimal thrust angles. With the appropriate choice of parameters, the number of optimization variables and constraints (and thus convergence speed) may be reduced significantly.

16:20 **AAS 05 - 376** **Six-Degree-of-Freedom Trajectory Optimization Utilizing A Two-Timescale Collocation Architecture**

Prasun N. Desai, NASA Langley Research Center; Bruce A. Conway, University of Illinois

Six-degree-of-freedom trajectory optimization of a reentry vehicle is solved using a two-timescale collocation methodology. This class of 6DOF trajectory problems are characterized by two distinct timescales in their governing equations, where a subset of the states have high-frequency variations (the rotational equations of motion) while the remaining states (the translational equations of motion) vary comparatively slowly. With standard collocation methods, the 6DOF problem size becomes extraordinarily large and difficult to solve. The converged solution utilizing the two-timescale collocation architecture shows a realistic landing profile and captures the appropriate high-frequency rotational dynamics. A large reduction in the overall problem size (by55%) is attained as compared to the standard single-timescale collocation method. Consequently, optimum six-degree-of-freedom trajectory problems can now be solved using collocation, which was not

16:45 **AAS 05 - 377** **Numerical Investigation of Mapping Orbits about Jupiter's Icy Moons**

John Aiello, Jet Propulsion Laboratory

A proposed mission that would orbit Callisto, Ganymede, and Europa will require low altitude, high inclination orbits for gravity and surface mapping. The inherent instability of these orbits poses a particular challenge to gravity field mapping which requires tracking of a spacecraft unperturbed by orbit maintenance maneuvers. Analytical investigations identify conditions that allow for an uncontrolled orbit over the time scales necessary for gravity mapping, yet these are typically obtained via a Hill model with various approximations to the force models. This paper explores the dynamics of these orbits by direct propagation against a full force ephemeris model. Initial conditions within the context of a mapping mission’s likely requirements are considered. The results complement the analytical studies and reveal additional dependencies.

Session 18: Dynamical Systems Theory & Applications

Chair: David Vallado
Analytical Graphics, Inc.

13:30 **AAS 05 - 378** **Stability Maps, Global Dynamics, and Transfers**
Benjamin Villac, Jet Propulsion Laboratory; Martin Lara, Real Observatorio de la Armada, Spain

Unstable periodic orbits offer a transport mechanism between separated regions of phase space via their associated stable/unstable manifolds and connections. While it is known that unstable periodic orbits are associated with resonance regions, the determination of their locations remains a difficult task. This paper presents a large class of unstable periodic orbits that exists near the boundary between the stability region associated with a stable periodic orbit and a region of strong chaos. The location of these unstable periodic orbits is provided by the computation of stability maps based on a Fast Lyapunov Indicator together with a differential corrector subroutine. These bounding unstable periodic orbits are shown to determine major transport routes that can be used for designing inexpensive transfers between different dynamical regimes.

13:55 **AAS 05 - 379** **Surface Structure of an Invariant Manifold of a Halo Orbit**
Anil N. Hirani, Martin W. Lo, Jet Propulsion Laboratory

We extract the surface structure of an unstable invariant manifold tube of a halo orbit. We do this by using transversal planes to intersect trajectories that approximate the tube. From these intersection points we construct spline-interpolated cross section curves which give a good idea of the very complex structure of the tube. We also construct surfaces made of quadrilaterals and triangles from these cross-sections. Our method is complementary to the constant-time cross-section method used by some other researchers. With our method, the surface structure of very long lengths of the tube can be extracted. Our work is motivated by applications to space mission design.

14:20 **AAS 05 - 380** **Chaining Simple Periodic Three Body Orbits**
Martin Lo, Jet Propulsion Laboratory; Jeffrey S. Parker, University of Colorado, Boulder

This paper studies the chaining of periodic orbits via their invariant manifolds to provide various types of low energy orbits for space exploration, particularly in the Sun-Earth-Moon system. This technique was used for the design of the Genesis mission as well as the Lunar Sample Return mission. Recent work shows that this approach may be used to design planetary flyby and planetary capture orbits. This shows that the technique for chaining periodic orbits is much more general and widely applicable, and not restricted to libration missions only. The use of invariant manifolds provides a unified theoretical approach for studying these different mission applications. It also provides robust numerical algorithms for the computation and optimization of such trajectories.

14:45 **AAS 05 - 381** **Lyapunov Stability of Hovering Spacecraft in Time-Invariant Systems**
Stephen B. Broschart, Daniel J. Scheeres, University of Michigan

In this paper, we derive criteria for Lyapunov stability of hovering spacecraft controlled by a one-dimensional, dead-band thrust control law in time-invariant Hamiltonian dynamic systems. We use the conservative properties of the system to define zero-velocity surfaces, then choose our control so trajectories near the hovering position are bounded. The effects of uncertainty in the initial hovering state are evaluated and a formulation for determining the maximum allowable perturbations in the initial state is also presented. Our result is applied to hovering in the two-body, restricted three-body, and Hill problems.

15:10 **Break**

15:30 AAS 05 - 382 A Low Energy Lunar Transportation System Utilizing Chaotic Dynamics

Edward Belbruno, Princeton University and Innovative Orbital Design, Inc.

The purpose of the paper is to describe a low energy lunar transportation system suitable for servicing a lunar base. This system utilizes both a Crew Exploration Vehicle and a robotic Tanker Craft. The Crew vehicle uses a Hohmann transfer, and the Tankeruses a 90 day ballistic capture lunar transfer (or WSB transfer). The Tanker provides the necessary propellant for the Crew Vehicle to travel from the Earth to the Moon, land on the Moon, and return to the Earth, while the Tanker returns to the Earth as well after off loading fuel. The Crew Vehicle and Tanker rendezvous in an interesting, dynamically sensitive(chaotic) capture orbit. This transportation system is in response to the Space Exploration Initiative as put forth by the Bush administration.

15:55 AAS 05 - 383 Shoot the Moon 3D

Jeffrey S. Parker, University of Colorado: Martin W. Lo, Jet Propulsion Laboratory

This study presents a three-dimensional trajectory that requires only a single deterministic maneuver at the Earth in order to become ballistically captured by the Moon. Most lunar orbits are directly accessible from the final stage in this ballistic transfer, including highly-inclined orbits and even polar orbits. The mission design process implements invariant manifold theory to construct this trajectory. Although the transfer requires about 100 days more time to reach the Moon compared with a typical Hohmann transfer, the total cost of the transfer is about 15% less than the Hohmann transfer.

16:20 AAS 05 - 384 On Parking Solutions Around Europa

Martin Lara, Royal Naval Observatory of Spain; Ryan Russell, Benjamin Villac, Jet Propulsion Laboratory

The long-term stable trajectories around Europa, one of the Galilean moons of Jupiter, are analyzed for their potential applications in spacecraft trajectory design, such as end of mission disposal options, backup orbits or intermediary targets for transfer trajectories. The phase space is analyzed via the computation of families of periodic orbits and the estimation of their associated stability domains using a Fast Lyapunov Indicator method. While the core analysis of the paper uses the circular restricted three body problem, a selected set of parking solutions is checked by integrating the corresponding initial conditions in an ephemeris model over several years.

Session 19: Atmospheric Entry/Reentry Breakup Analysis (Invited)

Chair: Ahmed Salama
Jet Propulsion Laboratory

08:00 **AAS 05 - 385** **Vehicle Breakup Analysis for Applications in Aerospace Nuclear Safety**
Lisa Ling, Dan Tuckness, Ahmed Salama, Angus McRonald, Jet Propulsion Laboratory

For decades, vehicle breakup analysis had been performed for space missions using nuclear heater or power units to assess aerospace nuclear safety in the event of a launch failure leading to inadvertent atmospheric reentry. Such pre-launch risk analysis is imperative to assess environmental impact, obtain launch approval, and for launch contingency planning. Work devoted to this area had been ongoing since 1959 and has been well-documented. This document discusses the background, objectives, and process of performing vehicle breakup analysis for applications in aerospace nuclear safety, specifically those conducted at the Jet Propulsion Laboratory (JPL) for launch approval.

08:25 **AAS 05 - 386** **A Methodology of MSL Breakup Analysis for Earth Accidental Reentry and its Application to Breakup Analysis for Mars Off-Nominal Entry**
Ahmed Salama, Lisa Ling, Jet Propulsion Laboratory

Vehicle breakup analysis has been performed for missions that carry nuclear fuel for heating or power purposes to assess nuclear safety in case of launch failure that leads to atmospheric reentry. Also, as the spacecraft starts the Mars entry, descent, and landing (EDL), several failure scenarios could lead to breakup as well. Since the Mars Science Laboratory (MSL) spacecraft includes a Radioisotope Thermoelectric Generator (RTG), an analysis of breakup in case of launch failure is required. Also, breakup during Mars EDL due to off-nominal entries could release the RTG heat source that has implications for planetary protection requirements. This paper presents a methodology of MSL breakup analysis for launch failure with application to Mars off-nominal entry.

08:50 **AAS 05 - 387** **A Genesis Breakup and Burn-Up Analysis in an Off-Nominal Earth Return and Atmospheric Entry**
Ahmed Salama, Lisa Ling, Angus McRonald, Jet Propulsion Laboratory

The Genesis capsule returned to Earth on September 8, 2004, carrying samples of solar wind charged particles. In an anomalous occurrence prior to entry, the spacecraft may break up and fragments could scatter over the Earth’s surface. The Genesis project conducted a detailed breakup/burnup analysis before the Earth return to determine if any spacecraft component could survive and reach the ground intact in case of an off-nominal entry. In addition, an independent JPL team was chartered with the responsibility of analyzing several definitive breakup scenarios to verify the official project analysis. This paper presents the analysis and results of this independent team.

09:15 **AAS 05 - 388** **Development of Hypersonic Aerodynamic Coefficients for Arbitrary-Shaped Body Obtained from Newtonian Theory Using Triangular Panels**
Lisa Ling, Jet Propulsion Laboratory; Dan Tuckness, University of Oklahoma

Vehicle breakup analysis is performed for the assessment of aerospace nuclear safety required for launch approval and contingency planning for space missions using nuclear heater or power units. Vehicle breakup typically occurs during the hypersonic regime of the reentry. Therefore, hypersonic aerodynamic coefficients of various vehicle configurations are needed for trajectory propagation and breakup analysis. This paper presents the derivation of the equations used to develop a panel code employing triangular panels for the calculation of hypersonic aerodynamic coefficients of an arbitrary-shaped body based on Newtonian theory for hypersonic flow. Validation of the panel code against two test cases is also presented.

09:40 **Break**

10:00 **AAS 05 - 389** **Development of Non-Arbitrary Atmospheric Entry Points for Impact Footprint Determination in an Inadvertent Earth Reentry During Launch Contingency**

Lisa Ling, Jet Propulsion Laboratory; Dan Tuckness, University of Oklahoma

In space missions using nuclear heater or power units, vehicle breakup analysis performed for risk assessment required for launch approval provides predictions of vehicle breakup and impact point of the nuclear power system for various launch contingency scenarios. During launch, a failure occurring while in the park orbit may lead to an out-of-orbit reentry. In order to predict the resulting impact point, a non-arbitrary entry point is needed for trajectory propagation and breakup analysis. The derivation of the equations for the modeling of inertial-fixed thrust and the calculation of non-arbitrary entry condition in an out-of-orbit reentry is presented in this paper. Validation of the entry condition is also presented.

10:25 **AAS 05 - 390** **Modeling of Local Winds and Real-Time Application in Impact Point Prediction for Inadvertent Earth Reentry During Launch Contingency**

Lisa Ling, Jet Propulsion Laboratory; Dan Tuckness, University of Oklahoma

In the event of a launch failure leading to inadvertent Earth reentry in a space mission using nuclear heater or power units, impact point prediction is required of the nuclear power system as specified in the launch contingency plan. To enhance the accuracy of the footprint prediction, the effects of real-time local winds obtained from the website of the National Oceanic and Atmospheric Administration are included in the trajectory propagation. This paper presents the derivation of the equations for the modeling of local winds and an example of its application to the pre-launch vehicle breakup analysis performed for the Mars Exploration Rover mission.

Session 20: Low Thrust Mission & Trajectory Design

Chair: Dennis Byrnes
Jet Propulsion Laboratory

08:00 **AAS 05 - 391** **Comparison of Gradient Optimization and Genetic Algorithms for Interplanetary Low Thrust Trajectory Design**
Glenn E. Peterson, Eric T. Campbell, John P. McVey, The Aerospace Corporation

In low thrust mission design, there are a host of variables that can influence the solution ranging from initial orbit conditions, mass of the spacecraft, injection time, arrival time, specific impulse, thrust magnitude, etc. This large solution space makes rapid prototyping of optimized trajectories difficult. Many different techniques have been applied to the low thrust optimization problem and this study examines several of these methodologies by comparing the performance and accuracy from three different techniques: a gradient optimization using a numerical integrator, a gradient optimization using conic sections, and genetic algorithms.

08:25 **AAS 05 - 392** **Optimisation of Low-Thrust Orbit Transfers Using the Q-law for the Initial Guess**
Anastassios E. Petropoulos, Gregory J. Whiffen, Jet Propulsion Laboratory

The Q-law is a Lyapunov feedback control law for effecting low-thrust orbit transfers between arbitrary pairs of orbits around a central body. The Q-law produces results representative of optimal orbit transfers. In this work we use the Q-law to generate initial guesses for optimising a variety of orbit transfers. For each orbit transfer, the Q-law produces transfer trajectories with different flight-times and propellant masses (depending on the amount of coasting). Each Q-law transfer trajectory is optimised using the Static Dynamic Control algorithm. The optimal solutions obtained are compared with the Q-law initial guess. The speed of optimisation, and nature of the optimal solutions found, are compared with optimal solutions obtained using the previously available, simplistic initial guesses.

08:50 **AAS 05 - 393** **Low-Thrust Orbit Transfer Optimization with Refined Q-law and Multi-objective Genetic Algorithm**
Seungwon Lee, Anastassios E. Petropoulos, Paul von Allmen, Jet Propulsion Laboratory

An optimization method for low-thrust orbit transfers around a central body is developed using the Q-law and a multi-objective genetic algorithm. In the method, the Q-law generates transfers between specified initial and final orbits, and the multi-objective genetic algorithm optimizes the Q-law parameters. The optimization goal is to minimize simultaneously the consumed propellant mass and flight time and to find Pareto-optimal orbit transfers. Five orbit transfers are considered, ranging from simple transfers to complex transfers. By utilizing a multi-objective optimization process, the present method produces a more extended Pareto front with significantly less computational effort than conventional single-objective optimization algorithms.

09:15 **AAS 05 - 394** **Maximum Deliverable Mass For Low-Thrust Geosynchronous Transfers Under Realistic Mission Constraints**
Alan B. Jenkin, The Aerospace Corporation

This paper considers a hypothetical low-thrust transfer to geosynchronous orbit that includes launch, chemical, and electric phases. It is generally expected that increasing thruster power will increase deliverable mass to geosynchronous orbit. However, for fixed electric thruster specific impulse and launch injection orbit parameters, deliverable mass cannot be increased beyond a threshold. It turns out that the upper limit on deliverable mass can be increased by varying the specific impulse and launch injection orbit parameters. This study focuses on the optimization of these parameters to maximize deliverable mass for several currently available launch vehicles using publicly available performance data.

09:40 **Break**

10:00 **AAS 05 - 395** **Low-Thrust Round-Trip Trajectories to Mars with One-Synodic-Period Repeat Time**
Masataka Okutsu, Damon Landau, James Longuski, Purdue University

We investigate the use of nuclear-electric propulsion for human missions to Mars. Employing a patched-conic solution as our initial guess, low-thrust trajectories are designed via a continuation method. We determine the propulsion requirements for a reusable human transportation system, in which a single vehicle makes a round trip between the Earth and Mars within a synodic period, thus allowing a mission at every launch opportunity. We find that the acceleration required for a typical mission exceeds current technology by an order of magnitude.

10:25 **AAS 05 - 396** **Analysis of Chemical, REP, and SEP missions to the Trojan Asteroids**
Eugene P. Bonfiglio, David Oh, Chen-Wan Yen, Jet Propulsion Laboratory

Recent studies suggest significant benefits from using Radioisotope Power Systems (RPS) as a power source for an electric propulsion (EP) mission to the outer planets. This study focuses on trajectories to the Trojan asteroids. A high level analysis is performed with chemical trajectories to determine potential candidates for REP trajectory optimization. Extensive analysis of direct trajectories using REP is performed on these candidates. Solar Electric Propulsion (SEP) trajectories are also considered for comparison against REP trajectories. A spacecraft mass is derived for the different types of missions, providing insight to how the REP missions compare with chemical and SEP missions.

10:50 **AAS 05 - 397** **Earth Gravity-Assist Trajectories to Jupiter Using Nuclear Electric Propulsion**
Daniel W. Parcher, Jon A. Sims, Jet Propulsion Laboratory

This paper examines optimal low-thrust gravity-assist trajectories to Jupiter using nuclear electric propulsion. The scope of the discussion will be limited to single and double-Earth gravity assists. For both of these cases, multiple locally optimal trajectory families, differentiated by transfer resonance between flybys and by flyby type, are considered. Trajectories that minimize initial injection energy by using low resonance transfers or several heliocentric revolutions to the first flyby offer the most delivered mass given sufficient flight time.

11:15 **AAS 05 - 398** **Gravity-Assist Trajectories to Jupiter Using Nuclear Electric Propulsion**
Daniel W. Parcher, Jon A. Sims, Jet Propulsion Laboratory

This paper examines optimal low-thrust gravity-assist trajectories to Jupiter using nuclear electric propulsion. Three different Venus-Earth gravity-assist (VEGA) types are presented and compared to other gravity-assist trajectories that use combinations of Earth, Venus, and Mars. Families of solutions for a given gravity-assist combination are differentiated by approximate transfer resonances, number of heliocentric revolutions, flight time between flybys, and by flyby types. Trajectories that minimize initial injection energy by using low resonance transfers or additional heliocentric revolutions offer the most delivered mass given sufficient flight time.

Session 21: Orbit Determination II

Chair: Bob Glover
AT&T

08:00 **AAS 05 - 399** **Linked, Autonomous, Interplanetary Satellite Orbit Navigation (LiAISON)**
Keric Hill, George H. Born, University of Colorado at Boulder; Martin W. Lo, Jet Propulsion Laboratory

For multiple spacecraft using Satellite-to-Satellite Tracking (SST) such as crosslink range, ground-based tracking is usually needed so that the states of all the spacecraft are observable. Trajectories with a unique size, shape, and orientation enable autonomous orbit determination using only SST. These unique trajectories exist where there is strong asymmetry in the acceleration field. LiAISON, or "Liaison Navigation" uses only SST to determine the orbits of multiple spacecraft when one is in a locally unique orbit. The three-body problem has strongly asymmetric accelerations around the smaller primary body and spacecraft there should be able to use Liaison Navigation.

08:25 **AAS 05 - 400** **Linked, Autonomous, Interplanetary Satellite Orbit Navigation (LiAISON) in Lunar Halo Orbits**
Keric Hill, George H. Born, University of Colorado at Boulder; Martin W. Lo, Jet Propulsion Laboratory

To test the feasibility of Liaison Navigation, simulated crosslink range measurements were generated for two spacecraft in the circular restricted three-body problem. With at least one of the spacecraft in a lunar halo orbit, it was found through covariance analysis that the orbits for both spacecraft were observable without Earth-based tracking. The orbit estimates were compared for various constellations to determine how the orbit geometry affects the accuracy of the solutions. A range bias estimate and constant force model errors were simulated also. Navigation accuracy on the order of 10 m might be possible using Liaison Navigation in lunar halos.

08:50 **AAS 05 - 401** **An Overview of the ANDE Risk Reduction Flight**
A. C. Nicholas, S. E. Thonnard, I. Galysh, Naval Research Laboratory; P. Kalmanson, Praxis, Inc.; B. Bruninga, United States Naval Academy

The Atmospheric Neutral Density Experiment (ANDE) Risk Reduction flight is a mission proposed by the Naval Research Laboratory to monitor the thermospheric neutral density at an altitude of 400km. The primary mission objective is to test the deployment mechanism from the Shuttle for the ANDE flight in early 2006. Scientific objectives of the ANDE risk reduction flight include; monitor total neutral density along the orbit for improved orbit determination of resident space objects, monitor the spin rate and orientation of the spacecraft, provide a test object for polarimetry studies using the HI-CLASS system.

09:15 **AAS 05 - 402** **Special Perturbations to General Perturbations Extrapolation Differential Corrections in Satellite Catalog Maintenance**
David Cappellucci, Lockheed Martin Integrated Systems and Solutions

This paper examines the extrapolation differential correction technique to generate SGP4-compatible element sets as part of routine maintenance of a special perturbations satellite catalog. Parameters affecting the quality of extrapolation including ephemeris density, length of extrapolation interval and the relative overlap of SP fit span and prediction span are examined. The study shows that the prediction quality of the resulting GP element sets is comparable in quality to the underlying SP predictions over the time span covered by the extrapolation fit. Concurrent improvements in SP theory will result in GP element sets substantially improved over current operational practices.

09:40 **Break**

10:00 AAS 05 - 403 Astrodyanmics Environment (ADE): An Alternative Approach to Astrodynamics Software

William B. Simpson, and Kenneth J. Ernandes, Braxton Technologies, Inc.

Astrodynamics software is commonly developed under one of two different paradigms. The traditional approach is software with tailored requirements that are logical increments from a legacy system. The recent approach is Commercial-Off-The-Shelf (COTS) software implementing functionality common to a targeted user base. The traditional method is often costly and may have long development time. The COTS approach distributes the cost and provides a validated turnkey system operating on common workstations. Alternatively, the ADE astrodynamics software provides a unique approach in that it is a COTS solution that also shares key advantages of the traditional development approach.

10:25 AAS 05 - 404 Nonlinear Mapping of Gaussian State Uncertainties: Theory and Applications to Spacecraft Control and Navigation

Ryan S. Park, Daniel J. Scheeres, University of Michigan

This paper discusses the nonlinear propagation of spacecraft trajectory uncertainties via solutions of the Fokker-Planck equation. We first discuss the solutions of the Fokker-Planck equation for a deterministic system with a Gaussian boundary condition. Next we derive an analytic expression of a nonlinear trajectory solution using higher-order Taylor series approach and discuss the region of convergence for the solutions and apply the result to spacecraft applications. Such applications consist of nonlinear propagation of the mean and covariance matrix, design of a statistically correct trajectory, and nonlinear statistical targeting. The two-body and Hill three-body problems are chosen as examples and realistic initial uncertainty models are considered.

10:50 AAS 05 - 405 Maneuver Estimation Model for Relative Orbit Determination

Tara R. Storch, William E. Wiesel, Chris Sabol, Kyle T. Alfriend, K. Kim Luu, US Air Force Research Laboratory, Hanscom AFB

This research investigated relative orbit determination of individual satellites within a cluster, focusing on instances when a maneuver has been detected or suspected. Developed using non-linear least squares estimation, the maneuver model estimates magnitude, direction, and time of a suspected maneuver. Observations for the DirecTV 4S and AMC-4 satellite collocation were obtained from the Air Force Maui Optical and Supercomputing (AMOS) site consisting of differential right ascension and declination. Dynamics are modeled using Hill's equations.

11:15 AAS 05 - 406 Using EOP and Solar Weather Data for Real-time Operations

David A. Vallado, Analytical Graphics Inc, Center for Space Standards and Innovation

The historical TLE operations used analytically generated datasets which largely ignored or approximated the precise coordinate system and force models required to accurately model the satellite. Numerical operations require precise adherence to a coordinate system and specific force models. In particular, the Earth Orientation Parameter (EOP) and solar weather data are crucial to proper calculations using numerically generated state vectors. This paper investigates the available data, compares products within and between organizations, and provides a methodology for which data should be used for real-time operations.

Session 22: Trajectory Design & Optimization III

Chair: Prasun Desai
NASA Langley Research Center

13:30 **AAS 05 - 407** **General Optimization Framework for Multiple-Impulse Fuel-Optimal Spacecraft Rendezvous Using a Hybrid Approach**
Ya-Zhong Luo, Guo-Jin Tang, National University of Defense Technology, China

A general nonlinear programming model for multiple-impulse fuel-optimal time-fixed rendezvous with path and terminal constraints is established, and a hybrid approach is proposed as a global solver. In the hybrid approach, a floating-coded GA is employed to locate an initial guess to SQP using an analytical propagator, while SQP will locate the accurate global solution using the high-fidelity trajectory model. Our general optimization framework is used on three test cases: 1) Holman rendezvous and the Lambert rendezvous, and 2) two and three-impulse homing rendezvous problem with and without communication window constraints 3) four-impulse non-coplanar elliptical rendezvous problem. The results show that the hybrid approach is effective and efficient in dealing with the general multiple-impulse rendezvous problem.

13:55 **AAS 05 - 408** **Trajectory Analysis of the Terminal Rendezvous Phase of the TECSAS Mission**
Mathieu A. Landry, Arun K. Misra, Johanne C. Heald, Federic J. Pelletier, Alfred Ng, McGill University, Canada

This paper presents the results of simulations of autonomous rendezvous related to two spacecraft in Low Earth Orbit (LEO). Various terminal rendezvous trajectories are compared in terms of the delta V fuel budget and the time of flight (TOF), and evaluated in terms of the TECSAS mission guidelines. Three terminal rendezvous trajectories are studied: a V-bar approach and two R-bar approaches. An optimized solution is sought as a balance between minimal delta V, minimal TOF, and operational constraints.

14:20 **AAS 05 - 409** **Calculation of Impulsive Hovering Trajectories via Relative Orbit Elements**
T. Alan Lovell, Air Force Research Laboratory; Mark V. Tollefson, Dynacs Military and Defense, Inc.

In previous years, a paper was presented at this conference that detailed the dynamics of a trajectory that puts a satellite into a quasi-hovering pattern relative to a reference satellite. Equations for this motion based on the Clohessy-Wiltshire-Hill's equations were developed in terms of the geometry of the trajectory shape. However, to obtain these expressions in closed form, symbolic computation software was required. The current paper revisits the impulsive hovering concept, with closed-form expressions for the motion developed by a much simpler method. This involves relative orbit elements, which give more of a geometric than a Cartesian description of the satellite's relative motion.

14:45 **AAS 05 - 410** **Robust Aero-Gravity Assisted Manoeuvers for a Multi-Objective Interplanetary Trajectory Design Optimization**
M. R. Lavagna, D. Lo Pinto, A. E. Finzi, Politecnico di Milano, Italy

An approach is proposed to deal with the preliminary trajectory design of complex interplanetary missions. A multi-objective optimization strategy is applied on a mixed continuous/discrete state variables domain to deal with possible multi-gravity and aero-gravity assist manoeuvres as further degrees of freedom of the problem, in terms of number, planets sequence and gravity assisted manoeuvre type selection for the DeltaV and the trip time span minimization. Possible uncertainties are directly managed by the algorithm to obtain a robust set of solutions in terms of both bank angle and angle of attack time histories, while minimizing the heat load.

15:10 **Break**

15:30 **AAS 05 - 300** **Mission Design of the First Robotic Lunar Exploration Program Mission: The Lunar Reconnaissance Orbiter**

Mark Beckman, David Folta, NASA Goddard Space Flight Center

The first Robotic Lunar Exploration Program (RLEP) mission will be the Lunar Reconnaissance Orbiter (LRO) scheduled for launch in 2008. It will be placed into a 50 km altitude, polar circular lunar orbit. Once in lunar orbit, the moon's non-spherical gravity causes significant eccentricity and argument of periapsis drift. Station keeping maneuvers are required to maintain altitude control ranging from +/-5 km to +/- 20 km. This paper presents LRO analysis with application to future RLEP missions of the transfer trajectory, station keeping using quasi-frozen orbits, end of mission options, and the impact of the propulsion system. Analysis of anticipated navigation performance based on expected tracking schedules and lunar potential models is provided.

15:55 **AAS 05 - 412** **Paper Withdrawn**

16:20 **AAS 05 - 413** **Potential Effects of Optical Solar Sail Degradation on Trajectory Design**

Bernd Dachwald, Marianne Goerlich, Franz Lura, Wolfgang Seboldt, DLR, Germany; Volodymyr Baturkin, National Technical University of Ukraine, Ukraine; Victoria Coverstone, University of Illinois at Urbana-Champaign; Benjamin Diedrich, NOAA; Gregory Garbe,NASA Marshal Space Flight Center; Manfred Leipold, Kayser-Threde GmbH, Germany; Malcolm Macdonald, University of Glasgow, United Kingdom; Colin McInnes, University of Strathclyde, United Kingdom; Giovanni Mengali, Alessandro Quarta University of Pisa, Ita

Optical degradation of solar sails due to the erosive effects of the space environment should be considered for a thorough mission analysis. Current solar sail models do not take sail degradation explicitly into account. Within this paper, a simple parametric model for optical solar sail degradation is presented. It describes variations of the sail film's optical coefficients with time, depending on its environmental history. For various interplanetary missions and for missions in non-Keplerian orbits, this model is used to investigate the potential effects of optical solar sail degradation on trajectory design.

16:45 **AAS 05 - 414** **An Ultra-High-Altitude Sun-Synchronous Orbit and the Perturbation Due to the Earth Gravity**

Keiko Kuroshima, University of Tokyo; Junichiro Kawaguchi, Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), Japan

This paper shows a very high altitude, sun-synchronous orbit around the earth for astronomy satellites. Considering the disturbance of the Earth gravity, the period of the in-plane motion and out-of plane motion vary and trajectory becomes Lissajous. The results are examined and compared with those via numerical integration. In addition, it is shown that the fuels amount, which is inquired to keep nominal Cart Wheel orbit properties, decreases as the altitude increases. And, the conclusion is that the Cart Wheel orbit is a kind of sun-synchronous orbit and highly practical with affordable correction velocity increment.

Session 23: Attitude Dynamics & Control III

Chair: Richard Longman
Columbia University

13:30 **AAS 05 - 415** **Error Propagation Model for Rhumb-Line Attitude Maneuvers**
Jozef van der Ha, Consultant, Mission Design and Operations

The attitude control of a spin-stabilized spacecraft is typically performed by a forced precession of the spin axis produced by a series of pulsed thrust actuations. Thruster performance characteristics (i.e., effective magnitude and centroid time of the thrust pulse) constitute the main error sources affecting the accuracy of an attitude control maneuver. These errors modify the maneuver evolution in terms of the total maneuver path-length and in its heading direction in inertial space, i.e. the rhumb angle. An analytical model is constructed for predicting the propagation of errors in the thrust-level and in the centroid angle into the resulting attitude error at the end of the maneuver. Simulations with practical relevance to geostationary transfer orbits and deep space applications have been performed.

13:55 **AAS 05 - 416** **Attitude Control of Solar Photon Thrustor vs. Plane Solar Sail**
Anna D. Guerman, University of Beira Interior, Portugal; Gueorgui Smirnov, University of Porto, Portugal

We study and compare attitude dynamics and control for two systems of solar propulsion, Plane Solar Sail and Solar Photon Thrustor. We use the simplest two-dimensional model of orbital dynamics. The coupled problem of orbital and attitude dynamics and control is examined. We use a number of test problems well known in the area, such as Earth-Mars transfer and optimal Solar System escape. This analysis showed the efficiency of SPT in terms of time response; the result was more pronounced when long-term missions were considered. We also revealed various benefits of the Solar Photon Thrustor when the attitude control is taken into account.

14:20 **AAS 05 - 417** **Three-Axis Magnetic Attitude Control Using Pseudospectral Control Law**
Hui Yan, Texas A&M University; I. Michael Ross, Naval Postgraduate School; Kyle T. Alfriend; Texas A&M University

In this paper we investigate three-axis attitude stabilization using magnetic torque. The control problem can be formulated as a linear quadratic regulator (LQR). We use pseudospectral method to discrete linear time-varying (LTV) systems. Then the LTV systems with quadratic criteria are reduced to solving a system a set of linear algebraic equations. Our results show the three-axis attitude stabilization is achieved by using the pseudospectral control law. The solutions from the pseudospectral control law are in good agreements with ones from Riccati equations but the computation speed improves by one order of magnitude.

14:45 **AAS 05 - 418** **Gimbal-Position Command Generation for a Cluster of Control Moment Gyroscopes**
Giulio Avanzini, Politecnico di Torino, Italy

A new technique based on a gimbal position command generation algorithm is proposed, that solves the problem of steering a satellite equipped with a cluster of single-gimbal control moment gyroscopes, in spite of the presence of singular gimbal configuration. The global stability of the system in arbitrary reorientation maneuvers is analytically demonstrated when the gimbal angles are small, and the resulting maneuver slow, but the technique is demonstrated also for fast large-angle maneuvers.

15:10 **Break**

15:30 AAS 05 - 419 Singularity-Free Optimal Steering of Control Moment Gyros

Andrew Fleming, I. Michael Ross, Naval Postgraduate School

Research on the attitude control of spacecraft using control moment gyros has been largely dominated by singularity avoidance. In this paper we show that the singularity problem disappears if the control is properly identified in terms of the actuator inputs rather than the torques on the spacecraft body. Under this formulation, the spacecraft can now be properly steered. Although any optimality criterion may be used for steering, we choose time-optimality as it a key problem in both control theory and spacecraft attitude maneuvering. Results for a small spacecraft based on the parameters of NPSAT1 demonstrate the details of our approach.

15:55 AAS 05 - 420 Quaternion-based Satellite Attitude Control Using Fuzzy Logic

Mélanie Bélanger, Jean de Lafontaine, Université de Sherbrooke, Canada

Most modern attitude controllers use quaternions instead of the Euler angles that are easier to work with, but have limitations. However, modern controllers do not use quaternions to their full strength, because they are not geometrically meaningful and not easy to work with. This paper presents 3 geometrically meaningful parameters that have been computed from a quaternion. A fuzzy implementation of the attitude controller has been developed using the new parameters to overcome some of the limitations of the more classical implementations. The simulation results show that the fuzzy controller achieves any desired attitude and is very robust to perturbations.

16:20 AAS 05 - 421 Precision Attitude Determination of High Resolution Earth Observation Satellite

Jae-Cheol Yoon, Sang-Ryool Lee, Yong-Sik Chun, Hak-Jung Kim, Yee-Jin Cheon, Jung-Hoon Keum, Korea Aerospace Research Institute, Korea; Dongseok Shin, Hungu Lee, Young-Ran Lee, Satrec Initiative Co. Ltd., Korea

A precision attitude determination system has been developed for high accurate geo-coding of 1-m resolution images which will be secured by the Republic of Korea multipurpose satellite-2. Sensor data from two star trackers and three gyros are used as measurement and dynamic data. Sensor data from star trackers are composed of QUEST and unit vector filter of which type can be chosen by user option. Filter algorithms consist of extended Kalman filter and batch least square method. In this research, a new method which estimates the misalignment of star trackers on the basis of the orbit periodic characteristics was suggested and its performance was verified. A new optimal operation concept of precision attitude determination system which considers the orbit characteristics is suggested.

16:45 AAS 05 - 422 Further Results in Reduced Order Compensators for Dynamic Systems Using LQG/LTR Methods

Donald L. Mackison, Andrew Sivess, University of Colorado

The computation of attitude control laws using Linear Quadratic Regulator/Loop Transmission Recovery (LQG/LTR) leads to classical compensators which contain sufficient pole-zero cancellation that they can be reduced to the ratio of one real zero over a complex conjugate pole pair. Similar results follow for a 3-car train connected by springs. Controllers for a number of randomly generated dynamic systems do not show this pole-zero cancellation unless the subject systems are Newtonian-structurally similar to the attitude dynamics problem. The resultant closed loop LQG/LTR system will have the LQ generated poles as the dominant modes, but slightly different eigenvectors .

Session 24: Libration Point Trajectories

Chair: Alan Segerman
AT&T @ Naval Research Laboratory

13:30 **AAS 05 - 423** **WMAP Solar Radiation Pressure Modeling during February 2005 Reaction Wheel Power Off Anomaly**
Dale R. Fink, Computer Sciences Corporation

The Wilkinson Microwave Anisotropy Probe (WMAP) satellite in orbit about L2 experienced an anomaly on February 17, 2005 when a reaction wheel powered off. During the anomaly, the trajectory changed as solar radiation pressure acted on the spacecraft in its safemode attitude. To keep the predicted ephemeris as accurate as possible, the trajectory was modeled by propagating the state before the anomaly with appropriate solar radiation coefficients for each phase of the anomaly. This paper describes the modeling that was done in real time to respond to the anomaly, and its effect as a solar sail maneuver.

13:55 **AAS 05 - 424** **A Control Procedure for the Station Keeping and Formation Maintenance of the TPF Mission**
G. Gomez, IEEC & Universitat de Barcelona, Spain; M.W. Lo, Jet Propulsion Laboratory; J.J. Masdemont, IEEC & Universitat Politecnica de Catalunya, Spain

The main goal of this paper is to extend the results of [1], related to the execution of the formation manoeuvres of the TPF constellation, including the controls for the station keeping and allowing a greater flexibility in the basic manoeuvres to be done by the formation. [1] G. Gomez, M.W. Lo, J.J. Masdemont, and K. Museth. Simulation of Formation Flight near L2 for the TPF mission, In ASS/AIAA Space Flight Mechanics Conference. Paper AAS 01-305, 2001.

14:20 **AAS 05 - 425** **A Control Configured Small Circular Halo Orbit Around L2**
Kohta Tarao, University of Tokyo, Japan; Jun'ichiro Kawaguchi, Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), Japan

A Lagrange point in Sun-Earth system, L1 or L2 is conceived the best point for astronomy and connection ports for outer planets. This paper describes a new useful control method for realizing and keeping small circular Halo orbits around the L2 point. First, a control law is mathematically obtained from linear equations of motion in restricted three body problem and the associated properties are discussed. And next, the station keeping strategy is verified using real ephemeris. The resulted Halo orbit is compact and circular realized with satisfactorily small thrust. The paper concludes the strategy is of very practical use.

14:45 **AAS 05 - 426** **Using Hill's 3-Body Equations To Approximate The Genesis Libration Trajectory**
Nicholas G. Smith, Lockheed Martin Company; Vincent C. Herr, Manhattan Insurance Group; Brandon S. Smith, St. John Vianney Theological Seminary

Since the 1970s, numerous missions have taken advantage of trajectory opportunities near the Sun-Earth libration points. Complex analysis tools have been developed to accurately plan and track these trajectories. Several years ago, a simple tool was developed to approximate the Genesis libration trajectory. First order dynamics due to gravitational accelerations from the Sun and Earth were modeled using Hill's 3-body equations. Although not intended to duplicate the accuracy of complex simulations, the simple tool proved useful in understanding performance sensitivities with respect to trajectory errors for the Genesis mission.

15:10 **Break**

15:30 **AAS 05 - 427** **Libration Points of a Gyrostat in a Generalized Restricted Three-Body Problem: Linear Stability**

J. A. Vera, A. Vigueras, Technical University of Cartagena, Spain

The zero order approximation dynamics, in some invariant manifolds, of motion of a gyrostat in Newtonian attraction with two spherical rigid bodies (or material points), by means of a Hamiltonian function that generalize the planar restricted three-body problem, is considered. The collinear equilibria and its number are studied as function of the parameters of the problem. And the stability is studied using the amended potential. The triangular equilibria have been completely characterized, the linear stability is studied and the classic result of the planar restricted three-body problem is obtained as a limit case.

15:55 **AAS 05 - 428** **A Mission to Earth-Moon L2 Lagrangian Point**

Tapan Kulkarni, Daniele Mortari, Texas A&M University

The Earth-Moon L2 (EM L2) Lagrangian point is a good vantage point. In this paper, we discuss the procedure of placing a spacecraft in a Halo orbit around EM L2 Lagrangian point. When in a halo orbit around EM L2, the Moon never eclipses the spacecraft and there is continuous radio contact with Earth. The far side/back side of the Moon can also be extensively mapped. Later, the spacecraft is inserted in Halo orbit around the Earth-Moon L1 Lagrangian point. In this way, the spacecraft continues to hop from Halo orbit from L2 and L1 and vice-versa.

16:20 **AAS 05 - 429** **Earth-Moon Triangular Libration Point Spacecraft Formations in the Circular Restricted Three-Body Problem**

Kathryn A. Catlin, Craig A. McLaughlin, University of North Dakota

Within the circular restricted three-body problem, equations of relative motion for spacecraft orbiting the triangular libration points of the Earth-Moon system are derived and leader-follower and parallel formations are designed. Circular and projected circular formations are also described for a planar approximation. Results are compared to numerically integrated data and sensitivity to initial conditions is quantified. Potential effects of perturbing forces are discussed and avenues for future exploration are indicated.

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