GUIDANCE AND CONTROL 2011

Edited by
Kyle B. Miller

American Astronautical Society

Volume 141

ADVANCES IN THE ASTRONAUTICAL SCIENCES

GUIDANCE AND CONTROL 2011

CONFERENCE COMMITTEE

Brent Abbott	Surrey Space
Vanessa Baez	Lockheed Martin Space Systems Co.
Lee Barker	Lockheed Martin Space Systems Co.
Jim Chapel	Lockheed Martin Space Systems Co.
Brian Clapp	Lockheed Martin Space Systems Co.
David A. Chart	Lockheed Martin Space Systems Co.
Michael Drews	Lockheed Martin Space Systems Co.
Bill Emery	University of Colorado
Scott Francis	Lockheed Martin Space Systems Co.
Kristen Francis	Lockheed Martin Space Systems Co.
Bill Frazier	Ball Aerospace & Technologies Corp.
Lis Garratt	Ball Aerospace & Technologies Corp.
Larry Germann	Left Hand Design
Ian Gravseth	Ball Aerospace & Technologies Corp.
Lisa Hardaway	Ball Aerospace & Technologies Corp.
Steven Jolly	Lockheed Martin Space Systems Co.
Mary A. Klaus	Lockheed Martin Space Systems Co.
Alex May	Lockheed Martin Space Systems Co.
James McQuerry	Ball Aerospace & Technologies Corp.
Shawn McQuerry	Lockheed Martin Space Systems Co.
Kyle Miller	Ball Aerospace & Technologies Corp.
Carolyn O'Brien	Lockheed Martin Space Systems Co.
Marv Odefey	Left Hand Design
Michael Osborne	Lockheed Martin Space Systems Co.
Brian Patterson	Lockheed Martin Space Systems Co.
Chris Randall	Ball Aerospace & Technologies Corp.
Ron Rausch	United Launch Alliance (Retired)
Jay Speed	Ball Aerospace & Technologies Corp.
Cheryl Walker	TASC, Inc.
Zach Wilson	Lockheed Martin Space Systems Co.

THE 35th ANNUAL
ROCKY MOUNTAIN SECTION GUIDANCE AND CONTROL CONFERENCE
Will be held at Breckenridge, Colorado, February 3–8, 2012,
Michael Osborne, Lockheed Martin Space Systems Co., Chairing

AAS PRESIDENT
Frank A. Slazer — Northrop Grumman

VICE PRESIDENT - PUBLICATIONS
Prof. David B. Spencer — Pennsylvania State University

EDITOR
Kyle B. Miller — Ball Aerospace & Technologies Corp.

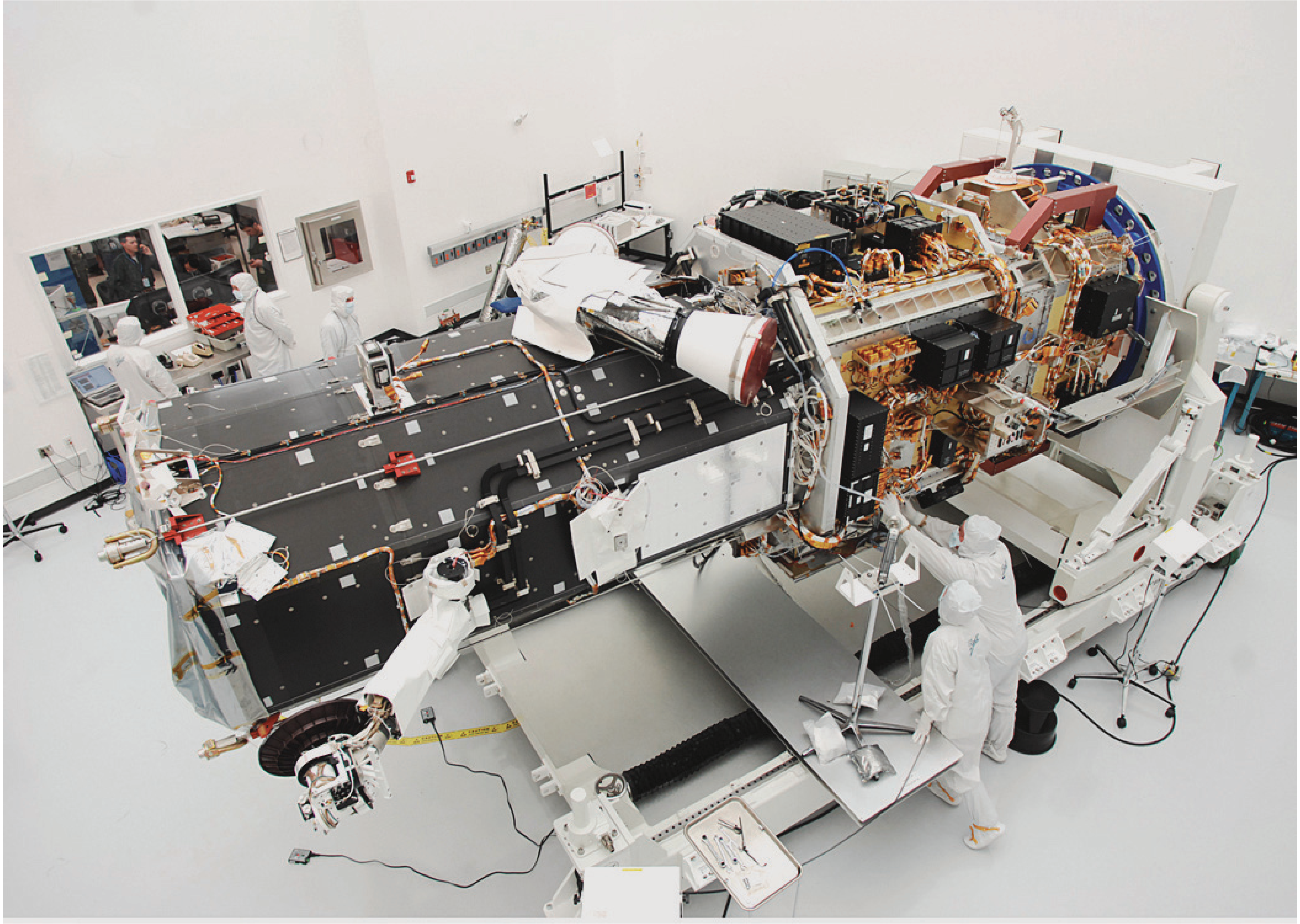
SERIES EDITOR
Robert H. Jacobs — Univelt, Incorporated

Front Cover Illustration:

The NPOESS Preparatory Program (NPP) Satellite is being prepared for launch in October 2011. The NPP program is NASA's next Earth-observing research satellite. It is the first of a new generation of satellites that will observe many facets of our changing Earth.
(Photo Credit: Courtesy of Ball Aerospace & Technologies Corp.)

Frontispiece:

The Worldview II satellite presents an example of both precision pointing and microvibration control, two themes of the 2011 AAS Guidance and Control conference papers in this volume. Worldview II was launched on October 8, 2009 and is capable of capturing nearly 1 million square kilometers of earth observation per day having a ground resolution of 0.5 meters.
(Photo Credit: Courtesy of Ball Aerospace & Technologies Corp.)



American Astronautical Society

GUIDANCE AND CONTROL 2011

Volume 141
ADVANCES IN THE ASTRONAUTICAL SCIENCES

Edited by
Kyle B. Miller

Proceedings of the 34th Annual AAS Rocky Mountain Section Guidance and Control Conference held February 4-9, 2011, Breckenridge, Colorado.

Published for the American Astronautical Society by
Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198
Web Site: http://www.univelt.com

Copyright 2011

by

AMERICAN ASTRONAUTICAL SOCIETY

AAS Publications Office
P.O. Box 28130
San Diego, California 92198

Affiliated with the American Association for the Advancement of Science
Member of the International Astronautical Federation

First Printing 2011

Library of Congress Card No. 57-43769

ISSN 0065-3438

ISBN 978-0-87703-571-8 (Hard Cover Plus CD ROM)
ISBN 978-0-87703-572-5 (CD ROM)

Published for the American Astronautical Society
by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198
Web Site: http://www.univelt.com

Printed and Bound in the U.S.A.

FOREWORD

HISTORICAL SUMMARY

The Annual Rocky Mountain Guidance and Control Conference began as an informal exchange of ideas and reports of achievements among local guidance and control specialists. Since most area guidance and control experts participate in the American Astronautical Society, it was natural to gather under the auspices of the Rocky Mountain Section of the AAS.

In the late seventies, Bud Gates, Don Parsons and Sherm Seltzer, collaborating on a guidance and control project, met in the Colorado Rockies for a working ski week. They jointly came up with the idea of convening a broad spectrum of experts in the field for a fertile exchange of aerospace control ideas, and a concurrent ski vacation. At about this same time, Dan DeBra and Lou Herman discussed a similar plan while on vacation skiing at Keystone.

Back in Denver, Bud and Don approached the AAS Section Chair, Bob Culp, with their proposal. In 1977, Bud Gates, Don Parsons, and Bob Culp organized the first conference, and began the annual series of meetings the following winter. Dan and Lou were delighted to see their concept brought to reality and joined enthusiastically from afar. In March 1978, the First Annual Rocky Mountain Guidance and Control Conference met at Keystone, Colorado. It met there for eighteen years, moving to Breckenridge in 1996 where it has been for the last sixteen years. The 2011 Conference was the 34th Annual AAS Rocky Mountain Guidance and Control Conference.

There were thirteen members of the original founders. The first Conference Chair was Bud Gates, the Co-Chair was Section Chair Bob Culp, with the arrangements with Keystone by Don Parsons. The local session chairs were Bob Barsocchi, Carl Henrikson, and Lou Morine. National session chairs were Sherm Seltzer, Pete Kurzhals, Ken Russ, and Lou Herman. The other members of the original organizing committee were Ed Euler, Joe Spencer, and Tom Spencer. Dan DeBra gave the first tutorial.

The style was established at the first Conference, and has been adhered to with rock-ribbed piety ever since. No parallel sessions, three-hour technical/tutorial sessions at daybreak and late afternoon, and a six-hour ski break at midday are the biblical constraints. For the first fifteen Conferences, the weekend was filled with a tutorial from a distinguished researcher from academia. The Conferences developed a reputation for concentrated, productive work that more than justified the hard play between sessions.

A tradition from the beginning has been the Conference banquet. It is an elegant feast marked by informality and good cheer. A general interest speaker has been a popular feature. These have been:

Banquet Speakers

1978	Sherm Seltzer, NASA MSFC, told a joke
1979	Sherm Seltzer, Control Dynamics, told another joke
1980	Andrew J. Stofan, NASA Headquarters, "Recent Discoveries through Planetary Exploration".
1981	Jerry Waldvogel, Cornell University, "Mysteries of Animal Navigation".
1982	Robert Crippen, NASA Astronaut, "Flying the Space Shuttle".
1983	James E. Oberg, author, "Sleuthing the Soviet Space Program".
1984	W. J. Boyne, Smithsonian Aerospace Museum, "Preservation of American Aerospace Heritage: A Status on the National Aerospace Museum".
1985	James B. Irwin, NASA Astronaut (retired), "In Search of Noah's Ark".
1986	Roy Garstang, University of Colorado, "Halley's Comet".
1987	Kathryn Sullivan, NASA Astronaut, "Pioneering the Space Frontier".
1988	William E. Kelley and Dan Koblosh, Northrop Aircraft Division, "The Second Best Job in the World, the Filming of Top Gun".
1989	Brig. Gen. Robert Stewart, U.S. Army Strategic Defense Command, "Exploration in Space: A Soldier-Astronaut's Perspective".
1990	Robert Truax, Truax Engineering, "The Good Old Days of Rocketry".
1991	Rear Admiral Thomas Betterton, Space and Naval Warfare Systems Command, "Space Technology: Respond to the Future Maritime Environment".
1992	Jerry Waldvogel, Clemson University, "On Getting There from Here: A Survey of Animal Orientation and Homing".
1993	Nicholas Johnson, Kaman Sciences, "The Soviet Manned Lunar Program".
1994	Steve Saunders, JPL, "Venus: Land of Wind and Fire".
1995	Jeffrey Hoffman, NASA Astronaut, "How We Fixed the Hubble Space Telescope".
1996	William J. O'Neil, Galileo Project Manager, JPL, "PROJECT GALILEO: JUPITER AT LAST! Amazing Journey—Triumphant Arrival".
1997	Robert Legato, Digital Domain, "Animation of Apollo 13".
1998	Jeffrey Harris, Space Imaging, "Information: The Defining Element for Superpowers-Companies & Governments".
1999	Robert Mitchell, Jet Propulsion Laboratories, "Mission to Saturn".
2000	Dr. Richard Zurek, JPL, "Exploring the Climate of Mars: Mars Polar Lander in the Land of the Midnight Sun".
2001	Dr. Donald C. Fraser, Photonics Center, Boston University, "The Future of Light".
2002	Bradford W. Parkinson, Stanford University, "GPS: National Dependence and the Robustness Imperative".
2003	Bill Gregory, Honeywell Corporation, "Mission STS-67, Guidance and Control from an Astronaut's Point of View".
2004	Richard Battin, MIT, "Some Funny Things Happened on the Way to the Moon".
2005	Dr. Matt Golombeck, Senior Scientist, MER Program, JPL, "Mars Science Results from the MER Rovers".
2006	Mary E. Kicza, Deputy Assistant Administrator for Satellite and Information Services, NASA, "NOAA: Observing the Earth from Top to Bottom".
2007	Patrick Moore, Consulting Senior Life Scientist, SAIC and the Navy Marine Mammal Program, "Echolocating Dolphins in the U.S. Navy Marine Mammal Program".

2008 Dr. Ed Hoffman, Director, NASA Academy of Program and Project Leadership, "The Next 50 Years at NASA – Achieving Excellence".

2009 William Pomerantz, Senior Director for Space, The X Prize Foundation, "The Lunar X Prize".

2010 Berrien Moore, Executive Director, Climate Central, "Climate Change and Earth Observations: Challenges and Responsibilities".

2011 Joe Tanner, Senior Instructor, University of Colorado, "Building Large Structures in Space".

OBSERVATIONS: CHALLENGES AND RESPONSIBILITIES

In addition to providing for an annual exchange of the most recent advances in research and technology of astronautical guidance and control, for the first fourteen years the Conference featured a full-day tutorial in a specific area of current interest and value to the guidance and control experts attending. The tutor was an academic or researcher of special prominence in the field. These lecturers and their topics were:

Tutorials

1978 Professor Dan DeBra, Stanford University, "Navigation"

1979 Professor William L. Brogan, University of Nebraska, "Kalman Filters Demystified"

1980 Professor J. David Powell, Stanford University, "Digital Control"

1981 Professor Richard H. Battin, Massachusetts Institute of Technology, "Astrodynamics: A New Look at Old Problems"

1982 Professor Robert E. Skelton, Purdue University, "Interactions of Dynamics and Control"

1983 Professor Arthur E. Bryson, Stanford University, "Attitude Stability and Control of Spacecraft"

1984 Dr. William B. Gevarter, NASA Ames, "Artificial Intelligence and Intelligent Robots"

1985 Dr. Nathaniel B. Nichols, The Aerospace Corporation, "Classical Control Theory"

1986 Dr. W. G. Stephenson, Science Applications International Corporation, "Optics in Control Systems"

1987 Professor Dan DeBra, Stanford University, "Guidance and Control: Evolution of Spacecraft Hardware"

1988 Professor Arthur E. Bryson, Stanford University, "Software Application Tools for Modern Controller Development and Analysis"

1989 Professor John L. Junkins, Texas A&M University, "Practical Applications of Modern State Space Analysis in Spacecraft Dynamics, Estimation and Control"

1990 Professor Laurence Young, Massachusetts Institute of Technology, Aerospace Human Factors"

1991 The Low-Earth Orbit Space Environment
Professor G. W. Rosborough, University of Colorado, "Gravity Models"
Professor Ray G. Roble, University of Colorado, "Atmospheric Drag"
Professor Robert D. Culp, University of Colorado, "Orbital Debris"
Dr. James C. Ritter, Naval Research Laboratory, "Radiation"
Dr. Gary Heckman, NOAA, "Magnetics"
Dr. William H. Kinard, NASA Langley, "Atomic Oxygen"

After 1991 there were no more tutorials, but special sessions or featured invited lectures served as focal points for the Conferences. In 1992 the theme was "Mission to Planet Earth" with presentations on all the large Earth Observer programs. In 1993 the feature was "Applications of Modern Control: Hubble Space Telescope Performance Enhancement Study" organized by Angie Bukley of NASA Marshall. In 1994 Jason Speyer of UCLA discussed "Approximate Optimal Guidance for Aerospace Systems". In 1995 a special session on "International Space Programs" featured programs from Canada, Japan, Europe, and South America. In 1996, and again in 1997, one of the most popular features was Professor Juris Vagners, of the University of Washington with "A Control Systems Engineer Examines the Biomechanics of Snow Skiing". In 2005, Angie Bukley chaired a tutorial session "University Work on Precision Pointing and Geolocation". In 2006, a special day for U.S. citizens only was inserted at the beginning of the Conference to allow for topics that were limited due to ITAR constraints. In 2007, two special invited sessions were held: "Lunar Ambitions— The Next Generation" and "Project Orion—The Crew Exploration Vehicle". In 2008, a special panel addressed "G&C Challenges in the Next 50 Years". The 2009 Conference featured a special session on "Constellation Guidance, Navigation, and Control".

From the beginning the Conference has provided extensive support for students interested in aerospace guidance and control. The Section, using proceeds from this Conference, annually gives $2,000 in the form of scholarships at the University of Colorado, one to the top Aerospace Engineering Sciences senior, and one to an outstanding Electrical and Computer Engineering senior, who has an interest in aerospace guidance and control. The Section has assured the continuation of these scholarships in perpetuity through a $70,000 endowment. The Section supports other space education through grants to K-12 classes throughout the Section at a rate of over $10,000 per year. All this is made possible by this Conference.

The student scholarship winners attend the Conference as guests of the American Astronautical Society, and are recognized at the banquet where they are presented with scholarship plaques. These scholarship winners have gone on to significant success in the industry.

Scholarship Winners

	Aerospace Engr Sciences	**Electrical and Computer Engr**
1981	Jim Chapel	
1982	Eric Seale	
1983	Doug Stoner	John Mallon
1984	Mike Baldwin	Paul Dassow
1985	Bruce Haines	Steve Piche
1986	Beth Swickard	Mike Clark
1987	Tony Cetuk	Fred Ziel
1988	Mike Mundt	Brian Olson
1989	Keith Wilkins	Jon Lutz
1990	Robert Taylor	Greg Reinacker
1991	Jeff Goss	Mark Ortega
1992	Mike Goodner	Dan Smathers
1993	Mark Baski	George Letey

1994	Chris Jensen	Curt Musfeldt
1995	Mike Jones	Curt Musfeldt
1996	Karrin Borchard	Kirk Hermann
1997	Tim Rood	Ui Han
1998	Erica Lieb	Kris Reed
1999	Trent Yang	Adam Greengard
2000	Josh Wells	Catherine Allen
2001	Justin Mages	Ryan Avery
2002	Tara Klima	Kiran Murthy
2003	Stephen Russell	Andrew White
2004	Trannon Mosher	Negar Ehsan
2005	Matt Edwards	Henry Romero
2006	Arseny Dolgove	Henry Romero
2007	Kirk Nichols	Chris Aiken
2008	Nicholas Hoffmann	Gregory Stahl
2009	Filip Maksimovic	Justin Clark
2010	Filip Maksimovic	John Jakes

The Rocky Mountain Section of the American Astronautical Society established a broad-based Conference Committee, the Rocky Mountain Guidance and Control Committee, chaired *ex-officio* by the next Conference Chair, to run the annual Conference. The Conference has been a success from the start. The Conference, now named the AAS Guidance and Control Conference, and sponsored by the national AAS, attracts about 200 of the nation's top specialists in space guidance and control.

	Conference Chair	**Attendance**
1978	Robert L. Gates	83
1979	Robert D. Culp	109
1980	Louis L. Morine	130
1981	Carl Henrikson	150
1982	W. Edwin Dorroh, Jr.	180
1983	Zubin Emsley	192
1984	Parker S. Stafford	203
1985	Charles A. Cullian	200
1986	John C. Durrett	186
1987	Terry Kelly	201
1988	Paul Shattuck	244
1989	Robert A. Lewis	201
1990	Arlo Gravseth	254
1991	James McQuerry	256
1992	Dick Zietz	258
1993	George Bickley	220
1994	Ron Rausch	182
1995	Jim Medbery	169
1996	Marv Odefey	186
1997	Stuart Wiens	192

1998	David Igli	189
1999	Doug Wiemer	188
2000	Eileen Dukes	199
2001	Charlie Schira	189
2002	Steve Jolly	151
2003	Ian Gravseth	178
2004	Jim Chapel	137
2005	Bill Frazier	140
2006	Steve Jolly	182
2007	Heidi Hallowell	206
2008	Michael Drews	189
2009	Ed Friedman	160
2010	Shawn McQuerry	189
2011	Kyle Miller	161

The AAS Guidance and Control Technical Committee, with its national representation, provides oversight to the local conference committee. W. Edwin Dorroh, Jr., was the first chairman of the AAS Guidance and Control Committee; from 1985 through 1995 Bud Gates chaired the committee; from 1995 through 2000, James McQuerry chaired the committee. From 2000 through 2007, Larry Germann chaired this committee, and James McQuerry has chaired the committee since. The committee meets every year at the Conference, and also sometimes at the summer Guidance and Control Meeting, or at the fall AAS Annual Meeting.

The AAS Guidance and Control Conference, hosted by the Rocky Mountain Section in Colorado, continues as the premier conference of its type. As a National Conference sponsored by the AAS, it promises to be the preferred idea exchange for guidance and control experts for years to come.

On behalf of the Conference Committee and the Section,

Kyle B. Miller
Ball Aerospace & Technology Corp.
Boulder, Colorado

PREFACE

This year marked the 34th anniversary of the AAS Rocky Mountain Section's Guidance and Control Conference. It was held in Breckenridge, Colorado at the Beaver Run Resort on February 4-9, 2011. The planning committee and the national chairs did an admirable job in creating an excellent conference experience and my thanks to everyone is boundless. Attendance was down this year, most likely due to economic conditions, but we did have an attendance of 161 conferees.

The conference formally began on the morning of February 5th with a special session on *Global Navigation Satellite Systems* chaired by Col. Stephen Steiner, the chief engineer of the Global Positioning Satellite Directorate at the US Space and Missile Center. This session addressed both current and future navigation system architectures. To cap off the day, the *Technical Exhibits* session was held in the afternoon. Seventeen companies participated in the technical exhibits with many hardware demonstrations as well as fostering excellent technical interchanges between conferees, vendors, and family. The session was accompanied by an excellent buffet dinner. Many family members and children were present, greatly enhancing the collegiality of the session. The highly experienced team of Kristin, Scott, and Vanessa did an outstanding job organizing the vendors and exhibits.

February 6th started with the ever-popular *Advances in G&C* in the morning and papers on robotic landers, specialized attitude control system designs, and development advances in a variety of attitude control system sensors. The afternoon session, *Commercial and Civil Overhead Imagery Systems* addressed line-of-site pointing control, geolocation accuracy, and future directions in the rapidly expanding commercial "spy" satellite business area.

The morning of February 7th emerged as snowy and cold, but the participants in the *Small Body Proximity Operations* where space operations of crewed and un-crewed vehicles near space objects, landing scenarios, and re-entry activities were discussed. Prior to the banquet in the evening, a foreshortened afternoon session addressed *Microvibration* topics including how to handle microvibration from rotating mechanisms and fuel slosh.

Mr. Joe Tanner, astronaut and space construction expert, provided an outstanding discussion on building large objects in space for the conference banquet. Joe went out of his way to answer questions about not only space construction, but also flying in space and his personal experiences. The banquet food was excellent, as usual, thanks to the great staff at Beaver Run.

February 8th also dawned cold and windy, a recurring theme of the 2011 conference, and the theme of the morning session, *Space Servicing*, engendered a good variety of papers on methods and concepts for extending the life of our valuable on-orbit assets through appropriate servicing approaches. As has become the norm, the *Recent Experiences* session closed the international section of the conference in the afternoon. The valuable lessons purveyed by this session will go a long ways toward creating successful missions in the future.

The conference wrapped up on the morning of the 9th with an ITAR-restricted session addressing *Design Approaches for Precision Pointing*. This session included a survey of past, present and future directions in precision pointing, laser pointing applications, pointing solutions for a variety of science missions, and an update from the JMAPS program on the effort to update star catalogs.

Overall, the 34th annual conference was a satisfying experience for all. Technically we are maintaining the high standards set by our predecessors and a new generation of conferees are continuing the traditions of our founders. The technical committee, session chairs, and national chairs are unfailingly helpful, cheerful, and just enjoyable to be around. Special thanks also goes to both Carolyn O'Brien of Lockheed Martin and Liz Garrett from Ball Aerospace for their abilities to herd the engineers, physicists, mathematicians, and gadflys in the right direction.

Kyle Miller, Conference Chairperson
2011 AAS Guidance and Control Conference

CONTENTS

GLOBAL NAVIGATION SATELLITE SYSTEMS

SESSION I

Since becoming operational, Global Positioning System (GPS) has ushered in a wave of new technologies, capabilities, and products taking advantage of precise timing and navigation signals. The GPS receiver industry was born, and GPS revolutionized military and commercial business, affecting everything from aviation and spacecraft, to cell phone technology and automobile navigation, to ship navigation and container tracking. Recent advances in GPS products, along with developments in other Global Navigation Satellite Systems (GNSS), further continue to push state of the art advances in a host of applications while striving to meet new requirements. Examples include Accuracy Improvements Initiatives (AII) by GPS, new military and civil signals in the latest generation of GPS IIR-M, and GPS IIF satellites, and new receivers. Development of the next generation of spacecraft and control systems is already underway for GPS, the European Galileo system, and others. This session is intended to discuss advances in GPS products including new capabilities and signals, advances in other GNSS systems (Galileo, GLONASS, COMPASS, etc), advances in GNSS receiver technology, and space applications of GNSS.

National Chairpersons:

Chris Hegarty
MITRE

Col. Stephen Steiner
Chief Engineer, Global
Positioning Systems Directorate

Local Chairpersons:

Lee Barker
Lockheed Martin
Space Systems Company

Shawn McQuerry
Lockheed Martin
Space Systems Company

The following papers were not available for publication:

AAS 11-011
“GPS Program Update,” Col. Stephen Steiner, SMC GPS Wing Commander (Presentation Only)

AAS 11-012
“The Evolution of GPS Capabilities,” Chuck Frey, Lockheed Martin Space Systems Company (Presentation Only)

AAS 11-013
“GPS Control Segment*,* Richard Canty,” Raytheon Company (Presentation Only)

The following paper numbers were not assigned:

AAS 11-018 to -020

RECENT DEVELOPMENTS IN GPS PERFORMANCE AND OPERATIONS

Willard Marquis*

Recent years have seen many changes in the GPS system as new satellites have taken the place of old ones, the control segment has been totally replaced, and user equipment has made exponential improvements. This paper will discuss some of these recent developments in SV performance and operations and how they impact users. The accuracy and availability of the signal will be highlighted along with trends in performance. The structure and benefits of the new modernized navigation message will be detailed, including how the new structure will improve accuracy. In addition, the future GPS III SVs and OCX control segment will expand the limit of new PRNs up to 63, signifying that more than 32 GPS SVs will exist in the future GPS constellation. Other improvements of the control segment, including the accuracy improvement initiative will be discussed. Highlights will be covered of the new L2C and L5 signals. Finally, the new GPS Block IIR-M and GPS III signals (L1M, L2M, L2C and L5, L1C, respectively) will be highlighted for their impact to user performance. In order to maintain the GPS "gold standard", it is critical that the GPS III series be launched as planned, starting in 2014. [View Full Paper]

* Senior Staff Engineer, Systems, GPS IIR and GPS III Flight Operations, Lockheed Martin Space Systems Company, 440 Discoverer Street, Suite 201, Schriever AFB, Coloarado 80912, U.S.A.

OVERVIEW OF SPACE APPLICATIONS OF GLOBAL NAVIGATION SATELLITE SYSTEMS

Penina Axelrad*

The Global Positioning System (GPS) has had a profound impact on the operation of near Earth spacecraft and their application to remote sensing. It is now a standard instrument for real-time moderate accuracy onboard positioning, time transfer, and attitude determination of low earth orbit platforms including the International Space Station and many scientific and commercial imaging satellites. Receivers onboard LEO satellites also provide essential observations used in high precision post processing for scientific satellites measuring sea level, the earth's gravity field, the ionosphere and atmosphere. The observations include conventional direct pseudorange, carrier phase, and amplitude, as well as a newer class of observations of signals occulted by the atmosphere and ionosphere. The application of GNSS to orbiting satellites is also being extended beyond LEO to the GEO environment. This paper will present an overview of the many applications of GNSS in space, and describe the unique challenges and benefits of operating in this environment. [View Full Paper]

* Professor, Department of Aerospace Engineering Sciences, Colorado Center for Astrodynamics Research, University of Colorado at Boulder, Boulder, Colorado, 80309-0431, U.S.A.

LAUNCH VEHICLE RANGE SAFETY: A GPS APPLICATION

John G. Reed* and Theodore C. Moore†

The history of Launch Vehicle Range Safety has been one of a reactive nature, requiring a human in the loop. The United States Air Force has embarked on an initiative known as Launch Enterprise Transformation (LET) that will significantly reduce Test Range Operations and Maintenance (O&M) cost by closing facilities and decommissioning ground assets. The first phase of the LET Initiative is implementation of Global Positioning System Metric Tracking (GPS MT) on launch vehicles that use the Vandenberg Air Force Base (VAFB) on the Western Range and the Cape Canaveral Air Force Station (CCAFS) on the Eastern Range.

GPS MT is a way to leverage the existing GPS satellite base navigation system's capability in order to significantly reduce the costs of Test Range Operations and Maintenance. United Launch Alliance (ULA), in partnership with the U.S. Government, is engaged in a three phased project plan to evolve the EELV fleet from dependence on ground based range assets to a Space Based Range operational concept. The first phase is development of the GPS MT System. The GPS MT System will make its first flight in 2012. Completion of flight certification is planned for 2013.

The GPS MT System will provide precise LV position, velocity and timing information that can replace ground radar tracking resource functionality. In its initial configuration, the GPS MT system will provide an independent position/velocity S-Band telemetry downlink to support the current man-in-the-loop ground-based commanded destruct of an anomalous flight. This paper discusses the challenges for GPS tracking and assesses approaches to comparison of GPS/INS (Inertial Navigation System) solutions as well as determination of flight termination. Finally, we conclude with a vision for future commercial operations. [View Full Paper]

* Technical Fellow, Guidance/Navigation, United Launch Alliance, 12257 S. Wadsworth Blvd., MS B6312, Littleton, Colorado 80125, U.S.A.

† GPS MT Project Manager, United Launch Alliance, 12257 S. Wadsworth Blvd., MS B6312, Littleton, Colorado 80125, U.S.A.

AAS 11-017

LION-NAVIGATOR: MULTI FREQUENCY, MULTI CONSTELLATION RECEIVER FOR SPACECRAFT NAVIGATION

Christopher Kuehl, Hannes Filippi, Andrés Barrios-Montalvo, Peter A. Krauss, Jens Heim and Eveline Gottzein*

The emergence of new civil signals and additional constellations like Galileo enhances the potential of RF navigation also for S/C applications. The paper describes the development of a next generation navigation receiver, the LION Navigator, which is capable to use all future open signals of GPS and Galileo. The performance improvement within reach by not only using dual frequencies but also signals from two constellations is demonstrated for S/C in Earth orbits from low to geosynchronous. [View Full Paper]

* Astrium GmbH, Germany.

ADVANCES IN GUIDANCE, NAVIGATION AND CONTROL

SESSION III

Many programs depend on heritage, but the future is advanced by those willing to design and implement new and novel architectures, technologies, and algorithms to solve the GN&C problems. This session is open to papers with topics ranging from theoretical formulations to innovative systems and intelligent sensors that will advance the state of the art, reduce the cost of applications, and speed the convergence to hardware, numerical, or design trade solutions.

National Chairpersons:

Brad Moran
Charles Stark Draper Laboratory

Gabe Rogers
Johns Hopkins University
Applied Physics Laboratory

Local Chairpersons:

Zach Wilson
Lockheed Martin
Space Systems Company

Alex May
Lockheed Martin
Space Systems Company

The following paper numbers were not assigned:

AAS 11-038 to -040

AAS 11-031

ROBOTIC LUNAR LANDER GUIDANCE, NAVIGATION AND CONTROL CONCEPT AND ANALYSIS

James Kaidy,[*] Thomas Criss,[*] Christopher Dong[*] and Wen-Jong Shyong[*]

A range of robotic lander descent missions have been studied and developed into the high fidelity 6-Degree of Freedom (6-DOF) simulation, Autonomous Precision Lander Simulation, (APLSim). Two of these missions are described here: a low precision navigation baseline lunar lander for a midlatitude landing zone with low slope terrain, and a high precision lander for a lunar polar region crater target zone. During this study, the final descent was assumed to start at the end of a solid rocket motor burnout several kilometers above the surface. The low precision lander Guidance, Navigation and Control (GNC) system utilizes a gravity turn descent guidance algorithm and a combination of inertial navigation and camera based image-to-image Least Squares Optical Flow (LSOF) algorithms to achieve a significantly better than the goal of 10 kilometer landing accuracy. The precision lander GNC utilizes a Time-To-Go guidance algorithm with inertial and camera based Terrain Relative Navigation (TRN) to achieve a 100 meter landing accuracy. With LSOF, a velocity measurement is generated by the algorithm by comparing successive images. With TRN, a lander position in the lunar fixed frame is computed based on an initial estimate of lander position and attitude, and an onboard terrain Digital Elevation Map (DEM). Both LSOF and APLNav measurements are passed into the navigation Kalman Filter for measurement update and state vector propagation. Acceleration control is accomplished with descent engine pulsed fire commanding. Terminal Descent phase is designed to issue commands to descend at the desired velocity and to null lateral position and velocity errors with respect to the landing site. Descent scenarios and a series of Monte Carlo runs demonstrate robustness and accuracy with dispersions to initial conditions and lander characteristics.
[View Full Paper]

* Professional Staff, Space Department, The Johns Hopkins University, Applied Physics Laboratory, Laurel, Maryland 20723, U.S.A.

AAS 11-032

GUIDANCE, NAVIGATION, AND CONTROL DEVELOPMENT FOR A ROBOTIC LANDER TESTBED

Timothy McGee,[*] James Kaidy,[*] Doug Reid,[*] Gail Oxton[*] and Mike Hannan[†]

The Marshall Space Flight Center (MSFC) and The Johns Hopkins University Applied Physics Laboratory (APL) are currently exploring various robotic lander mission concepts to targets including the moon or asteroids. As part of this larger effort, MSFC and APL are working with the Von Braun Center for Science and Innovation (VCSI) to construct a prototype monopropellant-fueled robotic lander. This paper provides an overview of the lander architecture, describes the guidance, navigation, and control (GNC) system that is being developed at APL and summarizes the GNC test program. [View Full Paper]

* Professional Staff, Space Department, The Johns Hopkins University, Applied Physics Laboratory, Laurel, Maryland 20723, U.S.A.

† GNC Engineer, NASA/Marshall Space Flight Center, MSFC, Alabama 35812, U.S.A.

AAS 11-033

AUTONOMOUS THRUSTER FAILURE RECOVERY ON UNDERACTUATED SPACECRAFT USING MODEL PREDICTIVE CONTROL

Christopher M. Pong,* Alvar Saenz-Otero† and David W. Miller‡

Thruster failures historically account for a large percentage of failures that have occurred on orbit. These failures are typically handled through redundancy, however, with the push to using smaller, less expensive satellites in clusters or formations there is a need to perform thruster failure recovery without additional hardware. This means that a thruster failure may cause the spacecraft to become underactuated, requiring more advanced control techniques. A model of a thruster-controlled spacecraft is developed and analyzed with a nonlinear controllability test, highlighting several challenges including coupling, nonlinearities, severe control input saturation, and nonholonomicity. Model Predictive Control (MPC) is proposed as a control technique to solve these challenges. However, the real-time, online implementation of MPC brings about many issues. A method of performing MPC online is described, implemented and tested in simulation as well as in hardware on the Synchronized Position-Hold, Engage, Reorient Experimental Satellites (SPHERES) testbed at the Massachusetts Institute of Technology (MIT) and on the International Space Station (ISS). These results show that MPC provided improved performance over a simple path planning technique. [View Full Paper]

* Graduate Research Assistant, Space Systems Laboratory, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139, U.S.A.

† Research Scientist, Space Systems Laboratory, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology.

‡ Professor, Department of Aeronautics and Astronautics, Director, Space Systems Laboratory, Massachusetts Institute of Technology.

AAS 11-034

DESIGN AND INTEGRATION OF AN ALL-MAGNETIC ATTITUDE CONTROL SYSTEM FOR FASTSAT-HSV01'S MULTIPLE POINTING OBJECTIVES

Brandon DeKock,* Devon Sanders,† Tannen VanZwieten‡ and Pedro Capó-Lugo†

The FASTSAT-HSV01 spacecraft is a microsatellite with magnetic torque rods as its sole attitude control actuator. FASTSAT's multiple payloads and mission functions require the Attitude Control System (ACS) to maintain Local Vertical Local Horizontal (LVLH)-referenced attitudes without spin-stabilization, while the pointing errors for some attitudes be significantly smaller than the previous best-demonstrated for this type of control system. The mission requires the ACS to hold multiple stable, unstable, and non-equilibrium attitudes, as well as eject a 3U CubeSat from an onboard P-POD and recover from the ensuing tumble. This paper describes the ACS, the reasons for design choices, how the ACS integrates with the rest of the spacecraft, and gives recommendations for potential future applications of the work. [View Full Paper]

* Guidance, Navigation, and Control Lead, Space Engineering Technology Division, bdSystems, a Science Applications International Corporation (SAIC) Company, Huntsville, Alabama, U.S.A.

† Aerospace Engineer, Controls Systems Design & Analysis, NASA Marshall Space Flight Center, EV41, MSFC, Alabama 35812, U.S.A. Corresponding author email address: devon.s.sanders@nasa.gov.

‡ Aerospace Engineer, Guidance, Navigation, and Mission Analysis, NASA Marshall Space Flight Center, EV41, MSFC, Alabama 35812, U.S.A.

ONE-ARCSECOND LINE-OF-SIGHT POINTING CONTROL ON EXOPLANETSAT, A THREE-UNIT CUBESAT

Christopher M. Pong,[*] Matthew W. Smith,[*] Matthew W. Knutson,[*] Sungyung Lim,[†] David W. Miller,[‡] Sara Seager,[§] Jesus S. Villaseñor[**] and Shawn D. Murphy[††]

ExoplanetSat is a proposed 10×10×34-cm space telescope designed to detect down to Earth-sized exoplanets in an orbit out to the habitable zone of bright, Sun-like stars via the transit method. Achieving this science objective requires one-arcsecond line-of-sight pointing control for the science CCD detector, an unprecedented requirement for CubeSats. A two-stage control architecture that coordinates coarse rigid-body attitude control with fine line-of-sight pointing control will be employed to meet this challenging pointing requirement. Detailed testing of the reaction wheels and CMOS detectors has been performed to extract key performance parameters used in simulations. The results of these simulations indicate that a 1.4 arcsecond pointing precision (3σ) is achievable. To meet the 1.0-arcsecond pointing requirement, several options are analyzed. In particular, a new technique to estimate reaction wheel vibrations for feedforward cancellation of reaction wheel vibrations is presented. This estimator adaptively estimates disturbances from noisy sensor measurements and effectively stores disturbance amplitude and phase in memory as a function of wheel speed. In addition to these simulation results, testing results from a hardware-in-the-loop (HWIL) testbed demonstrate the capability of the fine pointing control loop. Future plans for complete HWIL testing of the coarse and fine control loops are presented. [View Full Paper]

* Graduate Research Assistant, Space Systems Laboratory, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139, U.S.A.

† Senior Member of the Technical Staff, Aerospace Guidance & Control Group, The Charles Stark Draper Laboratory, 555 Technology Square, Cambridge, Massachusetts 02139, U.S.A.

‡ Professor, Department of Aeronautics and Astronautics, Director, Space Systems Laboratory, Massachusetts Institute of Technology.

§ Professor, Department of Earth, Atmospheric and Planetary Sciences, Professor, Department of Physics, Massachusetts Institute of Technology.

** Research Scientist, CCD Laboratory, Kavli Institute for Astrophysics and Space Research, Massachusetts Institute of Technology.

†† Division Leader, Earth and Space Science Program Office, The Charles Stark Draper Laboratory.

THE EUROPEAN SILICON MEMS RATE SENSOR TAKES TO SPACE

Mark Hartree,[*] Patrick Hutton,[*] Ben Olivier[†] and Daniele Temperanza[‡]

"When will the MEMS gyro be ready for Space?" is a question often asked by GNC engineers. "Does it meet our needs?" is often a follow-on question. The MEMS Rate Sensor (MRS) development programme (commercially known as SiREUS) is an ESA sponsored development of a Coarse Rate Sensor for attitude control. Presentations in this forum and elsewhere have shown how the design and development of the unit has progressed from the feasibility of transferring a terrestrial MEMS technology for Space requirements to the maturing of the electronic design and system integration.

This paper takes the story forward through the qualification of the unit to answer the questions asked above. An overview of this development and fundamentals of operation is provided with commentary on the challenges overcome during the development and qualification programme when using a novel MEMS gyro technology in a Space application. We discuss how early flight heritage has been achieved and the paper includes activities in the current development phase such as non-MEMS developments that were required to miniaturize the power supply which had several constraints. Rigorous integration of MEMS-based sensors in novel electronics design architecture enables system level performance requirements to be achieved and potentially improved. Containing the unit within the target specification while meeting Space product assurance requirements has been met. Analysis and detector evaluation activities are outlined with qualification testing results of SiREUS presented. This includes in-orbit results of an experimental unit and showing the actual performance achieved during qualification. The paper concludes with the next step on SiREUS journey to Space with a summary of lessons learnt on taking the SiREUS product to market. [View Full Paper]

* SELEX Galileo Limited, 2 Crewe Road North, Edinburgh, EH5 2XS, United Kingdom.

† Systems Engineering and Analysis Limited, Bristol Business Park, Coldharbour Lane, Bristol, BS16 1SU, United Kingdom.

‡ European Space Agency, ESTEC, Noordwijk, The Netherlands.

AAS 11-037

SYSTEMS "ON CHIP" ACTIVITIES DELIVERED THE FIRST SUN SENSOR PROTOTYPE

P. Fidanzati,[*] F. Boldrini,[*] E. Monnini,[*] W. Ogiers,[†] A. Pritchard[‡] and P. Airey[§]

The recent trend of electro-optics devices miniaturization in consumer electronics is now a reality also in the space equipments, with the first MEMS applications and the availability of highly integrated CMOS image sensors suitable for space usage. The Sun sensor miniaturization is, among different applications like star tracker or navigation cameras, the most promising one. Thanks to the high optical radiation provided by the Sun, it is possible to realize a sun sensor equipment using a very simple optics, like a pinhole, and avoiding the use of microprocessor and storage memory since on board software is not required. Taking full advantage of the experience in the attitude sensors field, SELEX Galileo (Italy), together with an industrial team made by CMOSIS (Belgium), BAE Systems (UK), and Thales Alenia Space (France) developed, in the frame of an ESA contract, a prototype of a miniaturized digital Sun sensor "on chip". One of the key technological challenges of the Sun sensor "on chip" was the integration of the simple optics (pinhole) directly onto the detector chip using MEMS technology, thus dramatically reducing the size of the complete attitude sensor itself, as well as the costs for assembly and testing. The miniaturization was then completed by integrating on the same chip all the logic to calculate the Sun position with advanced signal processing for false events rejection, the SpaceWire communication logic and drivers, the voltage regulators needed for powering the chip and the oscillator for the internal clock. Therefore the novel Sun sensor "on chip" is essentially made just by the chip itself, with MEMS optics integrated on it, and few components left outside the chip (like a quartz crystal). In the second half of 2010 the first prototype samples of the chip were manufactured, integrated with MEMS optics and packaged. The resulting chip was then characterized in terms of electro-optical properties. In fact the overall functionalities and accuracy of the chip used as Sun sensor were investigated and tested, using a dedicated breadboard prototype, demonstrating also tracking capabilities in presence of a real Sun scenario. Even if few issues during the prototype manufacturing and some minor design bugs were discovered, the testing goals of the unit were achieved. The system noise and accuracy were fully verified, showing promising results for an updated chip production, which will be likely completed in 2011. [View Full Paper]

* SELEX Galileo – Via A. Einstein, 35 – 50013 Campi Bisenzio (FI) – Italy.

† CMOSIS, Coveliersstraat 15 B-2600 Antwerp – Belgium.

‡ BAE Systems Advanced Technology Centre, P.O. Box 5, Filton, Bristol BS34 7QW, United Kingdom.

§ ESTEC – Keplerlaan, 1 – NL-2200 AG Noordwijk – The Netherlands.

COMMERCIAL AND CIVIL OVERHEAD IMAGERY SYSTEMS

SESSION IV

The commercial and municipal overhead imagery market has historically been met with airborne sensors while government intelligence demands have been met with large, space-based assets. Commercially-owned high-resolution space-systems now globally augment commercial, civil, and military imagery requirements leading to cross-market growth and a strong demand for high-performance imaging satellites. In this session, leading remote sensing contractors provide summaries of related GN&C requirements, solutions, and challenges.

National Chairpersons:

Dan Schuresko
National Geospatial Agency

Carl Adams
NASA
Goddard Space Flight Center

Local Chairpersons:

Bill Frazier
Ball Aerospace & Technology Corp.

Jay Speed
Ball Aerospace & Technology Corp.

The following paper was not available for publication:

AAS 11-043
(Paper Withdrawn)

The following paper numbers were not assigned:

AAS 11-046 to -050

AAS 11-041

LINE-OF-SIGHT POINTING AND CONTROL OF ELECTRO-OPTICAL SPACE SYSTEMS – AN OVERVIEW

Michael Santina,[*] Eric Falangas,[†] Timothy Ahern[‡] and Kevin O'keefe[§]

This paper provides an overview and introduction to the line-of-sight pointing and control of electro-optical space systems during payload image collection mode. We will focus our discussion on three areas: (a) Line of sight stabilization, (b) Geolocation, and (c) Collection capacity. Specifically, we will present the guidelines, analysis, design options and solutions to satisfy the objectives of these three areas. [View Full Paper]

* Senior Technical Fellow, The Boeing Company, Seal Beach, California, U.S.A.

† Principle Engineer, The Boeing Company, Huntington Beach, California, U.S.A.

‡ Senior System Engineer, The Boeing Company, Seal Beach, California, U.S.A.

§ Technical Fellow, The Boeing Company, Chantilly, Virginia, U.S.A.

AAS 11-042

VERTICALLY INTEGRATED GN&C ARCHITECTURES FOR LOW-COST COMMERCIAL IMAGERY SOLUTIONS

Jonathan Chapman[*] and Marissa Brummitt[*]

High end commercial imaging has come into its own in the past several years in the US. GeoEye and DigitalGlobe have created powerful, high agility, high resolution satellites with increasing capacity to serve the US commercial market and, to an even greater extent, the US government. Many remaining sectors of the commercial imagery market face lower priority tasking resulting in longer latencies. For many applications, including ocean science, crop health, migration patterns, population growth patterns and emergency services, these requirements may be met with lower resolutions and multiple satellite systems to provide global coverage.

Surrey Satellite Technology in the UK (and now Surrey Satellite Technology US) has long specialized in low-cost imagery products, with global coverage at resolutions varying from 22 m to 2.5 m. The RapidEye constellation and the Disaster Monitoring Constellation (DMC) provide examples of low-cost global coverage. A low latency solution was demonstrated with TopSat, which achieved a 20 minute turn-around time from tasking to product availability in theater. NigeriaSat-2, launching later this year, will provide 2.5m ground resolution imagery.

Surrey practices a vertical integration approach to spacecraft design and manufacturing that reduces risk and cost to achieve a high performance to cost ratio. The GN&C architectures specifically benefit from this approach. Sun and earth sensors, reaction wheels, magnetorquers, star trackers and GPS receivers are all constructed in-house from the piece part level. Each component is available in a range of capabilities and can be used in a customized combination to produce GN&C solutions for a wide range of imagery requirements, as demonstrated in this paper.

As the demand for commercial imagery rises, raising awareness of low-cost solutions becomes increasingly important. Surrey strives to show the applicability of the 80%/20% performance solution to satisfy the demands of a growing market. The range of cost-effective GN&C components we offer is essential to meet this goal.
[View Full Paper]

* Systems Engineer, Surrey Satellite Technology US LLC, 8310 S. Valley Hwy. Englewood, Colorado 80112, U.S.A.

AAS 11-044

GEOLOCATION ACCURACY EVALUATIONS OF COMMERCIAL SATELLITE IMAGERY: CHALLENGES AND RESULTS*

Paul C. Bresnahan†

The Civil and Commercial Applications Project (CCAP) is part of the National Geospatial-Intelligence Agency (NGA) Image Quality and Utility (NIQU) program. CCAP is responsible for the assessment of civil and commercial remote sensing systems for the Department of Defense and Intelligence Community. A major component is the assessment of geolocation accuracy. Since its inception, CCAP has assessed imagery from commercial satellites, such as IKONOS, QuickBird, OrbView-3, EROS-A, EROS-B, SPOT-5, WorldView-1, GeoEye-1, TerraSAR-X, Radarsat-2, Cosmo-Skymed, and WorldView-2. CCAP compared the results of these assessments against vendor specifications and expected performance, and CCAP has communicated these results to the user community. Through its experience in evaluating a diverse set of imaging satellites, CCAP has encountered and addressed numerous challenges during evaluation planning, execution, and data analysis. CCAP discusses some of these challenges along with recent results. [View Full Paper]

---

* Approved for Public Release 11-128.

† Photogrammetrist, National Geospatial-Intelligence Agency (contractor), 12310 Sunrise Valley Drive, Reston, Virginia 20191, U.S.A.

CONSTRUCTS FOR THE NEXT GENERATION OF COMMERCIAL IMAGERY

Joshua Hartman* and Eric Sundberg†

The history and current state of commercial imagery are used as the basis for exploring constructs for the next generation of U.S. commercial imagery systems. The United States government is currently the “anchor tenant” and its continued support is critical to the viability of the commercial imagery business in the United States. This paper explores the technical drivers and how they might be manipulated in the next generation of commercial imagery systems to allow commercial imagery providers to efficiently expand their business base, both within and outside the government. It also highlights what policy changes might expand both technical and business opportunities.
[View Full Paper]

* Principal, Center for Strategic Space Studies – CS3.

† Colonel, U.S. Air Force (Retired).

SMALL BODY
PROXIMITY OPERATIONS

SESSION V

Spacecraft proximity operations in the vicinity of small bodies such as asteroids and comets represent a challenge to traditional operations, mission design and navigation scenarios. Short orbital periods about small bodies coupled with the required small response times and long round-trip light times drive autonomy and robust mission designs. The mission design problem is greatly complicated by distended shapes that ultimately drive chaotic trajectories with sensitivities to initial condition errors, perturbations and gravity field errors. Navigation strategies must rely upon traditional radiometric data types coupled with optical imaging and landmark tracking. This session explores the current progress in trying to meet these challenges as mission enablers for future efforts.

National Chairpersons:

Chris D'Souza
NASA Johnson Space Center

Dan Scheeres
University of Colorado at Boulder

Local Chairpersons:

Dave Chart
Lockheed Martin
Space Systems Company

Ian Gravseth
Ball Aerospace & Technologies
Corporation

The following paper numbers were not assigned:

AAS 11-059 to -060

INITIAL CONSIDERATIONS FOR NAVIGATION AND FLIGHT DYNAMICS OF A CREWED NEAR-EARTH OBJECT MISSION

Dr. Greg N. Holt,* Joel Getchius† and William H. Tracy‡

A crewed mission to a Near-Earth Object (NEO) was recently identified as a NASA Space Policy goal and priority. In support of this goal, a study was conducted to identify the initial considerations for performing the navigation and flight dynamics tasks of this mission class. Although missions to a NEO are not new, the unique factors involved in human spaceflight present challenges that warrant special examination. During the cruise phase of the mission, one of the most challenging factors is the noisy acceleration environment associated with a crewed vehicle. Additionally, the presence of a human crew necessitates a timely return trip, which may need to be expedited in an emergency situation where the mission is aborted. Tracking, navigation, and targeting results are shown for sample human-class trajectories to NEOs. Additionally, the benefit of in-situ navigation beacons on robotic precursor missions is presented. This mission class will require a longer duration flight than Apollo and, unlike previous human missions, there will likely be limited communication and tracking availability. This will necessitate the use of more onboard navigation and targeting capabilities. Finally, the rendezvous and proximity operations near an asteroid will be unlike anything previously attempted in a crewed spaceflight. The unknown gravitational environment and physical surface properties of the NEO may cause the rendezvous to behave differently than expected. Symbiosis of the human pilot and onboard navigation/targeting are presented which give additional robustness to unforeseen perturbations. [View Full Paper]

* Flight Dynamics/Navigation, Mission Operations, NASA Johnson Space Center, Houston, Texas 77058, U.S.A.

† Engineering Staff, On-Orbit GNC, ESCG, Houston, Texas 77058, U.S.A.

‡ Flight Dynamics Officer, United Space Alliance, Houston, Texas 77058, U.S.A.

AAS 11-052

MISSION OPERATIONS AT NEAR-EARTH ASTEROIDS

Julie Bellerose, James Chartres,[*] Thomas Jones,[†] Pascal Lee,[‡] Franck Marchis[§] and Keaton Burns[**]

Small bodies are considered as one of the most primitive remnants of our solar system formation; understanding their formation and evolution provides direct insights into the evolution of our solar system evolution. To date, there have only been a few missions to these small bodies, namely comets and asteroids. Small bodies are now considered targets of opportunity for current mission concepts, with some specific targets such as multiple asteroid systems. Mission operations vary tremendously from 1 AU to > 5 AU, as the science is partially driven by the nature of the target, and the overall mission design and goals. When talking about precursor missions for human exploration, emphasis on resources and human technology demonstrations overrule operations design. The paper discusses the current status of small body exploration missions, and provides examples of proximity operations at single and multiple asteroid systems. Finally, the similarities and differences between science and exploration mission objectives are investigated and discussed. [View Full Paper]

* Research Scientist, Carnegie Mellon University Silicon Valley, NASA Ames Research Center, MS-202-3, Building 202, Room 200B-C, Moffett Field, California 94035, U.S.A.

† Research Consultant, Carl Sagan Center at the SETI Institute, Mountain View, California 94043, U.S.A.

‡ Planetary Geologist, Carl Sagan Center at the SETI Institute, Mountain View, California 94043, U.S.A.

§ Planetary Astronomer, Carl Sagan Center at the SETI Institute, Mountain View, California 94043, U.S.A.

** Research Intern, Carl Sagan Center at the SETI Institute, Mountain View, California 94043, U.S.A.

AAS 11-053

SMALL BODY SURFACE GRAVITY FIELD ESTIMATION FROM ORBIT DETERMINATION

Yu Takahashi* and Daniel J. Scheeres†

Scientific interest in small solar system bodies has been growing significantly during the last decade, and a number of mission studies, actual missions, and planned future missions are studied and discussed. We are especially interested in performing proximity operation on an asteroid; that is, sciences near or on the asteroid's surface. For any proximity operation around the asteroid, we need to have accurate model of the gravity field. This paper specifically addresses this problem and looks at the characterization of the gravity field of the asteroid at the early stages of the mission phase and discusses the characterization of internal density estimation. We first perform the numerical covariance and present the uncertainties with which we can estimate the gravity field. We carry out this determination by a series of flybys around the asteroid, maximizing the time we can dedicate to sciences around the body. Then, from the shape model generated by optical measurement, we can construct the shape model of the asteroid. The gravity field generated from the shape model will not, in general, be the same as that estimated from flybys. We will investigate the discrepancies between these two gravity field models and deduce the internal density distribution of the asteroid within the body. The result shows that out of five density distribution models we construct, we can detect the inhomogeneity in the density distribution for all models except for the one spherical core model placed at the center of mass. [View Full Paper]

* Student, Aerospace Engineering Sciences, University of Colorado at Boulder, 429 UCB, Boulder, Colorado 80309-0429, U.S.A.

† A. Richard Seebass Endowed Chair Professor, Aerospace Engineering Sciences, University of Colorado at Boulder, 429 UCB, Boulder, Colorado 80309-0429, U.S.A.

SMALL BODY PROXIMITY SENSING WITH A NOVEL HD3D LADAR SYSTEM

John L. Junkins,* Manoranjan Majji,† Brent Macomber,† Jeremy Davis,† James Doebbler† and Randy Nosterk‡

In this paper, we discuss the design and operation of the prototype of a novel sensor system: HD3D, that fuses high definition LADAR data with synchronized high definition video at frame rate, in near real time. This sensor and the associated algorithms enable proximity sensing and fast estimation of high fidelity geometric models of unknown objects. The range is measured by a MEMs scanning LADAR sensor at a rate of 15 million points/second, within a 1 σ range error of 3 mm, over a 30° field of view. Using an eye-safe realization of the sensor, the present standoff range varies from 1 km down to < 1 m, and a multi-resolution learning algorithm refines the geometry estimates with increasing lateral resolution as the range decreases. Via *a priori* calibration and synchronization, each impingement point is shown to be mapped into the focal plane pixel address of a high definition video camera. A first generation geometry reconstruction algorithm and its software implementation that enables fusion of overlapping point clouds to establish best estimates of the small body geometry and relative pose of the sensor in near real time is detailed. To this end, a rigorously linear least squares solution is derived for estimation of relative pose parameters to register the point clouds at successive frames. A statistical decision process (using a hypothesis testing procedure from random measurement subsets) is developed to identify consistent measurements while simultaneously obtaining the best motion model. This sensor and algorithm technology is shown to enable highly accurate simultaneous localization and mapping of space objects with high relevance to small body proximity mapping and GN&C. This technology demonstrated using experiments conducted in the Land, Air, and Space Robotics (LASR) laboratory at Texas A&M University. [View Full Paper]

* Regents Professor, Distinguished Professor, Royce E. Wisenbaker Chair in Engineering, Aerospace Engineering Department, Texas A&M University, 3141-TAMU, College Station, Texas 77843-3141, U.S.A.

† Research Associate, Aerospace Engineering Department, Texas A&M University, 3141-TAMU, College Station, Texas 77843-3141, U.S.A.

‡ President, Systems and Processes Engineering Corporation, Austin, Texas 78744, U.S.A.

AAS 11-055

A HOMOTOPY APPROACH TO LAMBERT PROBLEM AROUND SMALL-BODIES: APPLICATIONS TO CLOSE PROXIMITY OPERATIONS

Benjamin F. Villac*

Continuation and bifurcation analysis methods for two point boundary value problems are applied to the problem of two-impulse transfers around small bodies. Starting from the classical Lambert problem in a two-body field, a homotopy of the dynamic model is chosen to transfer a given Lambert solution into a realistic, small body orbiter dynamic model (that includes general rotating gravity field, solar radiation pressure and tides). The method generalizes the computation of periodic solutions in simplified small body models to the non-autonomous case. The results are applied to close proximity operations near small bodies, such as phasing and landing maneuvers. [View Full Paper]

* Assistant Professor, Mechanical and Aerospace Engineering, University of California, Irvine, 4200 Engineering Gateway, Irvine, California 92697-3975, U.S.A.

SMALL BODY LANDING ACCURACY USING IN-SITU NAVIGATION

Shyam Bhaskaran, Sumita Nandi, Stephen Broschart, Mark Wallace, L. Alberto Cangahuala[*] and Corwin Olson[†]

Spacecraft landings on small bodies (asteroids and comets) can require target accuracies too stringent to be met using ground-based navigation alone, especially if specific landing site requirements must be met for safety or to meet science goals. In-situ optical observations coupled with on-board navigation processing can meet the tighter accuracy requirements to enable such missions. Recent developments in deep space navigation capability include a self-contained autonomous navigation system (used in flight on three missions) and a landmark tracking system (used experimentally on the Japanese Hayabusa mission). The merging of these two technologies forms a methodology to perform autonomous onboard navigation around small bodies. This paper presents an overview of these systems, as well as the results from Monte Carlo studies to quantify the achievable landing accuracies by using these methods. Sensitivity of the results to variations in spacecraft maneuver execution error, attitude control accuracy and unmodeled forces are examined. Cases for two bodies, a small asteroid and on a mid-size comet, are presented. [View Full Paper]

[*] Guidance, Navigation, and Control Section, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, MS 230-205, 4800 Oak Grove Dr., Pasadena, California 91109, U.S.A. Phone: (818) 354-0015, E-mail: Sumita.Nandi@jpl.nasa.gov.

[†] a.i. solutions, 10001 Derekwood Lane, Suite 215, Lanham, Maryland 20706, U.S.A.

AAS 11-057

GN&C TRADES FOR TOUCH-AND-GO SAMPLING AT SMALL BODIES

L. Alberto Cangahuala, Stephen Broschart, Behcet Acikmese, Milan Mandic, Lars Blackmore, Ed Riedel, David Bayard and Mark Wallace*

Touch-And-Go (TAG) is an approach for asteroid/comet sample collection different from any other robotic mission phase. At a high level, the primary engineering trade is to optimize (a) the maximum integral of sample collection rate vs. operating duration of the hardware against (b) safety considerations for the spacecraft while preserving sample integrity and quality. There are several design choices that need to be made for a given sample collection approach, including required GN&C autonomy (beyond baseline capabilities), thruster suite capabilities, fault detection augmentations, control strategy, etc. This paper describes two TAG design examples (at comet Tempel 1 and Deimos) and shows how the target body and science goals force differences in the two designs. The paper documents (a) TAG functions and concept of operations, (b) design constraints and assumptions, (c) contact considerations such as position, velocity, orientation, and duration, and (d) forecasted safety margins and sample collection performance based on high fidelity simulations. In addition, the paper describes GN&C considerations and capabilities for sample verification. [View Full Paper]

* The authors are from the Autonomous Systems Division, Jet Propulsion Laboratory/California Institute of Technology, 4800 Oak Grove Drive, Pasadena, California 91109, U.S.A.

AAS 11-058

RETURN OF HAYABUSA SPACECRAFT AND REENTRY OF ITS CAPSULE

Jun'ichiro Kawaguchi,* Hitoshi Kuninaka and Makoto Yoshikawa

The Hayabusa spacecraft aiming at technology demonstration for the world's first sample and return from an extra-terrestrial object was launched by the fifth M-V rocket from Uchinoura Space Center, JAXA on May 9, 2003. It went through several troubles and hardships during totally 7 years of interplanetary flight. It successfully returned to the earth and completed the powered-flight by the ion thruster in the beginning of 2010. After successive trajectory correction maneuvers for the reentry, the mother spacecraft, Hayabusa successfully released a small sample-return capsule with asteroid Itokawa sample contained in the sample canister aboard. The capsule entered the earth atmosphere in the desert of Australia on June 13, 2010, and was successfully recovered by June 15. This paper overviews the return operation of the Hayabusa mother spacecraft and reentry flight and recovery operation of the sample return capsule. And the paper also will provide how these TCM and EDL activities were performed and some associated information regarding the Hayabusa mission. [View Full Paper]

* Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), 3-1-1 Yoshinodai, Chuo, Sagamihara, Kanagawa, 252-5210, Japan. Tel. +81-50-3362-4393, E-mail: kawaguchi.junichiro@jaxa.jp.

MICROVIBRATION

SESSION VI

Microvibration, with its effects on payloads and GNC systems, is becoming an ever more important consideration. As the sensitivity of missions has increased, requirements have tightened and the need for mitigation of microvibration has also increased. This has led to challenges in design, characterization and testing. This 'semi-tutorial' style session is intended to use real-world examples as an introduction to the sources and negative effects of micro-vibration on spacecraft. Additionally, this session will outline various techniques for mitigating and reducing the effects while also explaining the difficulties in measuring and testing for micro-vibration.

National Chairpersons:

Stephen "Phil" Airey
ESA TEC-ECC

Frank Cepollina
NASA Goddard
Space Flight Center

Local Chairpersons:

Lisa Hardaway
Ball Aerospace

Brian Clapp
Lockheed Martin
Space Systems Company

The following paper numbers were not assigned:

AAS 11-065 to -070

AAS 11-061

MICROVIBRATION DISTURBANCE FUNDAMENTALS FOR ROTATING MECHANISMS

Bill Bialke*

Microvibration disturbances from rotating mechanisms such as scanners, reaction wheels and momentum wheels affect spacecraft pointing jitter and have the potential to generate microphonics in payload instruments. A fundamental understanding of the sources and behavior of the disturbances from these mechanisms is necessary to predict their effects on the spacecraft dynamics in order to mitigate or avoid their total contribution to pointing jitter.

The sources of microvibration are defined and broken down into three distinct categories of rotating mass imbalance, bearing disturbances, and motor noise. The primary method of measuring the disturbances from a rotating device is with a sensitive force transducer, and spectral microvibration measurements taken on a rotating mechanism over a range of operating speeds are presented and interpreted with regards to the relationships between the speed dependent disturbances and the structural resonances, specifically the speed dependent whirl resonance. [View Full Paper]

* Goodrich ISR Systems, 950 Danby Road Suite 100, Ithaca, New York 14850-6437, U.S.A.

AAS 11-062

MTG MICROVIBRATION REQUIREMENTS AND ASSOCIATED POTENTIAL IMPACT ON THE SATELLITE DESIGN

P. Tanguy, E. Spalinger, M. Sghedoni and D. Guichon*

The Meteosat Third Generation satellites aim at renewing the current Meteosat fleet. They will be launched between 2016 and 2029 to provide services on a 20-year timespan. Unlike the previous generations, the MTG constellation will consist in two types of satellites based on the same platform: the MTG-I satellite will ensure the continuity of the imagery mission and provide lightning detection, whereas the MTG-S satellite will embark the Infra-Red Sounding (IRS) mission, and the Sentinel 4/UVN mission, which is part of the GMES program.

The MTG-I imaging instrument, called Flexible Combined Imager (FCI), features performance requirements similar to the ones of the Advanced Baseline Imager (ABI) of GOES-R, to be launched around 2014. Its sharpest resolution of 500 m calls for a microrad level stability over the 0.5 ms pixel integration time. The IRS instrument embarked on MTG-S is also susceptible to microvibrations but on a different frequency range due to its much longer dwell time of 10 s. In both cases, attitude control actuators, solar array drive mechanisms as well as the instrument active coolers, required to reach the demanding infra-red radiometric requirements, are potential sources of line of sight jitter.

In this paper, we propose to present the MTG microvibrations requirements derived from the mission specification, and to address the potential solutions at satellite level to reach this level of performances. [View Full Paper]

* The authors are associated with the MTG Program, Thales Alenia Space France, 100 Bvd du Midi – B.P. 99, 06156 Cannes La Bocca Cedex, France.

AAS 11-063

ACCURATELY CORRELATING EXPERIMENTAL AND COMPUTATIONAL SPACECRAFT FUEL SLOSH MODELS USING DIAPHRAGM-IMPLEMENTED PROPELLANT TANKS

Brian A. Lenahen,[*] Dillon J. Sances[*] and Sathya N. Gangadharan[†]

The unpredictable behavior of liquid propellant inside a spacecraft's fuel tank is of great concern when considering the attitude stability of the space vehicle. The dynamic motion of the propellant, known as fuel slosh, is responsible for applying small forces and torques within a spacecraft's fuel tank, which can cause attitude and rate perturbations, nutation growth and ultimately compromise the mission. Fuel movement within the tank can also lead to an uncertainty as to the location of the spacecraft's center of gravity, and thus be problematic for accurate spacecraft attitude control. In order to control the unsteady motion of the liquid propellant, most fuel tanks are integrated with propellant management devices (PMD's), which work to control propellant position, dampen the fuel slosh and eliminate these unfavorable internal forces within the spacecraft. PMD's are often made from thin, visco-elastic materials that conform to the liquid propellant surface and deform as the liquid deforms. In order to gain a better understanding of the propellant motions and to develop more accurate, predictive analyses of spacecraft and launch vehicle dynamics, NASA's Launch Services Program (LSP) at NASA's Kennedy Space Center (KSC) has been sponsoring slosh research for the past decade. Laboratory testing using diaphragm PMD's is often costly and time consuming and is minimized whenever possible. As an alternative source of "test" data, computational fluid dynamics-based fuel slosh models are desired as they minimize the time and costs associated with an experimental test. They also allow data generation under environmental conditions not readily available in the laboratory, such as zero-gravity. Methods have been developed to extract parameters from the CFD generated data for use in simplified mechanical analog models such as the standard pendulum slosh model. This research begins with simplified computational and experimental models and intends to develop accurate, validated modeling methods for all combinations of propellant tank sizes and shapes, diaphragm/PMD types and shapes, fill levels and propellant types. [View Full Paper]

* Graduate Student, Department of Mechanical Engineering, Embry-Riddle Aeronautical University, Daytona Beach, Florida 32114, U.S.A.

† Professor, Department of Mechanical Engineering, Embry-Riddle Aeronautical University, Daytona Beach, Florida 32114, U.S.A.

ACTIVE AND PASSIVE MICROVIBRATION MITIGATION SYSTEM FOR EARTH OBSERVATION AND SPACE SCIENCE MISSIONS

Fabrice Boquet,[*] Florence Malric-Smith[*] and Jean-Pascal Lejault[†]

Micro-vibrations are a major contributor to the performances of an increasing number of Earth observation and space science missions because line of sight stability requirements get tighter with increasing resolution and longer instruments integration time. These mission performances are sensitive to the presence of disturbance sources such as wheels, cryocoolers and solar array drive mechanisms. For the majority of Astrium's satellites, microvibrations attenuation is widely handled by considering passive isolators set at the reaction wheels interface. This solution allows guaranteeing good rejection of high frequency disturbances while providing sufficient performances for the current missions. Unfortunately, this so-called "passive"-based solution provides no isolation in low frequency and even degrades the performances in the vicinity of the isolator resonance modes. The work presented in this paper should be understood in this context. It results from research activities led by EADS Astrium and the European Space Agency on the design of an optimized passive/active solution for large frequency band microvibrations mitigation. The proposed solution is based on a passive isolator coupled with an active control system in charge of rejecting disturbances in the low frequency band. Several actuators/sensors types and configurations have been compared, and the retained solution consists of a 4 tri-axis piezo-based force sensors set between the passive isolator and the satellite, an active plate where the disturbance source is set together with 6 proof mass actuators generating forces along 3 vertical directions and 3 tangential directions; this active plate being set on the passive isolator. Two active controllers have been designed and implemented. The first one, called "anti-phase", consists in generating two sinusoidal signals having the same frequency and the same amplitude as two disturbance harmonics signals but with an opposite phase. The second control solution consists of a "large-band" multivariable controller where the synthesis model have been derived from a frequency-domain identification process performed from input/output experimental transfer functions measured on the real system. The performances of the solution have been evaluated firstly on a software simulator including Finite Element Models of the satellite, the wheel and the isolators, and secondly on a hardware test bench especially developed in the scope of this study. The performance measured on the breadboard with the anti-phase controller is comprised between 18 and 30dB for wheel rates in the range 18-54Hz, the performance increasing w.r.t. the wheel rate. [View Full Paper]

* Astrium, 31 rue des Cosmonautes ZI du Palays, 31402 Toulouse Cedex 4, France.

† European Space Research and Technology Center, Keplerlaan 1, 2201 AZ Noordwijk, The Netherlands.

SPACE SERVICING

SESSION VII

Extending the life of healthy on-orbit assets, repairing vehicles that have experienced failures, and safely disposing of vehicles that have suffered anomalies, all provide a compelling need to establish high-TRL space servicing capabilities. This session will explore the challenges and fundamental technologies of space servicing missions such as on-orbit refueling, replenishment or repair of payloads, installation of advanced instrumentation, in-situ assembly of large structures, and the capture of errant spacecraft for safe disposal.

National Chairpersons:

Bo Naasz
NASA
Goddard Space Flight Center

Fred G. Kennedy, III
Lt. Col., U.S. Air Force

Local Chairpersons:

Michael Osborne
Lockheed Martin
Space Systems Company

Mike Drews
Lockheed Martin
Space Systems Company

The following papers were not available for publication:

AAS 11-071
(Paper Withdrawn)

AAS 11-077
"Falcon 9-2 and Dragon – First Flight Results," Hans Koeningsmann, Jeffrey Tooley, Eric Hultgren and Chris Wilkins, Space Exploration Technologies Corporation (Paper Withdrawn)

The following paper numbers were not assigned:

AAS 11-078 to -080

AAS 11-072

SATELLITE SERVICING'S AUTONOMOUS RENDEZVOUS AND DOCKING TESTBED ON THE INTERNATIONAL SPACE STATION

Bo J. Naasz,[*] Matthew Strube,[†] John Van Eepoel,[‡] Brent W. Barbee[§] and Kenneth M. Getzandanner[**]

The Space Servicing Capabilities Project (SSCP) at NASA's Goddard Space Flight Center (GSFC) has been tasked with developing systems for servicing space assets. Starting in 2009, the SSCP completed a study documenting potential customers and the business case for servicing, as well as defining several notional missions and required technologies. In 2010, SSCP moved to the implementation stage by completing several ground demonstrations and commencing development of two International Space Station (ISS) payloads—the Robotic Refueling Mission (RRM) and the Dextre Pointing Package (DPP)—to mitigate new technology risks for a robotic mission to service existing assets in geosynchronous orbit. This paper introduces the DPP, scheduled to fly in July of 2012 on the third operational SpaceX Dragon mission, and its Autonomous Rendezvous and Docking (AR&D) instruments. The combination of sensors and advanced avionics provide valuable on-orbit demonstrations of essential technologies for servicing existing vehicles, both cooperative and non-cooperative. [View Full Paper]

* Aerospace Engineer, NASA Goddard Space Flight Center, Code 595, 8800 Greenbelt Road, Greenbelt, Maryland 20771, U.S.A.

† Aerospace Engineer, NASA Goddard Space Flight Center, Code 596, 8800 Greenbelt Road, Greenbelt, Maryland 20771, U.S.A.

‡ Aerospace Engineer, NASA Goddard Space Flight Center, Code 591, 8800 Greenbelt Road, Greenbelt, Maryland 20771, U.S.A.

§ Flight Dynamics Engineer, NASA Goddard Space Flight Center, Code 595, 8800 Greenbelt Road, Greenbelt, Maryland 20771, U.S.A.

** Aerospace Engineer, NASA Goddard Space Flight Center, Code 595, 8800 Greenbelt Road, Greenbelt, Maryland 20771, USA.

OPTIMAL LEVEL OF AUTONOMY FOR SATELLITE SERVICING MISSIONS

Josh Reitsema,[*] Wendell Chun[†] and John Ringelberg[‡]

Recent advances in technology and current government demonstration efforts have made servicing missions a viable option for resolving on-orbit anomalies. We present an overview of the satellite servicing market and issues to be addressed by industry. Satellite servicing presents unique challenges to autonomous operations that require human intervention, especially in autonomous grappling and repetitive robotic procedures. Supervised autonomy schemes allow for efficient and reliable satellite servicing operations. [View Full Paper]

* Software Engineer, Lockheed Martin Space Systems Company, 12257 S. Wadsworth Blvd., MS 1337, Littleton, Colorado 80125, U.S.A.

† Chief Systems Engineer, Lockheed Martin Space Systems Company, 12257 S. Wadsworth Blvd., MS H3005 Littleton, Colorado 80125, U.S.A.

‡ Mechanical Engineer Sr. Staff., Lockheed Martin Space Systems Company, 12257 S. Wadsworth Blvd., MS L3005, Littleton, Colorado 80125, U.S.A.

ENHANCING ON-ORBIT ASSETS THROUGH SERVICING AND ORBITAL DEBRIS

John Lymer* and Frank Teti†

Satellite servicing promises to extend mission duration through refueling, repair and replacement while reducing overall fleet cost. Through on-orbit or on-planet assembly, large structures can be constructed in space. The technology to accomplish these tasks exists and has been proven during space flight. In the 1990's, MDA began developing the necessary technologies required to perform on-orbit satellite servicing. In 2007, autonomous on-orbit satellite servicing was demonstrated on the DARPA Orbital Express mission. Nearly all of the International Space Station's robotic operations are performed from the ground. These same technologies and techniques can be applied to the ever-growing problem of orbital debris, specifically in low Earth orbit. This paper will summarize efforts to date and describe current, planned and potential projects in the areas of satellite servicing, orbital debris mitigation and large spacecraft assembly. [View Full Paper]

* Chief Engineer, MDA 9445 Airport Road, Brampton, Ontario L6S 4J3, Canada.

† Manager, Autonomous Robotics, MDA 9445 Airport Road, Brampton, Ontario L6S 4J3, Canada.

AAS 11-075

NATURAL FEATURE TRACKING FOR RENDEZVOUS AND PROXIMITY OPERATIONS

Kalle A. Anderson* **and Adam S. Howell***

This paper presents work to develop vision-based pose estimation software for rendezvous and proximity operations. Specifically we will discuss the case of estimating the relative 6-DOF pose of a resident-space-object (RSO) from single camera imagery using only the natural features of the RSO and without a prior 3D model. This process is often referred to as Structure-from-Motion (SfM) estimation or Monocular Simultaneous Localization and Mapping (SLAM). There are benefits to using a passive vision-based sensor over alternative active sensing techniques, such as LIDAR. However, there are also many challenges due to harsh lighting conditions and specular materials. As such, we will also discuss our use of photorealistic rendered imagery within a closed-loop non-real-time simulation environment. [View Full Paper]

* Lockheed Martin Advanced Technology Center, 3251 Hanover Street, Palo Alto, California 94304, U.S.A.

AAS 11-076

PROXIMITY OPERATIONS USING LOW-THRUST PROPULSION AND ANGLES-ONLY MEASUREMENTS IN GEOSYNCHRONOUS ORBITS

Robert W. Gillis* **and David K. Geller†**

Traditionally spacecraft proximity operations require large and expensive onboard sensors and significant ground support. Relative angle measurements can be obtained from small, simple, and inexpensive onboard sensors, but have not traditionally been used for proximity operations because of difficulty generating range information. In this paper it is shown that useful relative range data can be generated provided that the spacecraft is experiencing a small continuous thrust such as would be provided by a low thrust propulsion system. In previous work range observability was shown with impulsive thrust. This paper will expand this work to low-thrust spacecraft and will show how range can be observed under normal operating conditions. The low-thrust methods covered here may be particularly useful in higher orbits (such as GEO) where the gravity gradient is relatively small. A computer simulation is used to develop and test guidance, navigation, and control algorithms for such maneuvers. The capabilities and limitations of these techniques and algorithms are then analyzed. [View Full Paper]

* Graduate Student, Mechanical and Aerospace Engineering, Utah State University, 4130 Old Main Hill, Logan, Utah 84322-4130, U.S.A.

† Associate Professor, Mechanical and Aerospace Engineering, Utah State University, 4130 Old Main Hill, Logan, Utah 84322-4130, U.S.A.

RECENT EXPERIENCES IN GUIDANCE AND CONTROL

SESSION VIII

Lessons learned through experience prove most valuable when shared with others in the G&C community. This session, which is a traditional part of the conference, provides a forum for candid sharing of insights gained through successes and failures. Past conferences have shown this session to be most interesting and informative.

National Chairpersons:	Bob Friend Boeing Space Systems
	David Geller SDL and Utah State University
Local Chairpersons:	Chris Randall Ball Aerospace & Technologies Corp.
	Cheryl Walker TASC, Inc.

The following paper was not available for publication:

AAS 11-082
"Post-Flight Performance Assessment of the Mars Phoenix Terminal Descent Radar," Erik. S. Bailey, NASA/JPL (Paper Withdrawn)

The following paper numbers were not assigned:

AAS 11-088 to -090

AAS 11-081

SOLAR DYNAMICS OBSERVATORY LAUNCH AND COMMISSIONING

James R. O'Donnell Jr., Ph.D., Kristin L. Bourkland, Oscar C. Hsu, Kuo-Chia (Alice) Liu, Ph.D., Paul A. C. Mason, Ph.D., Wendy M. Morgenstern, Angela M. Russo, Scott R. Starin, Melissa F. Vess*

The Solar Dynamics Observatory (SDO) was launched on February 11, 2010. Over the next three months, the spacecraft was raised from its launch orbit into its final geosynchronous orbit and its systems and instruments were tested and calibrated in preparation for its desired ten year science mission studying the Sun. A great deal of activity during this time involved the spacecraft attitude control system (ACS); testing control modes, calibrating sensors and actuators, and using the ACS to help commission the spacecraft instruments and to control the propulsion system as the spacecraft was maneuvered into its final orbit.

This paper will discuss the chronology of the SDO launch and commissioning, showing the ACS analysis work performed to diagnose propellant slosh transient and attitude oscillation anomalies that were seen during commissioning, and to determine how to overcome them. The simulations and tests devised to demonstrate correct operation of all onboard ACS modes and the activities in support of instrument calibration will be discussed and the final maneuver plan performed to bring SDO on station will be shown. In addition to detailing these commissioning and anomaly resolution activities, the unique set of tests performed to characterize SDO's on-orbit jitter performance will be discussed. [View Full Paper]

* Aerospace Engineer, Attitude Control Systems Engineering Branch, NASA Goddard Space Flight Center, Mail Code 591, Greenbelt, Maryland 20771, U.S.A.

FIRST IN-ORBIT RESULTS FROM PICARD*

Christine Fallet, Florence Genin and Christelle Pittet†

Myriade is a microsatellite concept initiated by CNES, designed to produce several spacecrafts for different purposes. Its main goal is to set a common structure for microsatellite product line. This program intends to develop low-cost spacecraft for LEO missions, mainly to perform scientific experiments, using the existing concepts to reduce costs and lead time.

The PICARD program is the third MYRIADE scientific mission developed by CNES. It is dedicated to sun observation. The measurements obtained all along the mission will allow defining and tuning solar models and ultimately studying the influence of solar activity on Earth's climate. In order to achieve the high performances required by the mission, a new Fine Pointing Mode specific to PICARD has been developed with a new sun ecartometry sensor. To reach the final pointing accuracy, the last improvement has been performed in orbit during calibration phase. The PICARD satellite has been launched from Yasni on June 15th 2010 aboard a Dnepr launcher, into a sun synchronous orbit at 700 km altitude.

The paper will introduce PICARD. It will briefly describe the mission objectives and the satellite. Then, it will focus on the G&C architecture developed to reach the performances required by the PICARD mission. Next, the in-orbit calibration validation process will be described. The last part will present the preliminary in orbit behaviour, in orbit calibration phase and performances. [View Full Paper]

* Copyright © 2010 by CNES. Permission to publish this paper is granted to the American Astronautical Society.

† AOCS engineers at CNES, 18 avenue Edouard Belin, 31401 Toulouse Cedex 4, France.
E-mail: christine.fallet@cnes.fr, Phone: +33 5 61282911, Fax: +33 5 61282409.

AAS 11-084

GENIE FLIGHT TEST RESULTS AND SYSTEM OVERVIEW

Tye Brady,[*] Stephen Paschall II,[*] Timothy P. Crain II,[†]
Kyle Demars[‡] and Robert Bishop[§]

NASA has envisioned a suite of lander test vehicles that will be flown in Earth's atmosphere to incrementally demonstrate applicable lunar lander performance in the terrestrial environment. As each terrestrial rocket progresses in maturity, relevant space flight technology matures to a higher technology readiness level, preparing it for inclusion on a future lunar lander design. NASA's "Project M" lunar mission concept flew its first terrestrial rocket, RR1, in June 2010 in Caddo Mills, Texas. The Draper Laboratory built GENIE (Guidance Embedded Navigator Integration Environment) successfully demonstrated accurate, real time, embedded performance of Project M navigation and guidance algorithms in a highly dynamic environment. The RR1 vehicle, built by Armadillo Aerospace, performed a successful 60 second free flight and gave the team great confidence in Project M's highly reliable and robust GNC system design and implementation. This paper provides an overview of the GENIE system and describes recent flight performance test results onboard the RR1 terrestrial rocket.
[View Full Paper]

* Charles Stark Draper Laboratory, 555 Technology Square, MS27, Cambridge, Massachusetts 02139, U.S.A.

† NASA Johnson Space Center, 2101 NASA Parkway, Houston, Texas 77058, U.S.A.

‡ The University of Texas at Austin, Cockrell School of Engineering, WRW Laboratories, Austin, Texas 78712, U.S.A.

§ Marquette University, College of Engineering, Haggerty Hall 280, Milwaukee, Wisconsin 53201, U.S.A.

AAS 11-085

THE APS BASED STAR TRACKER AFTER ONE YEAR OF INFLIGHT LIFE

R. Bettarini,* F. Boldrini,* D. Procopio* D. Temperanza†

In July 2008 the SELEX Galileo "AA-STR" APS based Star Tracker successfully completed its on ground qualification campaign. In November 2009 the launch of PROBA-2, an ESA mission dedicated to the in-flight demonstration of innovative technologies, allowed the AA-STR to finally reach TRL-9. After one full year of in-flight life on board PROBA-2, in this paper are presented the measured in-flight performance of this Flight Demo sensor, which is the first star sensor based on the new APS CMOS detector technology ever flown. The Flight Demo sensor in-flight results are presented in comparison with respect to the design specifications and with special emphasis on any trend observed on the sensor and/or on the APS detector behaviour. The AA-STR sensor product of SELEX Galileo, although initially developed for the AlphaBus GEO Telecommunication spacecraft, demonstrated a large flexibility and, even if it was presented on the market quite recently, already found applications in Scientific, Earth Observation and Commercial programs. [View Full Paper]

* SELEX Galileo – Space Line of Business – Italy.

† ESA-ESTEC – The Netherlands.

IMPROVED STAR TRACKER INSTRUMENT MAGNITUDE PREDICTION FROM ICESAT FLIGHT TELEMETRY*

Noah Smith,† Richard Fowell,‡ Sungkoo Bae§ and Bob Schutz**

Accurate prediction of instrument magnitudes for both candidate guide stars and potentially interfering near neighbor stars can be difficult because standard astronomical data are not measured at the star tracker spectral passband or angular resolution. Publicly available flight data from the three ICESat star trackers were used to evaluate empirical models for predicting instrument magnitudes and to study prediction errors for near-neighbor and variable stars. Sixty models for predicting instrument magnitudes were evaluated. The test data were CT-602 instrument magnitudes for 4,319 stars. A typical good model had an rms prediction error of 0.071 magnitudes and was applicable to 90% of test stars. The magnitude and color responses of the three trackers and their variation over time were also characterized. Reduced instrument magnitude data is available and summarizes nearly one million star transits of 8,107 ICESat stars with instrument magnitudes less than 7.2 and covering over 90% of the sky. The first release of reduced magnitudes includes 590 stars that do not have instrument magnitudes in the SKY2000 catalog. The flight data is from two Ball CT-602 star trackers and one Goodrich HD-1003 star tracker. [View Full Paper]

* Copyright © 2010 Noah H. Smith, Boeing, Sungkoo Bae, Bob E. Schutz. Published by the American Astronautical Society with permission. Permission is granted for nonprofit educational uses of this article. All other uses require permission from the copyright holders.

† Doctoral Candidate, Center for Space Research, University of Texas at Austin, Texas 78212, U.S.A.

‡ Boeing Technical Fellow, Boeing, P.O. Box 92919, MC, Los Angeles, California 90009, U.S.A.

§ Research Scientist/Engineer, Center for Space Research, University of Texas at Austin, Texas 78712, U.S.A.

** Professor and Associate Director, Center for Space Research, University of Texas at Austin, Texas 78712, U.S.A.

AAS 11-087

GLOBALSTAR SECOND GENERATION AOCS DESIGN, DEVELOPMENT, AND FIRST FLIGHT RESULTS

O. Rouat, D. Forestier, V. Barbet and P. Charbonnel*

The Globalstar 2 mission is the follow on of the first constellation: forty-eight LEO satellites provide telecommunication services world wide. In 2006, Thales Alenia Space was awarded a contract to deliver the second-generation constellation, which will be more powerful and have a fifteen-year lifetime. The main AOCS function is to point the payload antennas towards the Earth center. The main requirements are:

- Earth pointing with moderate pointing accuracy required,
- Yaw steering motion or constant yaw, as a function of the angle between the Sun and the orbit plane, in order to ensure the electrical power on board, provided by the solar arrays,
- Good level of autonomy: automatic transition between modes, autonomy of two orbits without ground TC, autonomous guidance laws for satellite attitude and solar arrays orientation, onboard orbit propagator,
- Orbit raising and out-of-plane orbit correction capability for long duration: up to 10 hours in the plane, and up to 10 min out of the plane,
- Sun pointing safe mode to ensure the safety of the satellite after the launcher separation, or after a failure detection on board.

The main drivers are:

- The required lifetime (15 years), which impacts the selection and the design of the sensors and actuators that have to withstand the stringent radiation environment,
- The tight schedule for development, since a replacement constellation is needed to ensure the continuity of services Globalstar, Inc. is offering to users around the world,
- The reliability and availability required for the constellation,
- The safe mode without thruster use, which gives the guarantee that the orbital constellation is not degraded in case of satellite emergency return to safe mode,
- The recurring cost and industrialization capability for the large amount of AOCS units, which drives the selection of suppliers.

As a result, AOCS architecture is based on robust equipment with high reliability, and the proposed design is based on heritage in order to benefit from flight proven functions, and to minimize new developments. AOCS modes and equipment units will be presented, as well as the process which has permitted a rapid and efficient development.

* The authors are associated with Thales Alenia Space, 100 Boulevard du Midi, BP 99, 06156 Cannes La Bocca Cedex, France. E-mail: Olivier.Rouat@thalesaleniaspace.com.

After 3.5 years of development since program kick-off, the first batch of six Globalstar 2 satellites has been launched on October, 19th, 2010, from Soyouz launch center in Baïkonour. In parallel, the production of next flight models continues in Thales facilities.

The high level of autonomy of the satellites has allowed to design a so-called “NOM automatic sequence” which will autonomously perform the sequence from launcher separation to earth-pointed normal mode. The objective is to facilitate the ground operations related to six satellites launched at the same time, as well as to rapidly get ready to perform a thruster avoidance maneuver if needed. First flight results and AOCS performances observed during the LEOP (Launch and Early Orbit Phase) will be presented. [View Full Paper]

DESIGN APPROACHES FOR PRECISION POINTING

SESSION IX

(U.S. Only – attendance at this session was restricted by ITAR to U.S.-persons only)

Various spacecraft mission requirements continue the push for improved vehicle pointing performance. Significant advancements have recently been made in sensors, actuators, isolation systems, and spacecraft design for precision pointing applications. This session examines design approaches for jitter suppression and control, thermal effects mitigation, in-flight calibrations, extended state estimation for instrument pointing, and flexible-body excitation and control.

National Chairpersons:

Al Bosse
Charles Stark Draper Labs

Ronald Ninneman
Air Force Research Laboratory

Local Chairpersons:

Jim Chapel
Lockheed Martin
Space Systems Company

Larry Germann
Left Hand Design

The following papers were not available for publication:

AAS 11-092

"Precision Pointing of the Airborne Laser Testbed System," Ken Billman and David Hatch, Lockheed Martin Space Systems Co., Missile Defense Systems (ITAR Restricted Paper)

AAS 11-093

(Paper Withdrawn)

AAS 11-094

"Precision Pointing Performance of the James Webb Space Telescope," Chunlei Rui, Henry Fu, Cameron Haag, Magdy Wahbah, Satya Anandakrishnan, Northrop Grumman Aerospace Systems; Landis Markley, Peiman Maghami, NASA Goddard Space Flight Center, Frank Liu, Stinger Ghaffarian Technologies (ITAR Restricted Paper)

AAS 11-095

"GOES-R Gyro Scale Factor Calibration," Alan Reth, Donald Chu, Chesapeake Aerospace; David Lorenz, Stinger Ghaffarian Technologies (SGT); Douglas Freesland, ACS Engineering; Devin Stancliffe, Brian Clapp, Jim Chapel, David Cwynar, Lockheed Martin Space Systems Company; and Alexander Krimchansky, NASA Goddard Space Flight Center (ITAR Restricted Paper)

AAS 11-097

"JMAPS: On-board and Ground Algorithm Development and Mission Update," B. N. Dorland, G. S. Hennessy, V. V. Makarov, D. R. Veillette and R. P. Dudik, U.S. Naval Observatory; C. Berghea, Computation Physics; B. Lane and B. Moran, C. S. Draper Laboratory (ITAR Restricted Paper)

AAS 11-098

"High Precision Pointing for the Next Generation of Astrophysics Missions," P. Brugarolas and J. Alexander, NASA Jet Propulsion Laboratory (ITAR Restricted Paper)

The following paper number was not assigned: AAS 11-099

AAS 11-091

INSTRUMENT POINTING CAPABILITIES: PAST, PRESENT AND FUTURE*

Lars Blackmore,† Emmanuell Murray,† Daniel P. Scharf,† MiMi Aung,‡ David Bayard,† Paul Brugarolas,† Fred Hadaegh,† Bryan Kang,† Allan Lee,‡ Mark Milman,† and Sam Sirlin†

This paper surveys the instrument pointing capabilities of past, present and future space telescopes and interferometers. As an important aspect of this survey, we present a taxonomy for "apples-to-apples" comparisons of pointing performances. First, pointing errors are defined relative to either an inertial frame or a celestial target. Pointing error can then be further sub-divided into DC, that is, steady state, and AC components. We refer to the magnitude of the DC error relative to the inertial frame as absolute pointing accuracy, and we refer to the magnitude of the DC error relative to a celestial target as relative pointing accuracy. The magnitude of the AC error is referred to as pointing stability. While an AC/DC partition is not new, we leverage previous work by some of the authors to quantitatively clarify and compare varying definitions of jitter and time window averages. With this taxonomy and for sixteen past, present, and future missions, pointing accuracies and stabilities, both required and achieved, are presented. In addition, we describe the attitude control technologies used to and, for future missions, planned to achieve these pointing performances. [View Full Paper]

---

* This paper was released from ITAR restriction and therefore it was published in the general conference proceedings.

† Guidance & Control Analysis Group, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, M/S 198-326, Pasadena, California 91109, U.S.A.

‡ Guidance & Control Section, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, M/S 198-326, Pasadena, California 91109, U.S.A.

RAPID TARGETING SATELLITE G&C SYSTEM*

Nazareth S. Bedrossian† and Sagar Bhatt‡

This paper reviews an integrated Guidance and Control system for improved vehicle agility using Single Gimbal CMGs as actuators. It highlights key Guidance and Control system enabling technologies that provide a significant performance improvement. Control system elements include CMG actuator arrangement, steering, and singularity management. Guidance elements include singularity management, and time-optimal slews. Results indicate significant agility improvement, real-time singularity management with all slews completed in nonsingular configuration, singularity-free slews, faster-than-eigenaxis slews, minimum-time target engagement and tracking. Simulation results and flight demonstrations will be used to illustrate the performance improvements. [View Full Paper]

---

* This paper was released from ITAR restriction and therefore it was published in the general conference proceedings.

† Group Leader, Vehicle Dynamics & Control, The Charles Stark Draper Laboratory, 17629 El Camino Real, Suite 470, Houston, Texas, U.S.A.

‡ Technical Staff, Vehicle Dynamics & Control, The Charles Stark Draper Laboratory, 17629 El Camino Real, Suite 470, Houston, Texas, U.S.A.

POSTER SESSION

POSTER SESSION

Local Chairperson: Mary Klaus
Lockheed Martin
Space Systems Company

The following papers were not available for publication:

AAS 11-003*
"Avoiding Dynamic Obstacles via Adaptive Estimation," Venkatesh Madyastha, National Aerospace Laboratories, Bangalore, India (Paper Withdrawn)

AAS 11-007*
"Small Orbital Debris Mitigation Mission Architecture," Bruce Wiegmann, NASA Marshall Space Flight Center (Poster Only)

The following paper numbers were not assigned:

AAS 11-008 to -010

*

* The publisher has assigned different paper numbers from those listed in the original conference program for the papers presented in this session because paper numbers AAS 11-101 through -107 were assigned to papers presented at the AAS/AIAA Space Flight Mechanics Meeting, held 13–17 February 2011, New Orleans, Louisiana.

AAS 11-001*

TRAJECTORY CONTROL DYNAMICS FOR PATH FOLLOWING VEHICLES

Vivek Ahuja,† Kevin Albarado† and Roy Hartfield, Jr.‡

Analytical solutions to the Inverse Guidance Problem have been developed for the case of atmospheric flight fin-controlled launch-vehicle and planetary re-entry vehicles. This new methodology solves the issue of Navigation Gain factors associated with typical Proportional Navigation systems and allow tailored flights through navigation waypoints in three dimensions. The solution space is closed through the addition of linearized aerodynamic formulations for forces and moments about the vehicle, allowing for an inversion of the equations of motion in inertial spaces. This new guidance methodology has proven to be very robust and applicable to an array range of atmospheric vehicles flying through a range of trajectories. Numerical results of endo-atmospheric launch vehicle flight and Mars exploration vehicle re-entry mechanics are included. [View Full Paper]

* The publisher has assigned different paper numbers from those listed in the original conference program for the papers presented in this session because paper numbers AAS 11-101 through -107 were assigned to papers presented at the AAS/AIAA Space Flight Mechanics Meeting, held 13–17 February 2011, New Orleans, Louisiana.

† Graduate Research Assistant, Department of Aerospace Engineering, Auburn University, Auburn, Alabama 36849, U.S.A.

‡ Woltosz Professor, Department of Aerospace Engineering, Auburn University, Auburn, Alabama 36849, U.S.A.

AAS 11-002*

SENSING THE EARTH WITH THE SGR-RESI MULTI-ANTENNA SPACE GPS / GNSS RECEIVER

M. Unwin,† R. de Vos Van Steenwijk,† M. Brenchley,†
C. Gommenginger,‡ C. Mitchell§ and S. Gao**

SSTL has undertaken pioneering work in spaceborne GPS and GNSS, ranging from miniaturised space GPS receivers, to the GIOVE-A Galileo demonstrator satellite, which itself carried an experimental GEO GPS receiver. Recent activities in GNSS remote sensing undertaken by SSTL have included new reflected GNSS measurements over the poles from the experiment on the UK-DMC satellite, and in-orbit ionospheric scintillation measurements in connection with the Shrewsbury School instigated POISE experiment.

SSTL with partners from The National Oceanographic Centre, the University of Bath and the Surrey Space Centre have been developing a new generation GNSS instrument, with funding from the UK Centre for Earth Observation Instrumentation (CEOI), to further exploit GNSS potential for remote sensing in the fields of ocean and atmospheric monitoring. GNSS-Radio Occultation is a technique that is already well established and current satellite missions are providing valuable data to scientists around the world. GNSS Reflectometry, on the other hand, is a relatively new application and this technique seeks to derive information about the Earth by looking at GNSS signals that have been reflected off the Earth's surface and subsequently received by a satellite in low Earth orbit. In the process of reflecting, these signals are distorted by the reflecting surface and, through the use of inversion models, it is possible to subsequently derive information about that surface from the signals.

The driving application for this development is the monitoring of the Earth's oceans and, in particular, information about ocean roughness and wind speeds could be derived. Reflections off land and ice have also been detected and potentially contain a wealth of useful information. While the concept has been proven, more data from orbit is required to improve the models; the development of the SGR-ReSI (Space GNSS Receiver – Remote Sensing Instrument) seeks to address this.

---

* The publisher has assigned different paper numbers from those listed in the original conference program for the papers presented in this session because paper numbers AAS 11-101 through -107 were assigned to papers presented at the AAS/AIAA Space Flight Mechanics Meeting, held 13–17 February 2011, New Orleans, Louisiana.

† Surrey Satellite Technology Ltd., Guildford, Surrey GU2 7YE, United Kingdom.

‡ National Oceanography Centre, United Kingdom.

§ University of Bath, United Kingdom.

** Surrey Space Centre, United Kingdom.

At its heart, the SGR-ReSI is a highly versatile, multi-frequency GNSS navigation receiver. With the addition of multiple front-ends, reconfigurable DSP capabilities, a small data recorder and specialised antennas, the SGR-ReSI will support both Reflectometry and Radio Occultation applications. Building on SSTL's small satellite expertise and using state of the art technology, the instrument aims to provide a highly capable yet relatively compact and affordable way of studying the Earth from orbit, with core technology that can be reused for a new family of navigation-grade receivers. [View Full Paper]

AAS 11-004*

JASON-2 IN-FLIGHT EXPERIENCE

D. Guillon, D. Hervé, M. Beaumel, L. Paganelli, P. Jacob, B. Gelin,† P. E. Martinez‡ and P. Insalaco§

The SED16 star tracker has been operating for more than two years onboard JASON-2 satellite. The proton rich radiation environment experienced on JASON-2 orbit has a noticeable impact on CCD performance. Dark current non-uniformity and charge transfer inefficiency degradation have been recorded and compared to prediction model based on ground testing. Although significant, the degradations of performance were consistent with expectations. [View Full Paper]

* The publisher has assigned different paper numbers from those listed in the original conference program for the papers presented in this session because paper numbers AAS 11-101 through -107 were assigned to papers presented at the AAS/AIAA Space Flight Mechanics Meeting, held 13–17 February 2011, New Orleans, Louisiana.

† Sodern, 20 avenue Descartes, 94451 Limeil-Brévannes, France. E-mail: Benoit.Gelin@sodern.fr.

‡ CNES, 18 avenue Edouard Belin, 31401 Toulouse Cedex 4, France.
E-mail: Pierre-Emmanuel.Martinez@cnes.fr.

§ Thales Alenia Space, 100 Boulevard du Midi, BP 99, 06322 Cannes la Bocca Cedex, France.
E-mail: Patrick.Insalaco@thalesaleniaspace.com.

SPECTRAL COMPRESSION POSITIONING FOR ORBITAL NAVIGATION AND SCIENCE APPLICATIONS WITH SIGNALS OF OPPORTUNITY

Kenn L. Gold,† George Davis,‡ Michael Davies,§ Michael Mathews and Peter F. MacDoran††**

Operationally Responsive Space (ORS) missions require rapid satellite integration and launch, as well as on-orbit reconfiguration, to fulfill the needs of in-theatre commanders. Small satellites are needed for this operations concept, as are bus components that meet their size, weight and power (SWaP) requirements. The GPS receiver is a particularly critical component for ORS since it provides navigation and timing to the spacecraft and payload. To be truly responsive, however, the GPS receiver must be versatile and play many roles. In addition to tracking in low Earth orbit (LEO), it should also function in geostationary (GEO) and highly elliptical orbit (HEO). For maximum utility, it should also support applications such as radio occultation measurement for ionosphere mapping. Currently, no such GPS receiver exists, but Emergent Space Technologies and Loctronix Corporation have developed a technology capable of meeting all of these goals. It currently exists in a small footprint, low power terrestrial form factor developed for indoor tracking that utilizes both GPS and Signals of Opportunity (SoOP) for positioning. This receiver is currently being migrated to CubeSat applications and will exist as a SCA compliant software defined radio waveform embedded in a low power, PnP-compliant SDR transceiver. [View Full Paper]

---

* The publisher has assigned different paper numbers from those listed in the original conference program for the papers presented in this session because paper numbers AAS 11-101 through -107 were assigned to papers presented at the AAS/AIAA Space Flight Mechanics Meeting, held 13–17 February 2011, New Orleans, Louisiana.

† VP of Research and Development, Emergent Space Technologies, 6301 Ivy Lane, Suite 720, Greenbelt, Maryland 20770, U.S.A.

‡ President, Emergent Space Technologies, 6301 Ivy Lane, Suite 720, Greenbelt, Maryland 20770, U.S.A.

§ Aerospace Engineer, Emergent Space Technologies, 6301 Ivy Lane, Suite 720, Greenbelt, Maryland 20770, U.S.A.

** President, Loctronix Coporation, 18815 139th Ave. NE, Suite C, Woodinville, Washington 98072, U.S.A.

†† Chief Scientist, Loctronix Coporation, 18815 139th Ave. NE, Suite C, Woodinville, Washington 98072, U.S.A.

AAS 11-006*

THE AOCS OF THE 5 PROTEUS SATELLITES, A SUCCESSFUL STORY

David Brethé, Frank Majal,† Magali Tello and Ph. Landiech‡

With the 5 Proteus platforms launched between 2001 and 2009, Thales Alenia Space France have consolidated their knowledge on the attitude control of Low Earth Orbit satellite for Scientific and Earth Observation missions, directed by CNES. The Proteus platforms are particularly versatile, so that they could be launched by three different launchers, fulfill different missions, at altitudes up to 1350 km, and inclinations up to heliosynchronous orbits. With a cumulated flight time of more than 20 years, and all satellites still fulfilling their respective missions, Thales Alenia Space France present results from the flight experience for the 5 Proteus platforms. [View Full Paper]

* The publisher has assigned different paper numbers from those listed in the original conference program for the papers presented in this session because paper numbers AAS 11-101 through -107 were assigned to papers presented at the AAS/AIAA Space Flight Mechanics Meeting, held 13–17 February 2011, New Orleans, Louisiana.

† Thales Alenia Space, 100 Boulevard du Midi, BP 99, 06322 Cannes la Bocca Cedex, France.

‡ CNES, 18 avenue Édouard Belin, 31401 Toulouse Cedex 4, France.

TECHNICAL EXHIBITS

SESSION II

The Technical Exhibits Session was a unique opportunity to observe displays and demonstrations of state-of-the-art hardware, design and analysis tools, and services applicable to advancement of guidance, navigation, and control technology. The latest commercial tools for GN&C simulations, analysis, and graphical displays were demonstrated in a hands-on, interactive environment, including lessons learned and undocumented features. Associated papers not presented in other sessions were also provided and could be discussed with the authors.

Organizers:

Scott Francis
Lockheed Martin
Space Systems Company

Kristen Francis
Lockheed Martin
Space Systems Company

Vanessa Baez
Lockheed Martin
Space Systems Company

The Technical Exhibits did not consist of formal written text, and therefore papers for this session were not available for publication. The following papers and paper numbers were not available for publication, or were not assigned:

AAS 11-021 to -030

Participants in Technical Exhibits

Company:

Astro- und Feinwerktechnik Adlershof GmbH

Ball Aerospace

BEI Precision Systems & Space Division

EADS Astrium

EADS Sodern

Emergent Space Technologies, Inc.

Galileo

Jena-Optronik GmbH

Lockheed Martin SSC

MathWorks, Inc.

Microcosm Astronautics Books

MIT

Rockwell Collins

Servo Corp of America

Sierra Nevada Corporation

SimuLogix

Surrey Satellite Technology US LLC