GUIDANCE AND CONTROL
2010

CONFERENCE COMMITTEE

Brent Abbott	Surrey Space
Vanessa Baez	Lockheed Martin Space Systems Co.
Jay Brownfeld	NAVSYS Corp.
Jim Chapel	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.
Bill Frazier	Ball Aerospace & Technologies Corp.
Lis Garratt	Ball Aerospace & Technologies Corp.
Larry Germann	Left Hand Design
Arlo Gravseth	L-3 Communications Titan Group
Ian Gravseth	Ball Aerospace & Technologies Corp.
Heidi Hallowell	Ball Aerospace & Technologies Corp.
Steve Jolly	Lockheed Martin Space Systems Co.
Becky Jones	Ball Aerospace & Technologies Corp.
Mary A. Klaus	Lockheed Martin Space Systems Co.
Eric Lander	Advanced Solutions
James Masciarelli	Ball Aerospace & Technologies Corp.
Alex May	Lockheed Martin Space Systems Co.
James McQuerry	Ball Aerospace & Technologies Corp.
Shawn McQuerry	Lockheed Martin Space Systems Co.
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.
Ron Rausch	United Launch Alliance
Jay Speed	Ball Aerospace & Technologies Corp.
Kristen Terry	Lockheed Martin Space Systems Co.
Zach Wilson	Lockheed Martin Space Systems Co.
Deborah Wright	Lockheed Martin Space Systems Co.

THE 2011 ANNUAL AAS NOTES
ROCKY MOUNTAIN SECTION GUIDANCE AND CONTROL CONFERENCE
Will be held at Breckenridge, Colorado, February 4–9, 2011,
Kyle B. Miller, Ball Aerospace & Technologies Corp., Chairing

Front Cover Illustration:

GPS Block III will increase accuracy and speed for both soldiers and civilian users worldwide. The first of eight GPSIIIA satellites will be launched into space in 2014.
(Photo Credit: Courtesy of Lockheed Martin).

Frontispiece:

The GOES system provides accurate real-time weather forecast and early warning products to the public and private sectors. The GOES-R mission will improve forecasting quality and timeliness generating significant economic benefits to the nation in the areas of climate monitoring, ecosystems management, commerce and transportation.
(Photo Credit: Courtesy of Lockheed Martin).

GUIDANCE AND CONTROL 2010

Volume 137
ADVANCES IN THE ASTRONAUTICAL SCIENCES

Edited by
Shawn C. McQuerry

Proceedings of the 33rd Annual AAS Rocky Mountain Guidance and Control Conference held February 5-10, 2010, 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

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 2010

Library of Congress Card No. 57-43769

ISSN 0065-3438

ISBN 978-0-87703-561-9 (Hard Cover Plus 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 fifteen years. The 2010 Conference was the 33rd 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 religiously ever since. No parallel sessions, but only three-hour sessions at daybreak and late afternoon, with a six-hour ski break at midday, were firm 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".

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 "Internaional 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 had hither fore been off limits. 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. The winners over the years are:

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

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. The 2010 Conference was the thirty-third Conference.

	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

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 extant. 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,

Shawn C. McQuerry
Lockheed Martin Space Systems
Waterton Canyon, Colorado

PREFACE

This year marked the 33rd 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 5-10, 2010. My personal thanks to the planning committee and to the national co-chairs for their work in creating a memorable conference that included both old and new themes, had a remarkable attendance of 189 conferees, up from 160 in 2009, with outstanding attendance and technical interchange within our community.

The conference formally began on the morning of February 6th with the *Space Debris* session that served as both a tutorial and a technical session in providing valuable information on this traditional challenge to the GNC community. Due in part to recent issues associated with the 2006 Chinese Anti-Satellite test and the 2008 Iridium 33 and Cosmos 2251 collision, this session had both strong attendance and audience participation.

That evening, the always popular and traditional session, *Technical Exhibits*, took place. As you may recall, this unique session allows attendees to interact directly with the latest advances in GNC technology as well as with each other. Displays, demonstrations, hardware and tools all created a hands-on, one-on-one environment. The session was accompanied by the buffet that Beaver Run provides. Conferee's family and friends were encouraged to come and many young people were greatly inspired towards technical fields in their interaction with our colleagues. Many thanks to our TE chairpersons Kristin, Scott, and Vanessa.

February 7th was dedicated to *Advances in G&C*, in the morning session III included a series of systems related papers including papers on JMAPS, Proba-3, and SMALLGEO along with techniques for advanced aerocapture, GNC architectures, and lunar descent and landing. The afternoon session was dedicated to hardware related advances such as the use of the JMAPS sensor for ACDS, the Kepler mission, advanced inertial systems, and a variety of star tracker papers from advanced designs to how solar dust impacts their performance.

Precise Orbital Determination was discussed in the morning of February 8th. Topics included the use of vision systems for landing on the moon and elsewhere, formation flying, and advanced GPS techniques.

Prior to the banquet, an afternoon short session took pace discussing *Robotic Lunar Exploration*. This session discussed the current state and the next steps in lunar exploration discussing advanced concepts for lunar GNC, the Team Omega X-Prize approach for landing, the Kaguya orbiter, and the NEXT lander.

The traditional banquet followed that evening and featured this year's inspiring speaker, Dr. Berrien Moore III, the Executive Director of Climate Central. The title of his talk was "Climate Change and Earth Observations: Challenges and Responsibilities". As climate change is a recurring issue in national and international political conversations, this talk provided a timely reminder of the science of our times.

Session VII, *Altimetry*, took place on the morning of February 9th. This was a combined tutorial and technical section that discussed the GNC challenges associated with altimetry, advanced techniques in altimetry studies, and finally how these techniques can be applied to the field.

On the evening of the 9th, the *Recent Experiences* session closed the international section of the conference. As usual, the lessons learned from real flight experience eclipses all other forms of communication and emphasizes the general advancement of the state of design in our community. This session covered eight important papers covering the GOCE, Planck, Herschel, MLAS, LRO, and HST missions.

On the morning of the 10th, the final session accommodated papers that by their nature, could not achieve International Trade and Arms Regulation (ITAR) clearance, on Operational Responsive Space GN&C.

The 33rd annual conference was a great success. The technical content of the conference continues to improve and the attendance and support from our many colleagues is a testimony to that end. I have been supported by the best conference committee, chairpersons, and conferees in the country. My final thanks is to Carolyn O'Brien of Lockheed Martin, who served as our faithful conference coordinator. Special mention to her for also organizing several educational and entertaining events for our spouses and children.

Shawn McQuerry, Conference Chairperson
2010 AAS Guidance and Control Conference

CONTENTS

SPACE DEBRIS

SESSION I

Recent space collision events can be categorized as a disruptive moment in the history of space flight: Cosmos 1934 and Cerise were critically damaged in the 1990s from debris impacts; the 2006 Chinese anti-satellite test nearly doubled the number of catalogued fragments from 4000 to 7000; and in 2008, Iridium 33 and Cosmos 2251 were completely destroyed after colliding. The consequences of growing debris cross all lines of the space sector, placing astronauts at increased risk, prompting costly collision avoidance maneuvers, reducing mission lifetimes, and degrading or even destroying missions. Incidents also cross political boundaries, straining international relationships and spurring a 10-fold increase in US DoD investment in space surveillance. This session addresses the challenges of mitigating, tracking and avoiding debris, both near-term strategies and long-term opportunities.

National Chairpersons:

Nicholas Johnson
NASA Johnson Space Center

Robert Culp
University of Colorado

Local Chairpersons:

Mike Drews
Lockheed Martin
Space Systems Company

Michael Osborne
Lockheed Martin
Space Systems Company

The following paper numbers were not assigned:

AAS 10-001 to -010 and AAS 10-018 to -020

ORBITAL DEBRIS: THE GROWING THREAT TO SPACE OPERATIONS

Nicholas L. Johnson*

For nearly 50 years the amount of man-made debris in Earth orbit steadily grew, accounting for about 95% of all cataloged space objects over the past few decades. The Chinese anti-satellite test in January 2007 and the accidental collision of two spacecraft in February 2009 created more than 4000 new cataloged debris, representing an increase of 40% of the official U.S. Satellite Catalog. The frequency of collision avoidance maneuvers for both human space flight and robotic operations is increasing along with the orbital debris population. However, the principal threat to space operations is driven by the smaller and much more numerous uncataloged debris. Although the U.S. and the international aerospace communities have made significant progress in recognizing the hazards of orbital debris and in reducing or eliminating the potential for the creation of new debris, the future environment is expected to worsen without additional corrective measures. [View Full Paper]

* Chief Scientist for Orbital Debris, Orbital Debris Program Office, NASA Johnson Space Center, 2101 NASA Parkway, Houston, Texas 77058, U.S.A.

AAS 10-012

THE SPACE SURVEILLANCE NETWORK (SSN) AND ORBITAL DEBRIS

Timothy P. Payne* and Robert F. Morris†

The paper details the sensors that makeup the Space Surveillance Network (SSN) and their ability to track space debris. Comparisons between cataloged debris populations with current NASA estimates of the debris population are also included. Finally a short description of the Conjunction Assessment (CA) process and recent conjunction statistics are presented. [View Full Paper]

* Mr. Payne, Air Force Space Command, 250 S. Peterson Blvd, Suite 116, Peterson AFB, Colorado 80914, U.S.A.

† Mr. Morris, Air Force Space Command, 250 S. Peterson Blvd., Suite 116, Peterson AFB, Colorado 80914, U.S.A.

AAS 10-013

CURRENT AND NEAR-TERM FUTURE MEASUREMENTS OF THE ORBITAL DEBRIS ENVIRONMENT AT NASA

Gene Stansbery,[*] J.-C. Liou,[†] M. Mulrooney[‡] and M. Horstman[**]

The NASA Orbital Debris Program Office places great emphasis on obtaining and understanding direct measurements of the orbital debris environment. The Orbital Debris Program Office's environmental models are all based on these measurements. Because OD measurements must cover a very wide range of sizes and altitudes, one technique realistically cannot be used for all measurements. In general, radar measurements have been used for lower altitudes and optical measurements for higher altitude orbits. For very small debris, in situ measurements such as returned spacecraft surfaces are utilized. In addition to receiving information from large debris (> 5-10 cm diameter) from the U.S. Space Surveillance Network, NASA conducts statistical measurements of the debris population for smaller sizes. NASA collects data from the Haystack and Goldstone radars for debris in low Earth orbit as small as 2-4 mm diameter and from the Michigan Orbital DEbris Survey Telescope for debris near geosynchronous orbit altitude for sizes as small as 30-60 cm diameter. NASA is also currently examining the radiator panel of the Hubble Space Telescope Wide Field Planetary Camera 2, which was exposed to space for 16 years and was recently returned to Earth during the STS-125 Space Shuttle mission. This paper will give an overview of these on-going measurement programs at NASA as well as discuss progress and plans for new instruments and techniques in the near future. [View Full Paper]

* Program Manager, Orbital Debris Program Office, NASA/Johnson Space Center, Houston, Texas 77058, U.S.A.

† Lead, In-Situ Measurements, Orbital Debris Program Office, NASA/Johnson Space Center, Houston, Texas 77058, U.S.A.

‡ Orbital Debris Program Office, ESCG/MEI Technologies, Houston, Texas, U.S.A.

** Orbital Debris Program Office, ESCG/ERC Inc., Houston, Texas, U.S.A.

AAS 10-014

AN OVERVIEW OF NASA'S ORBITAL DEBRIS ENVIRONMENT MODEL

Mark Matney*

Using updated measurement data, analysis tools, and modeling techniques, the NASA Orbital Debris Program Office has created a new Orbital Debris Environment Model. This model extends the coverage of orbital debris flux throughout the Earth orbit environment, and includes information on the mass density of the debris as well as the uncertainties in the model environment. This paper will give an overview of this model and its implications for spacecraft risk analysis. [View Full Paper]

* Orbital Debris Program Office, NASA Johnson Space Center, Houston, Texas 77058, U.S.A.

AAS 10-015

NASA'S ORBITAL DEBRIS CONJUNCTION ASSESSMENT AND COLLISION AVOIDANCE STRATEGY

Richard T. Gavin*

Avoiding collisions with orbital debris has become an increasingly important part of NASA's spaceflight operations. The process began as part of the Shuttle Program return to flight effort after the Challenger accident. The initial process was developed using parametric data and involved using maneuver threshold boxes around the Shuttle. As the Space Station Program was being developed it was realized that using the box method would result in an unacceptably high maneuver rate. Therefore, a new approach for Space Station was developed collaboratively by NASA Johnson Space Center (JSC) & United States Strategic Command (USSTRATCOM)† using event specific probability calculations based on the covariances of the Space Station and debris object. The Space Shuttle Program also adopted this new approach. This methodology was later picked up by the NASA Goddard Space Flight Center (GSFC) to develop a process to protect NASA's unmanned (robotic) assets. This new event specific approach dramatically reduced the maneuver rate compared to using a threshold box, while still providing a high level of safety for NASA's spacecraft. [View Full Paper]

---

* Deputy Division Chief, Flight Dynamics Division, Mission Operations Directorate, NASA Johnson Space Center, Houston, Texas 77058, U.S.A.

† For simplicity, United States Strategic Command (USSTRATCOM) will be used throughout the paper, but prior to October 2002 United States Space Command (USSPACECOM) performed the orbital debris related functions.

AAS 10-016

THE KESSLER SYNDROME: IMPLICATIONS TO FUTURE SPACE OPERATIONS

Donald J. Kessler,* Nicholas L. Johnson,† J.-C. Liou‡ and Mark Matney**

The term "Kessler Syndrome" is an orbital debris term that has become popular outside the professional orbital debris community without ever having a strict definition. The intended definition grew out of a 1978 JGR paper predicting that fragments from random collisions between catalogued objects in low Earth orbit would become an important source of small debris beginning in about the year 2000, and that afterwards, "…the debris flux will increase exponentially with time, even though a zero net input may be maintained". The purpose of this paper is to clarify the intended definition of the term, to put the implications into perspective after 30 years of research by the international scientific community, and to discuss what this research may mean to future space operations. The conclusion is reached that while popular use of the term may have exaggerated and distorted the conclusions of the 1978 paper, the result of all research to date confirms that we are now entering a time when the orbital debris environment will increasingly be controlled by random collisions. Without adequate collision avoidance capabilities, control of the future environment requires that we fully implement current mitigation guidelines by not leaving future payloads and rocket bodies in orbit after their useful life. In addition, we will likely be required to return some objects already in orbit. [View Full Paper]

* Retired Senior Scientist for Orbital Debris Research at NASA/JSC, 25 Gardenwood Lane, Asheville North Carolina 28803, U.S.A.

† Chief Scientist for Orbital Debris, Orbital Debris Program Office, NASA Johnson Space Center, 2l01 NASA Parkway, Houston, Texas 77058, U.S.A.

‡ Lead Scientist for In-Situ Measurements, Orbital Debris Program Office, Mail Code KX, NASA Johnson Space Center, 2101 NASA Parkway, Houston Texas 77058, U.S.A.

** Lead Scientist for Modeling, Orbital Debris Program Office, NASA Johnson Space Center, 2l01 NASA Parkway, Houston, Texas 77058, U.S.A.

AAS 10-017

SUSTAINABLE USE OF SPACE THROUGH ORBITAL DEBRIS CONTROL

Heiner Klinkrad[*] and Nicholas L. Johnson[†]

The paper will describe the current orbital debris environment, outline its main sources, and identify internationally accepted debris mitigation measures to reduce orbital debris growth by controlling these sources. However, analyzes of the long-term effects of mitigation measures on the debris environment indicate that even extreme measures, such as an immediate halt of all launch activities, will not lead to a stable debris population. Some orbit altitudes, particularly in the LEO regime, already have critical mass concentrations that will trigger collisional cascading within a few decades, unless debris environment remediation measures are introduced. Physical principles and operational procedures for active mass removal will be described, and their effectiveness on the long-term sustainability of space activities will be demonstrated. [View Full Paper]

---

* Head, ESA Space Debris Office, ESA/ESOC, Robert-Bosch-Strasse 5, 64293 Darmstadt, Germany.

† Chief Scientist for Orbital Debris, Orbital Debris Program Office, NASA Johnson Space Center, 2l01 NASA Parkway, Houston, Texas 77058, U.S.A.

ADVANCES IN GN&C
PART 1 – SYSTEMS

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 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:

Bryan Dorland
U.S. Naval Observatory

Thomas Strikwerda
Johns Hopkins
Applied Physics Laboratory

Local Chairpersons:

Kyle Miller
Ball Aerospace & Technologies Corporation

Chris Randall
Ball Aerospace & Technologies Corporation

The following paper was not available for publication:

AAS 10-037
"Formation Flying System in the Proba-3 Mission," by J. Peyrard (GMV)
(Paper Withdrawn)

AAS 10-031

THE JOINT MILLI-ARCSECOND PATHFINDER SURVEY (JMAPS) INSTRUMENT FINE ATTITUDE DETERMINATION APPROACH

Tae W. Lim,* Frederick A. Tasker* and Paul G. DeLaHunt†

Joint Milli-Arcsecond Pathfinder Survey (JMAPS) is a spacecraft mission that will conduct astrometric and spectrophotometric survey of the full sky to support current and future star catalog needs. A step-stare observing method will be employed for the survey. While collecting science data, instrument itself will function as a star tracker providing an unprecedented 10 milli-arcsec attitude determination accuracy (1 sigma) at a 5 Hz rate. Instrument design to support this star tracker capability is presented including the description of guide star windows and their processing. Fine attitude determination algorithms are presented that are employed to update the attitude estimate using the guide star centroid data with respect to the reference attitude which was used to place the guide star windows on the focal plane. Thanks to small guide star window sizes, a small angle attitude determination assumption is valid and allows the development of an algorithm based on the homogeneous transformation method, which has been used widely to describe kinematics of robot manipulators. Its attitude determination performance in accuracy and computational efficiency is examined and described in comparison to well known, general purpose attitude determination algorithms such as TRIAD, q-method, and QUEST. [View Full Paper]

* Aerospace Engineer, † Section Head, Code 8231, Spacecraft Engineering Department, Naval Center for Space Technology, U.S. Naval Research Laboratory, 4555 Overlook Avenue, SW, Washington, D.C. 20375, U.S.A.

AAS 10-032

DEMONSTRATION OF AN AEROCAPTURE GN&C SYSTEM THROUGH HARDWARE-IN-THE-LOOP SIMULATIONS

James Masciarelli,[*] Jennifer Deppen,[†] Jeff Bladt,[‡] Jeff Fleck[**] and Dave Lawson[††]

Aerocapture is an orbit insertion maneuver in which a spacecraft flies through a planetary atmosphere one time using drag force to decelerate and effect a hyperbolic to elliptical orbit change. Aerocapture employs a feedback Guidance, Navigation, and Control (GN&C) system to deliver the spacecraft into a precise post-atmospheric orbit despite the uncertainties inherent in planetary atmosphere knowledge, entry targeting and aerodynamic predictions. Only small amounts of propellant are required for attitude control and orbit adjustments, thereby providing mass savings of hundreds to thousands of kilograms over conventional all-propulsive techniques. The Analytic Predictor Corrector (APC) guidance algorithm has been developed to steer the vehicle through the aerocapture maneuver using bank angle control.. Through funding provided by NASA's In-Space Propulsion Technology Program, the operation of an aerocapture GN&C system has been demonstrated in high-fidelity simulations that include real-time hardware in the loop, thus increasing the Technology Readiness Level (TRL) of aerocapture GN&C. First, a non-real-time (NRT), 6-DOF trajectory simulation was developed for the aerocapture trajectory. The simulation included vehicle dynamics, gravity model, atmosphere model, aerodynamics model, inertial measurement unit (IMU) model, attitude control thruster torque models, and GN&C algorithms (including the APC aerocapture guidance). The simulation used the vehicle and mission parameters from the ST-9 mission. A 2000 case Monte Carlo simulation was performed and results show an aerocapture success rate of >99.7%, >95% of total delta-V required for orbit insertion is provided by aerodynamic drag, and post-aerocapture orbit plane wedge angle error is <0.5 deg (3-sigma). Then a real-time (RT), 6-DOF simulation for the aerocapture trajectory was developed which demonstrated the guidance software executing on a flight-like computer, interfacing with a simulated IMU and simulated thrusters, with vehicle dynamics provided by an external simulator. Five cases from the NRT simulations were run in the RT simulation environment. The results compare well to those of the NRT simulation thus verifying the RT simulation configuration. The results of the above described simulations show the aerocapture maneuver using the APC algorithm can be accomplished reliably and the algorithm is now at TRL-6. Flight validation is the next step for aerocapture technology development. [View Full Paper]

---

* Principal Investigation, Ball Aerospace & Technologies Corp., 1600 Commerce St., Boulder, CO 80301, U.S.A.

† Systems/Project Engineer, Ball Aerospace & Technologies Corp., 1600 Commerce St., Boulder, CO 80301.

‡ ADCS Engineer, Ball Aerospace & Technologies Corp., 1600 Commerce St., Boulder, CO 80301.

** Flight Software Engineer, Ball Aerospace & Technologies Corp., 1600 Commerce St., Boulder, CO 80301.

†† Real Time Simulator Lead, Ball Aerospace & Technologies Corp., 1600 Commerce St., Boulder, CO 80301.

NIGERIASAT-2: ADVANCES IN GN&C THAT ENABLE A HIGH PERFORMANCE SMALL SATELLITE EARTH OBSERVATION MISSION

Andrew R. Carrel,[*] Andrew D. Cawthorne,[†]
Guy Richardson[‡] and Luis M. Gomes[**]

Surrey Satellite Technology has recently built the NigeriaSat-2 spacecraft. This is a state of the art small satellite Earth observation mission that will provide high resolution 2.5m imagery of the Earth. It will launch in 2010 into a low earth sun-synchronous orbit and will be used by the Nigerian government to monitor a number of environmental issues within the country. The key requirements of this mission are to provide highly accurate image targeting and geolocation coupled with agility sufficient to enable a wide range of complex operational modes. This paper focuses on the challenges associated with designing a spacecraft and GNC system that can support both of these things on a satellite that has a mass of less than 300kg.

How the stereo, mosaic and other imaging modes that can be employed using the agility of the spacecraft is described, along with the SSTL sensors and actuators used to create these capabilities. Inertia calibration and on-board navigation techniques used to give the required targeting accuracy are discussed. The interaction between the attitude control system and the mechanical design is detailed, in particular the payload isolation system used to ensure image quality and geolocation performance. [View Full Paper]

* Senior Engineer, Attitude and Orbit Control Systems, Surrey Satellite Technology Ltd., 20 Stephenson Rd, Guildford, Surrey GU2 7YE, United Kingdom.

† Earth Observation Business Line Engineer, Missions & Systems, Surrey Satellite Technology Ltd., Guildford, UK.

‡ Principle Engineer, Mechanical Department, Surrey Satellite Technology Ltd., Guildford, UK.

** Head of Earth Observation Business Line, Earth Observation & Science Business Unit, Surrey Satellite Technology Ltd., Guildford, UK.

STATIONKEEPING FOR AN OCCULTER-BASED EXOPLANETARY IMAGING MISSION

Dan Sirbu, Ephraim J. Chen, Matthew S. Isakowitz, Rachel L. Johnson, Daniel W. Maas and N. Jeremy Kasdin[*]

Space-based direct exoplanetary imaging using an external occulter requires formation flight of a spacecraft constellation. Here we are interested in the position control of a single occulter aligned with the telescope and target star. We consider the nonlinear relative motion spacecraft dynamics in the circularly restricted three-body model in the rotating Sun-Earth frame and generation of the unstable reference trajectory of the occulter in this corotating frame. We implement a linear quadratic regulator for position control of the occulter around a nominal trajectory, and implement an extended Kalman filter for state reconstruction of the occulter relative to the telescope using a least squares fit against the expected out-of-band leakage from the star based on the occulter shape. We provide simulation results of the integrated control and estimation scheme in the presence of solar radiation pressure. [View Full Paper]

* Department of Mechanical & Aerospace Engineering, Princeton University, Princeton, New Jersey 08540, U.S.A.

AAS 10-035

AUTOMATED REAL–TIME TARGETING AND GUIDANCE (ARTGUID) FOR LUNAR DESCENT AND PRECISION LANDING

Brent W. Barbee* **and David E. Gaylor†**

The guidance algorithms and software utilized during the Apollo missions for lunar descent and landing had fundamental limitations that precluded real–time guidance and autonomous Hazard Detection and Avoidance (HDA). This was partially due to the lack of closed form guidance solutions for the major portion of the descent braking phase. Emergent Space Technologies, Inc. has designed and developed prototype automated real–time targeting and guidance (ARTGUID) software for precision lunar landing and descent. Optimal control theory was successfully applied to produce closed form guidance solutions for the major portion of the descent braking phase. Improvements were also made to the quartic closed form solutions used (from Apollo) for the remainder of descent. Formulations for vehicle attitude were also developed and implemented, allowing the evolution of the vehicle attitude to be modeled and understood. The closed form constant thrust solutions and the improved quartics enabled real–time landing site re–targeting, which was demonstrated in simulation. This real–time re–targeting capability will be a key technology for autonomous Hazard Detection and Avoidance (HDA) during any future lunar landing mission. [View Full Paper]

* Aerospace Engineer, Emergent Space Technologies, Inc., 6301 Ivy Ln., Suite 720, Greenbelt, MD 20770, USA.

† Vice President, Emergent Space Technologies, Inc., 6301 Ivy Lane, Suite 720, Greenbelt, MD 20770, USA.

AAS 10-036

MODEL-BASED DESIGN AND IMPLEMENTATION OF POINTING AND TRACKING SYSTEMS: FROM MODEL TO CODE IN ONE STEP

Sungyung Lim,* Benjamin F. Lane,† Bradley A. Moran,‡ Timothy C. Henderson and Frank A. Geisel††**

The paper presents an integrated model-based design and implementation approach of pointing and tracking systems that can shorten the design cycle and reduce the development cost of GNC flight software. It provides detailed models of critical pointing and tracking system elements such as gyros, reaction wheels and telescopes, as well as essential pointing and tracking GNC algorithms. The paper describes the process of developing models and algorithms followed by direct conversion of the models into software for software-in-loop and hardware-in-loop tests. A representative pointing system is studied to provide valuable insights into the model-based GNC design.

[View Full Paper]

---

* Senior Member of the Technical Staff, Aerospace Guidance/Control Group, The Charles Stark Draper Laboratory, Inc., 555 Technology Square, Cambridge, Massachusetts 02138, U.S.A. E-mail: slim@draper.com.

† Senior Member of the Technical Staff, Sensors and Imaging Systems Group, The Charles Stark Draper Laboratory, Inc. E-mail: blane@draper.com.

‡ Senior Member of the Technical Staff, Mission Design, The Charles Stark Draper Laboratory, Inc. E-mail: bamoran@draper.com.

** Distinguished Member of the Technical Staff, Space Systems, The Charles Stark Draper Laboratory, Inc. E-mail: thenderson@draper.com.

†† Program Manager, Space Systems Program, The Charles Stark Draper Laboratory, Inc. E-mail: fgeisel@draper.com.

PREPARING THE GPS-EXPERIMENT FOR THE SMALL GEO MISSION

PETER ZENTGRAF,[*] Sten Berge,[†] Camille Chasset,[†] Hannes Filippi,[‡] Eveline Gottzein,[‡] Ignacio Gutiérrez-Cañas,[**] Mark Hartrampf,[‡] Peter A. Krauss,[‡] Christopher Kuehl,[‡] Bernhard Lübke-Ossenbeck,[**] Michael Mittnacht,[‡] Oliver Montenbruck,[††] Carsten Müller,[‡] Pablo Rueda Boldo,[‡‡] Attilio Truffi[‡‡]

This paper deals with the preparation of the Small GEO mission and the accommodation of a GPS receiver as an experiment. The expected benefits of using the GPS receiver for Small GEO are explained. The feasibility of using GPS for position determination is investigated by simulation using a MosaicGNSS receiver, which was stimulated by a Spirent RF signal generator. A procedure, how to evaluate flight data on ground is outlined. Success criteria of the experiment and the minimal size of the downlink stream required and reserved for the receiver TM are presented.
[View Full Paper]

* Formerly ESA/ESTEC; since 01.01.2010 University of Applied Sciences Rosenheim, Hochschulstraße 1, 83024 Rosenheim, Germany. E-mail: peter.zentgraf@fh-rosenheim.de.

† Swedish Space Corporation, P.O. Box 4207, SE-171 04 Solna, Sweden.

‡ Astrium GmbH, D-81663 Munich, Germany.

** OHB System, Universitätsallee 27-29, D-28539 Bremen, Germany.

†† German Space Operations Center, Germany.

‡‡ ESA/ ESTEC – Keplerlaan 1, 2201 AZ Noordwijk, The Netherlands.

AAS 10-039

ALIGNMENT CONTROL FOR AN EXTERNAL-OCCULTER TERRESTRIAL PLANET FINDER MISSION

Charley Noecker*

Terrestrial Planet Finder is NASA's family of mission concepts for detecting planets orbiting nearby stars (exoplanets) and characterizing them spectrally. One candidate mission concept uses an external occulter to block the blinding glare of each star and reveal any faint exoplanets in the neighborhood. The occulter must be 50-60 meters in diameter, positioned some 30-80,000 km away, and aligned to block the star with less than 1 meter lateral accuracy. A few sensors have been considered for this purpose, one of which is considered the primary sensor for a "probe-class" mission, and another which is applicable to a "flagship-class" mission. I present preliminary results from a control system model using both sensor types. The first sensor, with much higher noise, almost meets requirements. The second shows easily sufficient control performance.
[View Full Paper]

* Staff consultant, Ball Aerospace & Technologies Corp, M/S RA4, 1600 Commerce Street, Boulder, Colorado 80301, U.S.A.

AAS 10-040

SPACECRAFT PRECISION LANDING SYSTEM FOR LOW GRAVITY BODIES

James Kaidy,[*] Timothy McGee,[*] Thomas Criss,[†] Gene Heyler,[*] Wen-Jong Shyong[*] and Jose Guzman[‡]

A design concept is proposed here for a precision landing system that enables a spacecraft to soft-land and depart from the surface of a low gravity body such as an asteroid or a comet. Spacecraft attitude and body rate control functions are based on heritage planetary designs. New functions have been developed to address the unique challenges of translation guidance, navigation and control while in proximity to the low gravity asteroid body including trajectory guidance algorithms for the multiple mission phases, optical terrain relative navigation and thruster selection for multi-axis control. Successful landing is demonstrated with high fidelity six degree-of-freedom simulation. [View Full Paper]

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

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

‡ Former member of the Senior Technical Staff at APL

ADVANCES IN GN&C
PART 2 – HARDWARE

SESSION IV

National Chairperson: Stephen P. Airey
European Space Agency

Local Chairpersons: Kyle Miller
Ball Aerospace & Technologies Corporation

Chris Randall
Ball Aerospace & Technologies Corporation

The following paper was not available for publication:

AAS 10-048
“Sensors for 1001 Nights,” by J. Leijtens (TNO Science and Industry)
(Paper Withdrawn)

The following paper numbers were not assigned:

AAS 10-049 to -50

THE JOINT MILLI-ARCSECOND PATHFINDER SURVEY (JMAPS): MEASUREMENT ACCURACY OF THE PRIMARY INSTRUMENT WHEN USED AS FINE GUIDANCE SENSOR

Bryan N. Dorland,[*] Rachel P. Dudik,[†] Daniel Veillette,[†] Greg S. Hennessy,[†] Zachary Dugan,[†] Robert Hindsley,[‡] Benjamin F. Lane,[**] and Bradley A. Moran[††]

We describe the Joint Milli-Arcsecond Pathfinder Survey (JMAPS) mission, a bright-star astrometric survey mission with a launch date of 2013. We provide an overview of the mission and the primary instrument. We discuss use of the instrument as the fine guidance sensor, and show that given the current design, we can achieve the required on-board stellar position measurement accuracies needed to meet the extremely challenging attitude knowledge requirements for the mission. [View Full Paper]

* Chief, Astrometric Satellite Division, Astrometry Department, U.S. Naval Observatory, 3450 Massachusetts Avenue NW, Washington D.C. 20392, U.S.A.

† Astronomer, Astrometric Satellite Division, Astrometry Department, U.S. Naval Observatory, 3450 Massachusetts Avenue NW, Washington D.C. 20392, U.S.A.

‡ Astronomer, Remote Sensing Division, Naval Research Laboratory, 4555 Overlook Avenue SW, Washington D.C. 20375, U.S.A.

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

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

AAS 10-042

SOLAR PROBE PLUS: IMPACT OF LIGHT SCATTERING BY SOLAR SYSTEM DUST ON STAR TRACKER PERFORMANCE

Thomas Strikwerda,* Shadrian Strong† and Gabe Rogers‡

NASA's upcoming Solar Probe Plus mission will be the first to approach the Sun as close as 8.5 solar radii from the surface and provide in-situ observations of the Sun's corona. In the absence of observational data (e.g., Helios, Pioneer), for distances less than 0.3 AU, the ambient dust distribution close to the Sun remains poorly known and limited to model extrapolation for distances < 1 AU. For the Solar Probe Plus (SPP) mission it is critical to characterize the inner solar system dust environment to evaluate potential impacts on spacecraft health and, in particular, the attitude system. We have implemented a dust distribution model, along with Mie scattering effects, to estimate the magnitude of solar irradiance scattered towards an optical sensor, specifically a star tracker, as a function of ecliptic latitude and longitude for distances 0.05 to 1 AU. Background irradiance data from NASA's MESSENGER mission (down to 0.3 AU solar distance) reveal trends consistent with our model predictions, potentially validating the dust theory. This paper presents the scattering model, the irradiance distribution over the sky, and analysis of MESSENGER data gathered to date during the mission cruise phase. Implication for the SPP star tracker background irradiance, effects on star magnitude sensitivity and position accuracy, and operation are also discussed.
[View Full Paper]

* Space Engineering Branch, Johns Hopkins Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, Maryland 20723, U.S.A.

† Defense Analyses and Applications Group, Johns Hopkins Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, Maryland 20723, U.S.A.

‡ Mission Design, Guidance and Control Group, Johns Hopkins Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, Maryland 20723, U.S.A.

AAS 10-043

SHIFTING THE INERTIAL NAVIGATION PARADIGM WITH MEMS TECHNOLOGY

Timothy P. Crain II,[*] Robert H. Bishop[†] and Tye Brady[‡]

”Why don’t you use MEMS?” is of the most common questions posed to navigation systems engineers designing inertial navigation solutions in the modern era. The question stems from a general understanding that great strides have been made in terrestrial MEMS accelerometers and attitude rate sensors in terms of accuracy, mass, and power. Yet, when compared on a unit-to-unit basis, MEMS devices do not provide comparable performance (accuracy) to navigation grade sensors in several key metrics. This paper will propose a paradigm shift where the comparison in performance is between multiple MEMS devices and a single navigation grade sensor. The concept is that systematically, a sufficient number of MEMS sensors may mathematically provide comparable performance to a single navigation grade device and be competitive in terms power and mass allocations when viewed on a systems level. The implication is that both inertial navigation system design and fault detection, identification, and recovery could benefit from a system of MEMS devices in the same way that swarm sensing has benefited Earth observation and astronomy. A survey of the state of the art in inertial sensor accuracy scaled by mass and power will be provided to show the scaled error in MEMS and navigation graded devices, a mathematical comparison of multi-unit to single-unit sensor errors will be developed, and preliminary application to an Orion lunar skip atmospheric entry trajectory will be explored. [View Full Paper]

---

* Aerospace Engineer, NASA Johnson Space Center, Houston, TX 77058, U.S.A. Member AAS, Member AIAA.

† Professor, Aerospace Engineering Department, The University of Texas at Austin, Texas 78759-5321, U.S.A. Member AAS, Associate Fellow AIAA.

‡ Principal Member of Technical Staff, The Charles Stark Draper Laboratory, Cambridge, Massachusetts 02139, U.S.A. Member AAS, Member AIAA.

KEPLER FINE GUIDANCE SENSOR OPERATION

Dustin S. Putnam[*] and Charles N. Schira[*]

The Kepler spacecraft, carrying the largest telescope ever launched beyond Earth orbit, is in a heliocentric, Earth-trailing, drift-away orbit. It is a 3-axis stabilized, inertially-fixed pointer, and uses differential photometry (the transit method) to detect approximately Earth-sized planets in the habitable zone of their stars. Kepler uses a Fine Guidance Sensor to provide high accuracy relative attitude measurements during science data collection. This paper presents an overview of the Fine Guidance Sensor, its operation, measurement processing, and its observed on-orbit performance.

[View Full Paper]

* Ball Aerospace & Technologies Corporation, 1600 Commerce Street, Boulder, Colorado 80301, U.S.A.

ACTIVE PIXEL SENSOR TECHNOLOGY SUCCESSFULLY SPACE QUALIFIED FOR THE AUTONOMOUS STAR TRACKER ASTRO APS

U. Schmidt,* U. Meck,* K. Michel* and S. P. Airey†

The paper presents the achieved test results of the qualification of ASTRO APS star tracker which showed excellent performance in terms of robustness of operation under worst case environments and also in terms of measurement accuracy while simultaneously demanding low power and mass budgets. The qualification tests impressively confirmed the effectiveness of the implemented smart software algorithms which have been developed with the aid of the ESA contract “Robust Algorithms for Star Trackers”. Some highlights of the test campaign discussed in the paper show the ability for “lost in space” attitude acquisition without apriori information at high angular rates, the very low remaining low spatial frequency error due to the self-calibration capability and the operation under high temperature environments without the need for powering the thermal electrical cooler thanks to the smart autonomous background noise corrections. In early 2009 the qualification program was successfully completed. As a result the ASTRO APS star tracker has been selected by ESA and international industrial primes for a series of satellites in geostationary and low Earth orbit missions, among them AlphaSat, SmallGeo, Sentinel-2 and EarthCARE. [View Full Paper]

* Jena-Optronik GmbH, Prüssingstr. 41, 07745 Jena, Germany.

† ESTEC, Keplerlaan 1, 2200 AG Noordwijk ZH, The Netherlands.

AAS 10-046

ON-GROUND AND IN FLIGHT QUALIFICATION OF THE ALPHABUS PLATFORM APS BASED STAR TRACKER

R. Bettarini,* F. Boldrini,* D. Procopio,* S. D'Halewyn† and D. Temperanza‡

SELEX Galileo started in early 2002 activities aimed to develop a novel Star Tracker based on an APS (CMOS) imaging detector, being convinced that the use of this technology allows for lower cost and reduced mass/size, when compared to CCD based star tracker versions, combined with a significant burst in tolerance to harsh radiation environment.
First activities, done within an ESA contract to secure the technology for the Bepi Colombo ESA mission to the planet Mercury, lead to a Demonstration Model (DM) that showed the feasibility of a compact, light and simple star tracker based on APS detector.
A Flight Configuration Model (FCM) of this Bepi Colombo star tracker, already based on the state-of-the-art HAS APS detector, was delivered in late 2006 for integration on the PROBA-2 spacecraft and is currently flying as an experiment on-board this ESA mission dedicated to the in-flight demonstration of innovative technologies.

In July 2008 the SELEX Galileo "AA-STR" APS based star tracker achieved TRL-8. The AA-STR, dedicated to the ALPHABUS platform Product line for GEO Satellite Telecommunication (TLC) applications, and its HAS APS detector by that time completed a full on-ground qualification/evaluation program, thus demonstrating the ability to achieve their design goals both in terms of performance and survivability.
The AA-STR sensor product, although initially developed for a GEO Telecommunication spacecraft, demonstrated a large flexibility and, even if it was presented on the market quite recently, already found applications in Scientific (Bepi Colombo - ESA, Astro-G - JAXA), Earth Observation (PRISMA) and Commercial programs.

The recent launch of Proba-2 allowed the AA-STR to finally reach TRL-9, since the ALPHABUS AA-STR is mainly an "Hi-Rel configuration" of the sensor flying on board PROBA-2. In fact the first post-processed Telemetries from the sensor on board Proba-2 are confirming in-flight the results already obtained within the on-ground qualification.
In this paper is reported an overall description of the AA-STR, together with the main results obtained from its on-ground and in-flight qualification campaign.
[View Full Paper]

* SELEX Galileo – Space Line of Business - Italy.

† Thales Alenia Space – France.

‡ European Space Agency – The Netherlands.

AAS 10-047

MULTIPLE HEADS MANAGEMENT AND VALIDATION IN HYDRA STAR TRACKER

Benoit Gelin,* Chantal Chalté,* Laurent Majewski,* Ludovic Blarre,* Pierre-Emmanuel Martinez† and Stéphane Dussy‡

This paper presents the Multiple Heads algorithms developed for HYDRA SODERN APS based Star Sensor and the validation approach. The Multiple Heads algorithms were chosen in order to manage the multiple fields of view of the sensor as if it was a single wide field of view sensor. The main goal was the optimization of the Optical Heads availability and robustness with respect to classical star sensors and the autonomous management of the Optical Heads relative orientation.

The availability of each Optical Head is checked at each cycle, with respect to stray light, data link and thermal control. If one or two heads happened to be unavailable, the tracking mode is maintained on the Star Sensor but data from the unavailable head(s) are not included in attitude determination. However, for a short perturbation duration and low angular acceleration, the unavailable head(s) attitude is still propagated so that the heads resume in tracking mode as soon as the perturbation is over. This principle allows resuming the full performance in a very short time.

Thanks to these features, the Multiple Heads algorithm allows:

- Full accuracy on all axes;
- Autonomous Fault Detection, Identification and Recovery after loss of one or several Optical Heads;
- Immunity from Sun, Earth and Moon blinding allowing large simplifications in the on-board s/w and ground operations;
- Autonomous adaptation to low frequency thermo-elastic deformation of the s/c structure.

The Multiple Heads System is the best response to meet the requirements of highly autonomous and agile spacecraft. [View Full Paper]

* EADS-SODERN, 20 avenue Descartes, 94451 Limeil brévannes, France. E-mail: benoit.gelin@sodern.fr.

† CNES, 18 av Edouard Belin 31401, Toulouse Cedex 4, France. E-mail: pierre-emmanuel.martinez@cnes.fr.

‡ ESA-ESTEC, Keplerlaan 1, Postbus 299, 2200 AG Noorwijk, The Netherlands. E-mail: Stephane.Dussy@esa.int.

PRECISE ORBITAL DETERMINATION

SESSION V

Orbit determination is accomplished with a wide variety of methods, varying from ground ranging, to GPS measurements, to DSN observations and landmark navigation around other planetary bodies. Similarly, the methods for control vary widely, ranging from systems that perform maneuvers which are entirely planned on the ground and uploaded to the vehicle to missions that require time critical, real time onboard estimation and maneuver planning to meet mission objectives. This session is intended to discuss the challenges associated with precision orbit determination and control for space vehicles, ranging from Earth orbiting missions that require precise orbit knowledge to Constellation programs and deep space missions that have real time orbit determination and control requirements.

National Chairpersons:	Tim Crain NASA Johnson Space Center
	Bruce Haines Jet Propulsion Laboratory
Local Chairpersons:	Dave Chart Lockheed Martin Space Systems Company
	Ian Gravseth Ball Aerospace & Technologies Corporation

The following paper was not available for publication:

AAS 10-051

“Evaluation of Linked, Autonomous, Interplanetary Satellite Orbit Navigation (LiAISON) in Sun-Earth Lagrange Regime using Herschel and Plank Ephemeris Data,” by B. Cheetham, E. Villalba, K. Davis and G. Born, University of Colorado at Boulder (Paper Withdrawn)

The following paper numbers were not assigned:

AAS 10-058 to -060

AAS 10-052

CRATER IDENTIFICATION ALGORITHM FOR THE LOST IN LOW LUNAR ORBIT SCENARIO

Chad Hanak,* Tim Crain† and Dr. Robert Bishop‡

Recent emphasis by NASA on returning astronauts to the Moon has placed attention on the subject of lunar surface feature tracking. Although many algorithms have been proposed for lunar surface feature tracking navigation, much less attention has been paid to the issue of navigational state initialization from lunar craters in a lost in low lunar orbit (LLO) scenario. That is, a scenario in which lunar surface feature tracking must begin, but current navigation state knowledge is either unavailable or too poor to initiate a tracking algorithm. The situation is analogous to the lost in space scenario for star trackers. A new crater identification algorithm is developed herein that allows for navigation state initialization from as few as one image of the lunar surface with no a priori state knowledge. The algorithm takes as inputs the locations and diameters of craters that have been detected in an image, and uses the information to match the craters to entries in the USGS lunar crater catalog via non-dimensional crater triangle parameters. Due to the large number of uncataloged craters that exist on the lunar surface, a probability-based check was developed to reject false identifications. The algorithm was tested on craters detected in four revolutions of Apollo 16 LLO images, and shown to perform well. [View Full Paper]

* Dr. Hanak is associated with the GN&C Autonomous Flight Systems Branch (EG6), Aeroscience and Flight Mechanics Division, NASA Johnson Space Center, 2101 NASA Parkway, Houston, Texas 77058, U.S.A. E-mail: chad.hanak-1@nasa.gov.

† Dr. Crain is associated with the GN&C Autonomous Flight Systems Branch (EG6), Aeroscience and Flight Mechanics Division, NASA Johnson Space Center, 2101 NASA Parkway, Houston, Texas 77058, U.S.A.

‡ Dr. Bishop is associated with the Department of Aerospace Engineering and Engineering Mechanics, Cockrell School of Engineering, The University of Texas at Austin, 210 E. 24th St., WRW 318B, 1 University Station, C0600, Austin, Texas 78712, U.S.A.

AAS 10-053

FORMATION FLYING FOR PLANET SEARCHES WITH AN EXTERNAL OCCULTER

Roger Linfield and Sarah Lipscy*

In the external occulter technique for detection of planets around other stars, a starshade blocks out most of the light from the star. A telescope on a separate (and tens of thousands of km distant) spacecraft can then search for planets. Formation flying for such a system is challenging. The occulter spacecraft (with the starshade) moves ~15,000 km when the target star changes, but must be maintained to <1 m in the two shear dimensions during observations. We present a multi-stage concept for formation flying with an external occulter. [View Full Paper]

* Ball Aerospace & Technologies Corporation, 1600 Commerce Street, Boulder, Colorado 80301, U.S.A.

VALIDATION OF IAU2000A/IAU2006 FRAME TRANSFORMATION IMPLEMENTATIONS*

Lee Barker,† Art Dorsey‡ and Nick Stamatakos**

Celestial to terrestrial frame transformation is a topic thoroughly covered in basic astrodynamics and used extensively in spacecraft navigation and reference problems. The transformation is typically modeled with equations for precession, nutation, Earth rotation, and polar motion (which is often ignored). For many analyses and trades, simplifications are often sufficient.

For systems requiring precision reference or performance analysis, accuracy of the transforms, and often consistency, is held to a higher standard. The International Astronomical Union (IAU) resolutions and associated International Earth Rotation Service (IERS) conventions provide both an adopted set of standards and code, and the basis for precise very long baseline interferometry (VLBI) measurements used by models in the convention standard transformations.

The IAU2000A and IAU2006 resolution standards for transformations that relate the Geocentric Celestial Reference System (GCRS) to the International Terrestrial Reference Frame (ITRF) update standards based on the IAU1976/IAU1980 precession-nutation. Fully and properly implemented, these new standards provide the means to obtain the GCRS to a specified consistency. Improvements in both measurement observation techniques and theory, as well as the dependency of precise measurement observations on the newly adopted theory, motivate users to migrate to the newer standards.

For systems migrating from earlier theory to IAU2000A or IAU2006, challenges include 1) sorting through the numerous methodologies presented in literature and achieving proper implementation, and 2) validation of the selected implementation. The current literature has not always been consistent and can cause confusion.

This paper will briefly summarize the progression of the contemporary frame transformations standards, discuss and reference the current state of literature that defines the standards, illustrate the variety of methods available to choose from, discuss potential implementation traps found in the literature, and discuss implementation validation options available to developers. [View Full Paper]

---

† Lockheed Martin Space Systems Company, Sunnyvale, California 94089, U.S.A.

‡ Lockheed Martin Integrated Systems and Global Solutions.

** U.S. Naval Observatory.

AAS 10-055

ORION OPTICAL NAVIGATION FOR LOSS OF COMMUNICATION LUNAR RETURN CONTINGENCIES

Joel Getchius[*] and Chad Hanak[†]

The Orion Crew Exploration Vehicle (CEV) will replace the Space Shuttle and serve as the next-generation spaceship to carry humans back to the Moon for the first time since the Apollo program. For nominal lunar mission operations, the Mission Control Navigation team will utilize radiometric measurements to determine the position and velocity of Orion and uplink state information to support Lunar return. However, in the loss of communications contingency return scenario, Orion must safely return the crew to the Earth's surface. The navigation design solution for this loss of communications scenario is optical navigation consisting of lunar landmark tracking in low lunar orbit and star- horizon angular measurements coupled with apparent planetary diameter for Earth return trajectories. This paper describes the optical measurement errors and the navigation filter that will process those measurements to support navigation for safe crew return. [View Full Paper]

* Jacobs Engineering, Houston, Texas 77058, U.S.A.

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

AAS 10-056

NEAR REAL TIME GPS ORBIT DETERMINATION: STRATEGIES, PERFORMANCE, AND APPLICATIONS TO OSTM/JASON-2

Jan P. Weiss, Willy Bertiger, Shailen D. Desai, Bruce J. Haines and Christopher M. Lane*

We present strategies and results for near real-time (NRT) precise orbit determination (POD) of the Global Positioning System (GPS) constellation. The POD for the GPS constellation is performed using a global network of 40 ground stations. The resulting products are available with a latency of about one hour, and include orbit and clock estimates for the GPS satellites, as well as widelane phase bias information from the global solution. The widelane information, when used with the orbit and clock estimates, enables singlereceiver, ambiguity resolved GPS-based positioning. Comparisons to definitive final products from the Jet Propulsion Laboratory and International GNSS Service show that NRT orbit accuracies of 5 cm RMS (3D) and clock accuracies of 5 cm RMS are achieved. Daily point positioning of a variety of static ground station receivers using these products yields repeatabilities of 1 cm. An additional NRT process, in turn, utilizes the GPS orbit, clock, and widelane products to perform POD for the Ocean Surface Topography Mission (OSTM)/Jason-2 satellite, which carries an advanced dual-frequency "Blackjack" GPS receiver. The radial accuracy of the resulting OSTM/Jason-2 orbits is typically 1 cm (RMS) with a latency of 2 hours. These new orbit solutions provide the basis for computing accurate sea-surface height information for operational oceanographic and low-latency scientific applications of satellite altimeter data. [View Full Paper]

* The authors are associated with the Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, M/S 238-600, Pasadena, California 91109, U.S.A.

A VISION-BASED NAVIGATION ALGORITHM FOR PIN-POINT LANDING

Vincent Simard Bilodeau,[*] Sébastien Clerc,[†] Jean de Lafontaine,[‡] Rémi Drai[**] and David Neveu[††]

This paper addresses the development of a navigation algorithm for precision landing. Inertial-only navigation is unable to reach the 100 m precision required for some lunar exploration missions and needs to be augmented by vision-based navigation. Firstly, the overall mission hypotheses and the spacecraft characteristics are presented. Secondly, the proposed navigation system is detailed. This algorithm is based on an Extended Kalman Filter (EKF) using the measurements from an Inertial Measurement Unit (IMU), camera images and a database of geo-referenced features. It combines two techniques: the Terrain-Relative Relative Navigation (TRRN) that tracks features between successive images to estimate the motion of the camera pose (velocity) and the Terrain-Relative Absolute Navigation (TRAN) that estimates the camera pose relative to the surface by detecting and matching the features of a given image in the geo-referenced database. A comprehensive literature survey of image processing for the detection, identification and tracking of visual features is presented as well as their pros and cons for the present mission. The complete proposed estimator algorithm is derived and a new TRRN formulation based on the epipolar constraint between image pairs is introduced. Finally, numerical results show the benefit of using both TRAN/TRRN and the advantages of the proposed TRRN approach with respect to existing algorithms.
[View Full Paper]

* Ph.D. Candidate, Department of Electrical and Computer Engineering, Université de Sherbrooke, 2500 Boul. De l'Université, J1K 2R1, Sherbrooke, Canada. E-mail: vincent.simard.bilodeau@{ngcaerospace.com, usherbrooke.ca}. Phone: (819) 348-9430, ext.: 225.

† Ph.D., GNC Engineer, Business Line Optical Observation and Science, Thales Alenia Space, 100 Boul. du Midi, 06156, Cannes la Bocca, France.

‡ Professor, Department of Electrical and Computer Engineering, Université de Sherbrooke, 2500 Boul. De l'Université, J1K 2R1, Sherbrooke, Canada. President, NGC Aerospace Ltd., 1650 rue King Ouest, Office 202, J1J 2C3, Sherbrooke, Canada.

** Ph.D., GNC Analyst, European Space Agency ESTEC, Keplerplaan 1, Noordwijk, The Netherlands.

†† MA.Sc, GNC Engineer, NGC Aerospace Ltd., 1650 rue King Ouest, Office 202, J1J 2C3, Sherbrooke, Canada.

ROBOTIC LUNAR EXPLORATION

SESSION VI

Robotic exploration of the moon has experienced a resurgence in the past few years. From recent international missions to the Google Lunar X Prize competition – teams from a wide variety of backgrounds are designing new ways to deal with the GN&C challenges of lunar exploration. This session will focus on GN&C solutions, performance, mission design, and lessons learned from both recent and upcoming missions to the moon.

National Chairperson: Stephen P. Airey
European Space Agency

Local Chairpersons: Mary Klaus
Lockheed Martin
Space Systems Company

Zach Wilson
Lockheed Martin
Space Systems Company

The following paper was not available for publication:

AAS 10-063
"Challenges of Control and Guidance of Chandrayaan-1," by T. K. Alex, ISRO (Paper Withdrawn)

The following paper numbers were not assigned:

AAS 10-066 to -070

TAKING THE NEXT GIANT LEAP*

Babak E. Cohanim,
Phillip Cunio, Jeffrey Hoffman, Michael Joyce,
Todd Mosher and Seamus Tuohy†

As part of the Google Lunar X-Prize, the Next Giant Leap team is developing a lander/hopper architecture that will demonstrate a new method of surface mobility for future planetary missions. Current government funded efforts to explore space are costly one of a kind missions. The Next Giant Leap team is creating an affordable architecture to win the Google Lunar X-Prize while developing a repeatable platform for future exploration and science missions.

This paper describes the GNC prototype being built at Draper and MIT to test out operational concepts and algorithms for planetary hopping. As part of the development and promotion of the Next Giant Leap team, a lunar robotic hopper testbed is being developed to mature hopper operations, algorithms, and experience. The test is designed to mimic the lunar environment by providing a 1/6th Earth-gravity mode. Additionally, this paper describes the current testbed and how it is being used to develop the Next Giant Leap vehicle. [View Full Paper]

† The authors are associated with The Charles Stark Draper Laboratory, Inc., Cambridge, Massachusetts 02139, U.S.A.

GUIDANCE, NAVIGATION AND CONTROL CHALLENGES FOR TEAM OMEGA ENVOY'S GLXP MISSION DESIGN

Tapan R. Kulkarni,[*] Jason Dunn,[†] Dillon Sances[‡] and Ruben D. Nunez[**]

Team Omega Envoy presents a number of fully numerically integrated trajectories from Earth-launch to a soft landing on the Moon. The trajectories are based on different approaches such as 5-day transfer to direct lunar landing, 5-day transfer to lunar parking orbit, and Earth to Earth-Moon L1 to lunar orbit transfer. All the trajectories have been simulated in STK/Astrogator module that has high-precision numerical integrator(s) using full force model. The authors also discuss the merits and drawbacks of each of above approaches and the effect of other parameters such as lighting conditions, landing site on the mission design, the approach taken, and the nature of results or conclusions that can be expected. [View Full Paper]

* GNC Lead, Earthrise Space Inc. AIAA Senior Member.

† Chief Engineer, Earthrise Space Inc. AIAA Member.

‡ Lunar Spacecraft Development Lead, Earthrise Space Inc. AIAA Student Member.

** Project Director, Earthrise Space Inc.

AAS 10-064

KAGUYA AOCS EVALUATION RESULTS ON LUNAR ORBIT

Shuichi Matsumoto,* Hironori Maejima,* Keita Ogo,† Yoshihiro Iwamoto,† Yosuke Iwayama,† Kazuhisa Tanaka,† Tatsuo Kawamura,† Shingo Ikegami,‡ Shinichiro Ichikawa‡ and Akira Sasaki‡

KAGUYA is Japan's first full-scale lunar explorer launched on September 14, 2007. KAGUYA had been obtaining valuable scientific data and images from the lunar circular orbit for 18 months, and finally KAGUYA conducted a deorbit maneuver and hit into the Moon on June 10, 2009. Through the 18 months AOCS operation of KAGUYA on lunar orbit, we had experienced interesting angular momentum accumulation, reaction wheel's anomalous behavior, deorbit operation on the verge of propellant depletion and etc. Thus this paper describes the interesting topics we had experience during the KAGUYA AOCS operation on lunar orbit: evaluation of wheel drag torque, evaluation of wheel unloading on lunar orbit, evaluation of attitude determination for lunar-centerpointing, and the de-orbit operation on the verge of propellant depletion. [View Full Paper]

* Japan Aerospace Exploration Agency, 2-1-1 Sengen, Tsukuba, Ibaraki, 305-8505, Japan.

† NEC TOSHIBA Space Systems, Ltd., 1-10 Nicchin-cho, Fuchu, Tokyo, 183-8551, Japan.

‡ NEC Corp., 1-10 Nicchin-cho, Fuchu, Tokyo, 183-8501, Japan.

NEXT LUNAR LANDER: DESCENT AND LANDING GNC ANALYSIS, DESIGN AND SIMULATIONS

D. Neveu,* J.-F. Hamel,† J. Christy,‡ J. de Lafontaine** and V.S. Bilodeau††

Initiated in 2001, the objective of the European Space Agency (ESA) Aurora Program is to contribute to the international effort on the exploration of the solar system, and to prepare the European long-term participation in the first human mission to Mars. With the ExoMars mission due for launch in 2013, and with the Mars Sample Return (MSR) mission foreseen in the 2020 timeframe, ESA is considering the opportunity, between these two events, for two intermediate missions, so called NEXT (Next Exploration Science and Technology). The NEXT missions – one to Mars and the other one to the Moon – would enhance and complement the capabilities acquired through ExoMars while preparing Europe for the MSR mission and future exploration missions in general. The technological goal of the NEXT Lunar Lander mission is to demonstrate high precision landing with autonomous hazard detection and avoidance (HDA). Mobility would be provided with a rover as a baseline. At the same time, such a mission offers the opportunity to perform scientific measurements on a region of the Moon that has never been explored before, namely the South Pole. The NEXT Lunar Lander Phase A study led to the analysis of the Descent & Landing (D&L) options, to the conceptual design of a Lander module with the relevant sensors and propulsion architecture, and to the development of a representative simulator from the lunar orbit to the ground. This paper reports the results of this study. [View Full Paper]

* GNC Engineer, NGC Aerospace, 1650 rue King Ouest, Office 202, Sherbrooke, Québec, Canada. E-mail: david.neveu@ngcaerospace.com.

† GNC Engineer, NGC Aerospace, 1650 rue King Ouest, Office 202, Sherbrooke, Québec, Canada.

‡ GNC Engineer, Thales Alenia Space, 100 Boul. du Midi, BP 99, 06156 Cannes La Bocca Cedex, France.

** President, NGC Aerospace, 1650 rue King Ouest, Office 202, Sherbrooke, Québec, Canada.

†† Ph.D. Candidate, Department of Electrical and Computer Engineering, Université de Sherbrooke, 2500 Boul. De l'Université, J1K 2R1, Sherbrooke, Canada.

ALTIMETRY

SESSION VII

Satellite-based-altimetry is one of the key methods of global and local environmental monitoring such as ocean topography (hence currents), lakes/river elevations and land ice thickness. This session will highlight demands placed on GN&C systems to support these unique missions, including precision orbit determination, timing, and pointing controls.

National Chairpersons:

Greg Jacobs
Naval Research Laboratory

Nicolas Picot
Centre National
d'Etudes Spatiales

Local Chairpersons:

Bill Emery
University of Colorado

Bill Frazier
Ball Aerospace & Technologies
Corporation

The following papers were not available for publication:

AAS 10-075
"ICESat Precision Orbit Determination," by H.-J. Rim and S. Yoon, University of Texas (Paper Withdrawn)

AAS 10-077
"CryoSat-2, An Unusual Way to Specify a Mission," by R. Francis, ESA/ESTEC (Paper Withdrawn)

The following paper numbers were not assigned:

AAS 10-078 to -080

AAS 10-071

COMMAND AND CONTROL REQUIREMENTS FOR MAPPING THE OCEAN MESOSCALE CIRCULATION IN SATELLITE RADAR ALTIMETRY

W. Emery,[*] Nicolas Picot[†] and Pierre Thibaut[‡]

Radar altimetry has greatly enhanced our ability to map the mesoscale geo- strophic circulation of the upper ocean and it has become common practice to merge altimeter data from a large number of presently operating satellite altimeters in spite of their differences in instrument characteristics, corrections available and orbital behavior. This assumes a level of orbital accuracy that permits the cm corrections in each sensor to be able to accurately map even the active circulations of the oceanic mesoscale. These orbit and repeat track requirements for measuring the ocean's mesoscale circulations and their time/ space variability will be addressed both in terms of presently operating altimeter systems and as sampling requirements for future altimeter missions. The accuracies of these measurements are tied to the accuracies of the altimeters themselves and this implication will also be addressed. Finally we will discuss the present state of altimeter observations and discuss the status of possible future satellite altimeter measurements of the oceanic mesoscale. [View Full Paper]

* Colorado Center for Astrodynamics Research, University of Colorado, Boulder, Colorado 80309, U.S.A.

† Centre National d'Études Spatiales(CNES), Toulouse, France.

‡ Collecte Localisation par Satellite (CLS), Toulouse, France.

AAS 10-072

MODERN RADAR ALTIMETRY CHALLENGES TO PRECISE ORBIT DETERMINATION

Frank G. Lemoine,[*] Luca Cerri,[†] Nikita P. Zelensky,[‡] John C. Ries[**] and William I. Bertiger[††]

From the launch of the first spaceborne altimeters, Precision Orbit Determination (POD) has been driven by the science goals of the geodetic altimeter missions. The accurate knowledge of the spacecraft ephemeris in an accurate conventional reference frame is essential to the successful science derived from radar altimetry, particularly for global ocean circulation and Mean Sea Level (MSL) studies. It was with the launch of TOPEX/Poseidon (TP) in 1992 and the breakthrough in POD which ushered in the age of modern satellite altimetry. Although radial accuracies of 1.5 cm for TP, and 1-cm for the follow-on missions Jason-1 and Jason-2, have been currently achieved, growing interest in using altimeter data to recover small ocean signals, such as the mean sea level trends, places increasingly stringent requirements on orbit accuracy and the reference frame definition. With Jason-1 and Jason-2, there is now an increasing need for delivery of short latency precise orbit products to support the needs of operational oceanography. Meeting mission POD accuracy requirements has depended on advances in satellite force modeling, tracking technology, measurement modeling, measurement processing and improvements in the terrestrial reference frame. This paper presents advances in modeling and tracking technology which have been vital to achieving the current orbit accuracies for TP, Jason-1, and Jason-2, illustrating the reduction of orbit error due to improvements in modeling static gravity, tides, time varying gravity, and the terrestrial reference frame. The current challenges to POD, the impact on altimetry, and prospects for future improvements are discussed. We review the orbit products, their current accuracies and latencies that are now routinely delivered for Jason-1 and Jason-2.
[View Full Paper]

* Research Scientist, Planetary Geodynamics Laboratory, Code 698, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, U.S.A. Member.

† Engineer, Centre National d'Etudes Spatiales (CNES), Toulouse, France.

‡ Chief Scientist, SGT-Inc., 7701 Greenbelt Road, Greenbelt, Maryland 20770, U.S.A.

** Senior Research Scientist, University of Texas Center for Space Research, Austin, Texas 78712, U.S.A.

†† Scientist, Jet Propulsion Laboratory (JPL), Pasadena, California 91109, U.S.A.

AAS 10-073

GPS-BASED PRECISE ORBIT DETERMINATION IN NEAR REAL TIME FOR OPERATIONAL ALTIMETRY

Shailen D. Desai, Willy Bertiger, Angela Dorsey, Bruce J. Haines, Christopher Lane and Jan P. Weiss*

We describe a near-real-time (NRT) precise orbit determination (POD) system for the Ocean Surface Topography Mission/Jason-2 satellite altimeter mission that processes tracking data from the onboard "BlackJack" Global Positioning System (GPS) receiver. The NRT POD system is now operational, and the resulting orbit solutions are being used to generate a value-added NRT sea surface height product for operational altimetry applications. The NRT GPS-based orbit solution features radial orbit accuracies of 1 cm (RMS) with a latency of < 4 hours. These orbit accuracies are achieved through the use of Ultra-Rapid solutions for the orbits and clocks of the GPS constellation of satellites. We use satellite laser ranging tracking data and sea surface height crossover residuals as external metrics for evaluating orbit accuracy. We also provide comparisons to other orbit solutions of varying latencies to illustrate the trade between accuracy and timeliness. [View Full Paper]

* All the authors are at Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, M/S 238-600, Pasadena, California 91109, U.S.A.

AAS 10-074

A NEW TRACKING MODE FOR ALTIMETERS USING A DIGITAL ELEVATION MODEL

Jean-Damien Desjonquères,* Nathalie Steunow† and Nicolas Picot†

The Jason2 (OSTM) altimetry mission was launched on June 20th, 2008. The main objective of the mission is to provide an accurate altimeter service in the continuity of the Topex/Poseidon and Jason1 missions. The main mission requirements address the ocean observation. The Jason2 mission has been designed to insure the observation of various oceanic signals as the intra-seasonal and intra-annual changes, dynamic topography, tides, mesoscale variability (a few cm signal with typical scales of 30 days / 30 km) and the mean sea level (a 2-3 mm per year signal must be measured). This information is of most importance to the scientific community, in the context of global climate change studies. The Jason2 mission differs from Jason1 on one additional goal, which is to provide measurements over coastal area and inland waters.

In order to provide higher data availability for altimetry missions, new modes have been designed in CNES. The Diode Acquisition Mode to speed up the acquisition duration and the coupling Diode/DEM which is more innovative and is based on the use of a Digital Elevation Model and the onboard navigator (Diode). Thanks to these new modes, POSEIDON-3 offers the capability to track non-oceanic echoes without reducing the performance over oceanic surfaces.

This paper will present the Diode/DEM mode. [View Full Paper]

* CNES Toulouse Space Center, 18, av. Edouard Belin, 31401 Toulouse Cedex, France.
E-mail: jean-damien.desjonqueres@cnes.fr.

† CNES Toulouse Space Center, 18, av. Edouard Belin, 31401 Toulouse Cedex, France.

AAS 10-076

LOW-LATENCY POD FOR OPERATIONAL ALTIMETRY

Bob E. Schutz,[*] Scott Mitchell[†] and William Frazier[†]

Modern applications with satellite-borne altimeters, which include operational altimetry, place requirements on Precision Orbit Determination (POD) that include automation and near real-time or low latency (e.g., < 12 hours) in the generation of the POD products. The Ice, Cloud and land Elevation Satellite (ICESat) has achieved some POD automation in support of laser altimetry but the latency requirements are not near real-time. Nevertheless, ICESat data provides an opportunity to explore approaches for near real-time POD by adapting the ICESat methodologies to experiment with various options to reduce the POD product latency from a few days to less than 12 hours. For these experiments, it was assumed that the POD would be generated in a stand-alone ground environment using an ICESat-like on-board GPS receiver. Factors that influence the overall latency include the latency associated with the flight GPS receiver and the latencies associated with other data required for the generation of the POD product. Focus is given to a scenario which produces an ephemeris for the GPS receiver host satellite with < 5 cm radial accuracy and with a net latency of less than 7 hours, where the latency is primarily determined by delays in receipt of data from the flight GPS receiver. [View Full Paper]

* Professor/Associate Director, Center for Space Research, The University of Texas at Austin, R1000, Austin, Texas 78712, U.S.A.

† Staff Consultant, Ball Aerospace and Technologies Corporation., Boulder, Colorado 80301, 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:	Tom Darone The Aerospace Corporation
	Sam Thurman Jet Propulsion Laboratory
Local Chairpersons:	Jim Chapel Lockheed Martin Space Systems Company
	Kevin Benedict Ball Aerospace & Technologies Corporation

The following paper numbers were not assigned:

AAS 10-089 to -090

AAS 10-081

GOCE MISSION: DESIGN PHASES AND IN-FLIGHT EXPERIENCES

A. Allasio,[*] A. Anselmi,[*] G. Catastini,[*] S. Cesare,[*] M. Dumontel,[*] M. Saponara,[*] G. Sechi,[†] A. Tramutola,[*] B. Vinai,[*] G. André,[‡] M. Fehringer,[‡] and D. Muzi[‡]

The Gravity and steady state Ocean Circulation Explorer (GOCE) is the first Earth Explorer Core Mission of ESA's Living Planet Program. It was successfully launched on March 17, 2009 with the ROCKOT Launcher from Plesetsk Cosmodrome in Northern Russia.

The scientific objectives of GOCE are the determination of the Earth's steady state gravity field anomalies with an accuracy of $1x10^{-5}$ m/s^2, and the determination of geoid heights with accuracy between 1 to 2 cm, at length scales down to 100 km. To achieve the scientific objectives, GOCE flies in a Sun-synchronous orbit (96.7° inclination, ascending node at 18.00h) with altitude in the range 250÷280km (now the mean spherical altitude is 259.5km), and it carries out two measurements: gravity gradients by the Electrostatic Gravity Gradiometer, and Precise Orbit Determination based on GPS data. An essential element for meeting the mission requirements is the Drag Free and Attitude Control using an ion engine for compensating the along track non-gravitational forces and a set of magnetic torquers for attitude control. The nominal mission duration is 20 months.

By all standards, the GOCE DFAC is an innovative design. Among its distinctive features, GOCE is the first European drag-free mission, based on ultra-sensitive accelerometers, it flies at a very low altitude, and it has the first pure magnetic attitude control system for a medium-sized Low Earth Orbit scientific satellite. The mission induces requirements not only on the magnitude of the residual disturbances, but also their spectral density in the science measurement bandwidth of [5,100] mHz. To cope with such requirements, the payload measurements are fed to the control loop.

After presentation of the GOCE mission architecture, the satellite and the payload, the paper focuses on the DFAC design and verification with program experiences, and the in-flight DFAC performance compared with the expectations and requirements. [View Full Paper]

* Thales Alenia Space Italia, Strada Antica di Collegno, 253 - 10146 Torino, Italy.

† Corresponding author at Thales Alenia Space Italia, Strada Antica di Collegno, 253 - 10146 Torino, Italy. E-mail: gianfranco.sechi@thalesaleniaspace.com.

‡ ESA/ESTEC, Keplerlaan 1- 2200 AG Noordwijk, The Netherlands.

IN ORBIT EXPERIENCE – LEOP & COMMISIONING OF THE ATTITUDE AND ORBIT CONTROL OF PLANCK

**D. Zorita, A. Agenjo, S. Llorente,*
G. Chlewicki, A. Cocito,†
S. Thuerey, C. Watson, A. McDonald, M. Mueck, J. de Bruin‡**

After some 10 years of development, Planck was successfully launched on May 2009. The AOCS behaves perfectly. The SC is seen to keep its attitude within the safe domains properly, to perform the trajectory manoeuvres with high autonomy, and to point towards the targets with extreme accuracy. This paper presents commissioning of Planck AOCS, held along 3 months at the European Space Operations Center. It gives the findings and features encountered. [View Full Paper]

* SENER Ingeniería y Sistemas, Spain. Demetrio.Zorita@sener.es.

† Thales Alenia Space, Milano, Italy.

‡ European Space Agency. ESTEC and ESOC. The Netherlands and Germany.

LIFE IN L2: HERSCHEL EARLY IN-ORBIT EXPERIENCE

M. J. A. Oort,[*] M. Palomba,[†] D. Procopio,[‡] A. Bacchetta,[**] Y. Roche,[††] D. Dungate, M. Pigg , S. Hardacre,[‡‡] C. Seemann and M. Ochoa[***]

Herschel, one of ESA's Scientific Program major milestone missions, was launched on May 14, 2009 together with its sister spacecraft Planck by the Ariane 5 launcher. Destination: a Lissajous orbit around the Sun-Earth L2 point, where it arrived some two months later. Herschel is the successor to the highly successful ISO infrared mission, taking the accuracy requirements to an unprecedented level. We present the experiences with the in orbit operation of the Attitude Control and Measurement System (ACMS), which is performing well within specification. [View Full Paper]

* Dutch Space b.v, P.O. Box 32070, 2303 DB Leiden, The Netherlands.

† LSE Space at European Space Agency, P.O. Box 299, 2200 AG Noordwijk, The Netherlands.

‡ Selex Galileo, Via A. Einstein 35, 50013 Campi Bisenzio (Fl), Italy.

** Thales Alenia Space, Strada Antica di Collegno, 253, 10145 Turin, Italy.

†† Thales Alenia Space, BP99, 06156 Cannes la Bocca Cedex, France.

‡‡ Tessella, Tessella plc, Elopak House, Rutherford Close, Meadway Technology Park, Stevenage, Herts SG1 2EF, England. Note: Sean Hardacre is currently working for EADS Astrium Ltd, UK.

*** Northrop Grumman Guidance & Electronics Company, Inc., 21249 Burbank Boulevard, Woodland Hills, California 91367-6675, U.S.A.

AAS 10-084

DESIGN EXPERIENCES AND FLIGHT TEST RESULTS FROM NASA'S MAX LAUNCH ABORT SYSTEM (MLAS): A FLIGHT MECHANICS PERSPECTIVE

Cornelius (Neil) J. Dennehy,[*] Daniel E. Yuchnovicz,[†] Raymond J. (Jim) Lanzi,[‡] Philip R. Ward[‡] and Christopher M. Shreves[**]

At the request of the NASA's Exploration System Mission Directorate, the NASA Engineering and Safety Center (NESC) designed, developed and flew the alternative Max Launch Abort System (MLAS) as risk mitigation for the baseline Orion spacecraft LAS already in development. The NESC was tasked with both formulating a conceptual Objective System (OS) design of this alternative MLAS as well as demonstrating this concept with a simulated pad abort flight test. The goal was to obtain sufficient flight test data to assess performance, validate models/tools, and to reduce the design and development risks for a MLAS OS. Less than 2 years after Project start the MLAS simulated pad abort flight test was successfully conducted from Wallops Island on 8 July 2009. The entire flight test duration was 88 seconds during which multiple staging events were performed and nine separate critically timed parachute deployments occurred as scheduled. Overall the as-flown flight performance was as predicted prior to launch. This paper provides an overview of the distributed MLAS project organization, management practices and technical approaches employed on this rapid prototyping activity. This paper describes, from the combined perspectives of both the Flight Mechanics and Landing & Recovery System teams, the methodology used to design the MLAS flight test vehicle. The inter-related driving technical issues and challenges faced by both teams will also be described. Lessons that were learned during the MLAS rapid prototyping project are also summarized. [View Full Paper]

* NASA Technical Fellow for Guidance, Navigation & Control (GN&C), NASA Engineering and Safety Center (NESC), Mail Code 590, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, U.S.A.

† Systems Engineer, NESC, Mail Code 102, NASA Langley Research Center, 100 NASA Road, Hampton, Virginia 23681, U.S.A.

‡ Aerospace Engineer, NASA Wallops Flight Facility, Mail Code 598, 34200 Fulton, Wallops, Virginia 23337, U.S.A.

** Aerospace Engineer, NASA Wallops Flight Facility, Mail Code 548, 34200 Fulton, Wallops, Virginia 23337, U.S.A.

LAUNCH AND COMMISSIONING OF THE LUNAR RECONNAISSANCE ORBITER (LRO)

Neerav Shah,* Philip Calhoun,* Joseph Garrick,* Oscar Hsu* and James Simpson†

The Lunar Reconnaissance Orbiter (LRO) launched on June 18, 2009 from the Cape Canaveral Air Force Station. LRO, designed, built, and operated by the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center in Greenbelt, MD, is gathering crucial data on the lunar environment that will help astronauts prepare for long-duration lunar expeditions. To date, the Guidance, Navigation and Control (GN&C) subsystem has operated nominally and met all requirements. However, during the early phase of the mission, the GN&C Team encountered some anomalies. For example, during the Solar Array and High Gain Antenna deployments, one of the safing action points tripped, which was not expected. Also, the spacecraft transitioned to its safe hold mode, SunSafe, due to encountering an end of file for an ephemeris table. During the five-day lunar acquisition, one of the star trackers triggered the spacecraft to transition into a safe hold configuration, the cause of which was determined. These events offered invaluable insight to better understand the performance of the system they designed. An overview of the GN&C subsystem will be followed by a mission timeline. Then, interesting flight performance as well as anomalies encountered by the GN&C Team will be discussed in chronological order. [View Full Paper]

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

† Hubble Space Telescope Project Office, Code 440.8, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, U.S.A.

AAS 10-086

FLIGHT RESULTS FROM THE HST SM4 RELATIVE NAVIGATION SENSOR SYSTEM

Bo J. Naasz,[*] John Van Eepoel,[†] Steven Z. Queen,[†] C. Michael Southward II[‡] and Joel Hannah[**]

On May 11, 2009, Space Shuttle Atlantis roared off of Launch Pad 39A enroute to the Hubble Space Telescope (HST) to undertake its final servicing of HST, Servicing Mission 4. Onboard Atlantis was a small payload called the Relative Navigation Sensor experiment, which included three cameras of varying focal ranges, avionics to record images and estimate, in real time, the relative position and attitude (aka ”pose”) of the telescope during rendezvous and deploy. The avionics package, known as SpaceCube and developed at the Goddard Space Flight Center, performed image processing using field programmable gate arrays to accelerate this process, and in addition executed two different pose algorithms in parallel, the Goddard Natural Feature Image Recognition and the ULTOR Passive Pose and Position Engine (P3E) algorithms. [View Full Paper]

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

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

‡ Aerospace Engineer, Emergent Space Technologies, Inc., Greenbelt, Maryland 20770, U.S.A.

** Electrical/Software Engineering Manager, Advanced Optical Systems, Inc., Huntsville, Alabama 35806, U.S.A.

STRAIGHT ON ’TIL MORNING: GUIDANCE AND CONTROL FLIGHT EXPERIENCE FROM THE DAWN SPACECRAFT*

C. Anthony Vanelli, Brett Smith, Edward Swenka and Steve Collins†

NASA’s Dawn spacecraft, a low-thrust mission leveraging the prior experience of NASA’s Deep Space 1 spacecraft, was launched in September 2007 on a mission to investigate the large asteroids Vesta and Ceres. This paper provides a brief overview of the Dawn attitude control subsystem, describes the challenges faced by the small flight team during the mission so far, and offers a few lessons learned. Special attention will be given to experiences realized from flying a low-thrust mission under tight margins for missed thrust, reaction wheel momentum management while operating under solar-electric propulsion, the recent Mars Gravity Assist, and planning for the upcoming encounter with Vesta in 2011. [View Full Paper]

---

† All authors are with the Jet Propulsion Laboratory, California Institute of Technology. All correspondence should be sent to C. Anthony Vanelli, Jet Propulsion Laboratory, M/S 264-854, 4800 Oak Grove Drive, Pasadena, California 91109, U.S.A. E-mail: tony.vanelli@jpl.nasa.gov.

AAS 10-088

KEPLER ADCS OVERVIEW AND EARLY MISSION EXPERIENCES

Charles N. Schira and Dustin S. Putnam*

The Kepler spacecraft was launched on March 7, 2009. Designed and built for NASA by Ball Aerospace & Technologies Corp., the Kepler mission uses the transit method to detect Earth-like exoplanets – approximately Earth-sized planets that are in the habitable zone of their stars.

Kepler, the largest telescope ever launched beyond Earth orbit, is in a heliocentric, Earth-trailing, drift-away orbit. It is a 3-axis stabilized, inertially-fixed pointer, using a combination of sun sensors, star trackers, inertial measurement units, and fine guidance sensors for attitude determination and reaction wheels and hydrazine thrusters for attitude and momentum control. This paper presents an overview of the Kepler mission, the ADCS design and some early mission experiences. [View Full Paper]

* Ball Aerospace & Technologies Corporation, 1600 Commerce Street, Boulder, Colorado 80301, U.S.A.

TECHNICAL EXHIBITS

SESSION II

The Technical Exhibits Session is 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 are demonstrated in a hands-on, interactive environment, including lessons learned and undocumented features. Associated papers not presented in other sessions are also provided and can be discussed with the author.

Organizers:

Scott Francis
Lockheed Martin
Space Systems Company

Kristen Terry
Lockheed Martin
Space Systems Company

Vanessa Baez
Lockheed Martin
Space Systems Company

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

AAS 10-021, and -026 to -030

TECHNICAL EXHIBITS – SUMMARY

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 included in the other sessions, were also presented in this session, and the authors were available for discussion. This session took place in a social setting, and family members were welcome to attend.

Industrial representatives were present from the following organizations:

a.i. Solutions

Advanced Solutions, Inc.

Astro- und Feinwerktechnik Adlershof GmbH

AAS 10-025 "The World's Smallest Reaction Wheel – The Development, Fields of Operation and Flight Results of the RW 1"
Stephan Stoltz, Katrin Courtois, Christian Raschke and Frank Baumann

Ball Aerospace & Technologies Corp.

BEI Precision Systems and Space Division

EADS-Sodern

AAS 10-022 "Total Dose, Displacement Damage and Single Event Effects in the Radiation Hardened CMOS APS HAS2"
Dirk Van Aken, Dominique Hervé and Matthieu Beaumel

Emergent Space Technologies, Inc.

Lockheed Martin Space Systems Company

The Mathworks, Inc.

AAS 10-023 "Model-Based Design for Large High Integrity Systems: A Discussion on Data Modeling and Management"
Mike Anthony and Matt Behr

Monarch High School Robotics Team

AAS 10-024 "2009 with Monarch High School Robotics"
Divya Arcot, William Lounsbury, Noah Clark and Matthew Eastman

NAVSYS Corporation

Rockwell Collins

SELEX Galileo

Servo Corporation of America

Sierra Nevada Corporation

SimuLogix

Surrey Satellite Technology US LLC

AAS 10-022

TOTAL DOSE, DISPLACEMENT DAMAGE AND SINGLE EVENT EFFECTS IN THE RADIATION HARDENED CMOS APS HAS2

Dirk Van Aken,* Dominique Hervé† and Matthieu Beaumel†

Experimental results of several radiation test campaigns performed on the HAS2 CMOS imager are presented. The radiation testing includes Cobalt-60 total ionizing dose at low and high dose rate, proton and electron displacement damage, proton induced single event transient, and heavy ion single event effect. HAS2 electro-optical performances have been characterized during irradiation at low and room temperature, and after annealing at low, room and high temperature. The gathered data are consistent with radiation hardness properties of the HAS2 sensor. The most significant radiation drift coefficients have been assessed for dark current and electrical offsets. Transient signal under proton flux has been characterized at various proton energies. Robustness to single event latch-up has been demonstrated up to 79 MeV.cm²/mg.

Keywords: Image sensors, Cobalt-60, proton, electrons, heavy ions, total ionizing dose, displacement damage, single event transient, star tracker. [View Full Paper]

* Cypress Semiconductor Belgium BVBA - Schaliënhoevedreef 20B, 2800 Mechelen, Belgium.

† EADS Sodern – 20, Avenue Descartes, 94451 Limeil-Brévannes, France.

AAS 10-023

MODEL-BASED DESIGN FOR LARGE HIGH INTEGRITY SYSTEMS: A DISCUSSION ON DATA MODELING AND MANAGEMENT

Mike Anthony* **and Matt Behr†**

One of the most important concepts in Model-Based Design is that of the model as an executable specification. Building large models for the generation of production-quality embedded software requires the development of a modeling style that guides and enforces model architecture, interface definition, modeling standards, and data management. This paper focuses specifically on data management with Model-Based Design using MATLAB and Simulink. Models necessarily rely on external data and functionality to create an environment that allows initialization, trim, linearization, simulation, analysis, and code generation. This paper describes the fundamentals of how to define and manage parameters and signals within a model. It also discusses the implications of data management style on componentization, flexibility, readability, and code generation. Where relevant, recommendations suited for models targeting embedded code generation for mission-critical and high integrity systems are highlighted. [View Full Paper]

* Application Engineering, The MathWorks, Inc., 3 Apple Hill Drive, Natick, Massachusetts 01760-2098, U.S.A.

† Aerospace Industry Marketing, The MathWorks, Inc., 3 Apple Hill Drive, Natick, Massachusetts 01760-2098, U.S.A.

2009 WITH MONARCH HIGH SCHOOL ROBOTICS

Divya Arcot, William Lounsbury, Noah Clark and Matthew Eastman*

FIRST (For Inspiration and Recognition of Science and Technology) is an organization which challenges students of all ages and nationalities to participate in the building of robots and to familiarize themselves with the other aspects which attribute to the successful completion of engineering tasks (Finance, Project Management, Web Design, etc.). For high school students, FIRST holds the annual FRC (FIRST Robotics Challenge) competition. Monarch High School has participated in FRC competitions since 2003. Thanks to our sponsors, including the AAS Rocky Mountain Section, we have once again competed in the 2008-2009 school year. In this paper, we address our experiences from our last competition: the building process, robot functions, and what we learned. We will discuss the basic design of our robot including the controls and programming. We will supplement this information with a description of the competition, and how we function as a team. [View Full Paper]

* Monarch High School Robotics, Louisville, Colorado 80027.

THE WORLD'S SMALLEST REACTION WHEEL – THE DEVELOPMENT, FIELDS OF OPERATION AND FLIGHT RESULTS OF THE RW 1

Stephan Stoltz,[*] Katrin Courtois,[†] Christian Raschke[‡] and Frank Baumann[**]

Astro- und Feinwerktechnik Adlershof GmbH (AFW) has a long experience in developing reaction wheels. In cooperation with the Berlin Institute of Technology (TUB) and Magson GmbH we developed the reaction wheel RW 1, the world's smallest reaction wheel. The paper will give an overview about the development. It will highlight what performance parameters can be reached with such small reaction wheels. Besides the original use in Cubesats there are other fields of operations for the RW 1. Furthermore the paper will include some results of the initial flight with the BEESAT Cubesat of the TUB. [View Full Paper]

* Dipl.-Ing., Product Development, Astro- und Feinwerktechnik Adlershof GmbH, Albert-Einstein-Str. 12, 12489 Berlin, Germany.

† Dipl.-Ing. (FH), Product Development, Astro- und Feinwerktechnik Adlersh of GmbH, Albert-Einstein-Str. 12, 12489 Berlin, Germany.

‡ Dipl.-Ing., Satellite Engineering, Astro- und Feinwerktechnik Adlershof GmbH, Albert-Einstein-Str. 12, 12489 Berlin, Germany.

** Dipl.-Ing., Department of Astronautics, Institute of Aeronautics and Astronautics, Berlin Institute of Technology, Marchstrasse 12, 10587 Berlin, Germany.

OPERATIONAL RESPONSIVE SPACE GN&C (U.S. ONLY)

SESSION IX

High reliability national space systems are plagued by extremely long development and build schedules, yet the warfighter needs for new and modified space assets may develop in weeks and months. The Operationally Responsive Space office has recognized the need for the short-term injection of capability and has begun to answer the needs of the warfighter through short-turnaround mission implementation and modification of existing assets tasked to satisfy urgent military needs. This session focuses on the technical and programmatic challenges associated with flexible GNC design for responsive mission deployment and existing system modifications.

National Chairpersons:

Adam Fosbury
U.S. Air Force
Research Laboratory

Paul Graven
Microcosm, Inc.

Local Chairpersons:

Alex May
Lockheed Martin
Space Systems Company

James Speed
Ball Aerospace & Technologies
Corporation

The following papers were not available for publication:

AAS 10-091
"Open Questions and Other Thoughts on Responsive Space Guidance, Navigation and Control," by A. Fosbury, Air Force Research Laboratory (ITAR Restricted Paper)

AAS 10-092
"Onboard Inertia Estimation and Adaptive Compensation for Large-Scale Actuator Misalignments in Responsive Space Systems," T. Mercker, M. Akella, University of Texas at Austin (ITAR Restricted Paper)

AAS 10-093
"Guidance Navigation and Control Challenges Associated with ORS Utilization of Earth-Moon Lagrange Orbits," B. Cheetham, University of Colorado at Boulder (ITAR Restricted Paper)

AAS 10-094

“Minitature Momentum Control System: A Small Control Moment Gyroscope System that Enables Agile Responsive Space Satellites,” by M. McMickell, Honeywell (ITAR Restricted Paper)

AAS 10-095

“Precise Torque Mapping for Pico-Satellite Single-Gimbal Control Moment Gyroscopes,” by F. Leve, University of Florida (ITAR Restricted Paper)

AAS 10-096

“Self-Calibration and Self-Alignment for Spacecraft GN&C Components and Payloads,” by K. Kolcio, Microcosm, Inc. (ITAR Restricted Paper)

AAS 10-097

“STP-SIV Attitude Determination and Control,” by K. Reese, Air Force Research Laboratory; B. Marotta, Ball Aerospace (ITAR Restricted Paper)

The following paper numbers were not assigned:

AAS 10-098 to -099