GUIDANCE AND CONTROL 2012

Edited by
Michael L. Osborne

American Astronautical Society

Volume 144

ADVANCES IN THE ASTRONAUTICAL SCIENCES

GUIDANCE AND CONTROL
2012

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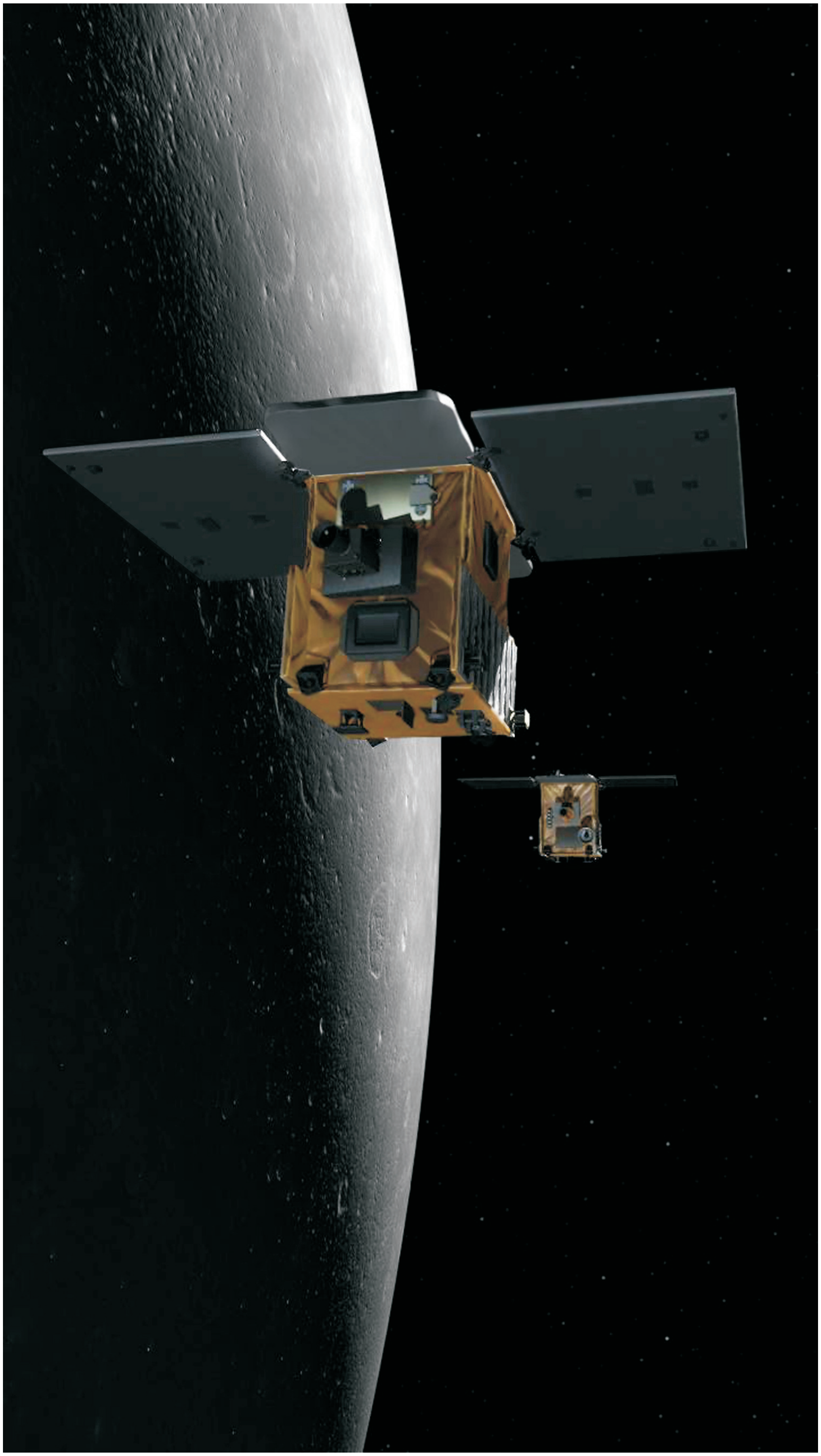
THE 36th ANNUAL
ROCKY MOUNTAIN SECTION GUIDANCE AND CONTROL CONFERENCE
Will be held at Breckenridge, Colorado, February 1–6, 2013,
Chairperson: Lisa Hardaway, Ball Aerospace & Technologies Corp.

Front Cover Illustration:

The Juno spacecraft, built for NASA/JPL by Lockheed Martin, was launched in 2011 and will arrive at Jupiter in 2016. Juno's mission is to peer deep within the gas giant's atmosphere and help answer questions about the planet's formation, thus providing insights to the early evolution of our solar system. (Image Credit: Courtesy of NASA/JPL)

Frontispiece:

NASA's twin GRAIL spacecraft, Ebb and Flow, are currently in orbit around the Moon. GRAIL (short for Gravity Recovery And Interior Laboratory) measures radio signals between the two formation-flying spacecraft to map the moon's gravitational field to an unprecedented level of detail. The spacecraft were built by Lockheed Martin and launched in 2011.
(Image Credit: Courtesy of NASA/JPL-Caltech/MIT)



GUIDANCE AND CONTROL 2012

Volume 144
ADVANCES IN THE ASTRONAUTICAL SCIENCES

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Michael L. Osborne

Proceedings of the 35th Annual AAS Rocky Mountain Section Guidance and Control Conference held February 3-8, 2012, Breckenridge, Colorado.

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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 participated in the American Astronautical Society (AAS), it was natural to gather under the auspices of the Rocky Mountain Section of the AAS.

In 1977 Martin Marietta and Ball Aerospace engineers approached the AAS Section Chair at the University of Colorado with their proposal and organized the first conference, thus beginning the annual series of meetings the following winter. 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.

The Conference is now held annually the first week of February and is a technical conference on aerospace attended by Government Labs, NASA facilities, DOD, Aerospace, Industry Component Manufactures, Academia, and International Participants. The 2012 Conference was the 35th Annual AAS Rocky Mountain Guidance and Control Conference.

The conference has maintained the original theme of no parallel sessions, with two three-hour sessions per day and a six-hour break at midday. This provides a forum for exchange of technical ideas, accomplishments and recent events in the aerospace industry in a social environment promoting an opportunity to meet customers, associates and industry partners one-on-one.

A tradition from the beginning has been the Conference banquet, an elegant dinner open to attendees and their guests. For these wider audiences, general-interest speakers have been quite popular. The banquet speakers from the past ten years have been:

Banquet Speakers

2002	Bradford W. Parkinson, Stanford University, "GPS: National Dependence and the Robustness Imperative".
2003	Bill Gregory, Honeywell Corporation, "Mission STS-67, Guidance and Control from an Astronaut's Point of View".
2004	Richard Battin, MIT, "Some Funny Things Happened on the Way to the Moon".
2005	Dr. Matt Golombeck, Senior Scientist, MER Program, JPL, "Mars Science Results from the MER Rovers".
2006	Mary E. Kicza, Deputy Assistant Administrator for Satellite and Information Services, NASA, "NOAA: Observing the Earth from Top to Bottom".
2007	Patrick Moore, Consulting Senior Life Scientist, SAIC and the Navy Marine Mammal Program, "Echolocating Dolphins in the U.S. Navy Marine Mammal Program".

2008	Dr. Ed Hoffman, Director, NASA Academy of Program and Project Leadership, "The Next 50 Years at NASA – Achieving Excellence".
2009	William Pomerantz, Senior Director for Space, The X Prize Foundation, "The Lunar X Prize".
2010	Berrien Moore, Executive Director, Climate Central, "Climate Change and Earth Observations: Challenges and Responsibilities".
2011	Joe Tanner, Senior Instructor, University of Colorado, "Building Large Structures in Space".
2012	Greg Chamitoff, NASA Astronaut, "Completing Construction of the International Space Station – The Last Mission of Space Shuttle *Endeavour*".

Tutorials and special sessions or featured invited lectures have served as focal points for the Conferences. In 2005, the tutorial session's theme was "University Work on Precision Pointing and Geolocation". In 2006, a day for U.S. citizens only was inserted at the beginning of the Conference to allow for topics that were limited due to ITAR constraints. In 2007, two invited sessions were held: "Lunar Ambitions—The Next Generation" and "Project Orion—The Crew Exploration Vehicle". In 2008, a panel addressed "G&C Challenges in the Next 50 Years". The 2009 Conference featured a special session on "Constellation Guidance, Navigation, and Control". This year continued the tradition with a tutorial on "Space Weather".

From the beginning, the Conference has provided extensive support for students interested in aerospace guidance and control. The Section annually gives $2,000 in the form of scholarships at the University of Colorado. One scholarship is awarded to the top Aerospace Engineering Sciences senior, and another 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 region. All this is made possible by proceeds from the Conference.

The student scholarship winners attend the Conference as guests of the American Astronautical Society. They are recognized at the banquet where they are presented with scholarship plaques. These scholarship winners have gone on to great successes in the industry. The winners from the past few years are:

Scholarship Winners

Academic Year	Aerospace Engr Sciences	Electrical and Computer Engr
2002–2003	Tara Klima	Kiran Murthy
2003–2004	Stephen Russell	Andrew White
2004–2005	Trannon Mosher	Ehsan Negar
2005–2006	Matthew Edwards	Henry Romero
2006–2007	Arseny Dolgov	Henry Romero
2007–2008	Christopher Aiken	Kirk Nichols
2008–2009	Nicholas Hoffmann	Gregory Stahl
2009–2010	Justin Clark	Filip Maksimovic
2010–2011	John Jakes	Filip Maksimovic
2011–2012	Wenceslao Shaw-Cortez	Andrew Thomas
2012–2013	Nicholas Mati	Jacob Haynes

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 attracts the nation's top specialists in space guidance and control. Chairpersons from recent years are:

	Conference Chair	Attendance
2002	Steve Jolly	151
2003	Ian Gravseth	178
2004	Jim Chapel	137
2005	Bill Frazier	140
2006	Steve Jolly	182
2007	Heidi Hallowell	206
2008	Michael Drews	189
2009	Ed Friedman	160
2010	Shawn McQuerry	189
2011	Kyle Miller	161
2012	Michael Osborne	140

The AAS Guidance and Control Technical Committee, with its national representation, provides oversight to the local conference committee. From 2000 through 2004, Larry Germann chaired this committee, and James McQuerry has chaired the technical committee since 2005. The committee meets every year at the Conference.

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

On behalf of the Conference Committee and the Section,

Michael L. Osborne
Lockheed Martin Space Systems Company
Littleton, Colorado

James McQuerry
Ball Aerospace & Technologies Corp.
Boulder, Colorado

PREFACE

This year marked the 35th anniversary of the AAS Rocky Mountain Section's Guidance and Control Conference. It was held in Breckenridge, Colorado at the Beaver Run Resort from February 3-8, 2012. The planning committee and the national chairs did an outstanding job in creating a highly-technical conference experience, and I extend many thanks to all those involved.

The conference formally began on the morning of Saturday, February 4th with a plenary session new to the format this year. The speaker was Mr. Keith Uebele of Intel Corporation on "The Future of Computing for Space and Ground Systems: Exploring the Limits". After this well-received kick-off, the first session began with *Space Debris – Tracking, Characterization & Mitigation*. This session investigated the nature of debris and ways to ensure our safe future in space.

To cap off the day, the *Technical Exhibits* session was held Saturday afternoon. Nineteen companies and organizations participated with many hardware demonstrations as well as excellent technical interchanges between conferees, vendors, and family. The session was accompanied by a buffet dinner. Many family members and children were present, greatly enhancing the collegiality of the session. The highly-experienced technical exhibits team did an outstanding job organizing the vendors and exhibits.

Sunday, February 5th marked a return of the tutorial sessions with a morning *Space Weather Tutorial*. This session, expanding upon the hazards of space, included a discussion of the current state of space and upper-atmospheric physics along with an overview of measuring systems and available data sources.

Continuing in the educational spirit, MathWorks held a special workshop that afternoon on "Using MATLAB & Simulink for Model-Based Design of Control Systems". This well-attended lunch-time event covered the iterative process of analysis, design, and optimization involved in the development and implementation of a real-world practical application.

The ever-popular *Advances in G&C* was held later that same afternoon. And with so much interest this year in the topic, a special follow-up *Advances* session was held Monday morning to further examine the current state-of-the-art. In the afternoon of February 6th, *GN&C – The Future* addressed how new concepts of operation, algorithms, and components will be required to meet increasingly-sophisticated mission needs in the years to come.

The banquet was held later that evening, and featured Dr. Greg Chamitoff, NASA Astronaut and Mission Specialist who performed the last spacewalk of the Space Shuttle Program. Greg described his mission experiences and life in space in his captivating speech entitled "Completing Construction of the International Space Station – The Last Mission of Space Shuttle *Endeavour*". The images and videos he showed were truly awe-inspiring.

The sessions continued Tuesday, the morning of February 7th, with *Current & Future Advanced European Programs* highlighting innovations in that continent's space agencies, industries, technologies, and missions. Tuesday afternoon featured *INR from UAVs*, a session that showcased hardware and software systems for Image Navigation & Registration from Unmanned Aerial Vehicle platforms.

Finally, the morning of Wednesday, February 8th featured the popular closing session *Recent Experiences*. This traditional session contained candid first-hand accounts of the successes and failures, trials and tribulations encountered in the space industry with valuable lessons for all to help ensure continued successes in the future.

The participation and support of our many colleagues in the industry helped make the 35th Annual Rocky Mountain AAS G&C conference a great success. The technical committee, session chairs, and national chairs were unfailingly supportive and fully committed to the technical success of the conference. Special thanks also go to Carolyn O'Brien of Lockheed Martin, Lis Garratt of Ball Aerospace, and the staff at Beaver Run for their professionalism and attention to the operational details that made this conference happen!

Michael L. Osborne, Conference Chairperson
2012 AAS Guidance and Control Conference

CONTENTS

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SPACE DEBRIS:
TRACKING, CHARACTERIZATION, AND MITIGATION

SESSION I

A safe space environment without substantial debris threats is crucial for scientific, defense, and commercial needs. Debris mitigation is a topic of global concern and has international attention. An improved understanding of what debris is up there, where it is, and how it is moving is important to characterize what actions we must take. Methods to help prevent satellite collisions and breakups are continuously being refined and employed in operations, and innovative ways to actively remove debris are gaining more traction. This session covers these topics to ensure that space debris will not obstruct our future in space.

National Chairpersons:

Moriba Jah
Air Force Research Laboratory

Scott Daw
TASC Inc.

Local Chairpersons:

Alex May
Lockheed Martin Space Systems

Cheryl Walker
TASC Inc.

The following papers were not available for publication:

AAS 12-012
(Paper Withdrawn)

The following paper numbers were not assigned:

AAS 12-019 to -020

SATELLITE CONJUNCTION ASSESSMENT AND COLLISION AVOIDANCE SUPPORT FROM AN OPERATIONAL PERSPECTIVE

Robert A. Massey*

Under Space Situational Awareness (SSA) sharing provisions of the new U.S. National Space Policy, commercial and international Guidance, Navigation, and Control professionals and satellite owner/operators concerned about orbital safety now have expanded access to systems, processes, and information used by the United States Strategic Command (USSTRATCOM) Joint Space Operations Center (JSpOC) for high-accuracy satellite Conjunction Assessment (CA) and collision avoidance support. Recent contributions to the orbital debris population and historical Satellite Catalog growth are reviewed with commentary on catalog-growth projections. A brief background of operational debris avoidance strategy for ISS/Shuttle and its progression to include all current active payloads is presented. Key systems, software applications and underlying algorithms used by the JSpOC for high-accuracy satellite catalog maintenance, CA, and collision avoidance support are reviewed. The simplified 2-D formulation and supporting key assumptions for computed probability of collision are illustrated and explained. The general CA process used by JSpOC Orbit Safety Analysts (OSAs) for consistent orbit determination and improved covariances leading to actionable relative miss predictions and computed collision probabilities is described. A close-conjunction asset versus debris case study example is presented. [View Full Paper]

* Sr. Space Analyst and former JSpOC 1st Space Control Squadron Orbital Safety Analyst; Colorado Springs, Colorado, U.S.A.; 719-360-3549 mobile, E-mail: robert_massey@zoho.com.

SPADOC 4[*] TRACK ASSOCIATION AND SHORT ARC INITIAL ORBIT DETERMINATION

James A. Peugh[†]

The catalog of man-made objects in space was established, and is maintained using observations provided by a network of sensors that collectively: anticipate and point toward specific objects at scheduled intervals; survey portions of the sky; or act as a “fence” to observe objects passing through. Continued collections are necessary since environmental and space object parameters used in orbit prediction are not known precisely, some objects internally generate orbit changes, and many undiscovered objects are still to be cataloged. As the current surveillance network has limited capacity to ideally satisfy collection requirements, new sensor concepts are being evaluated for inclusion. To maintain tracking, and to support discovery and change detection on deep space objects, angles-only (angles and angular rates) optical sensor concepts have been proposed that provide increased frequency of collections through wide area survey and the use of Too Short Arcs (TSAs). Such tracking does not provide range or range rate information, and the incomplete state information creates difficulties in object correlation and initial orbit determination (IOD). While methods are being developed to resolve these problems, the viability of using widely spaced TSAs to perform the space surveillance mission is still in debate. What follows is a discussion of the current use of angles-only observations in space operations, including observation association, an introduction to IOD using TSAs, operational impacts of using TSAs, identification of shortcomings and recommendations to mitigate them, and an illustration of the correlation and IOD problem encountered when TSAs are applied to a cluster of satellites residing in the geosynchronous belt. [View Full Paper]

* The Space Defense Operations Center, SPADOC, refers to the Space Control Center (SCC), while “SPADOC 4” refers to the computer hardware and software that support SCC operations. In this paper we are referring to the processing and procedures used to maintain the space catalog, but for simplicity we will use the term “SPADOC.”

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AAS 12-014

SPACE OBJECT MASS-SPECIFIC INERTIA MATRIX ESTIMATION FROM PHOTOMETRIC DATA

Richard Linares,* Fred A. Leve,† Moriba K. Jah‡ and John L. Crassidis§

This works investigates the problem of estimating the scaled inertia parameters of a space object using photometric and astrometric data. The inertia matrix is parameterized in terms of the relative scaled inertias and the orientation of the principal components because the system is not completely observable. A Unscented Kalman Filter (UKF) is presented that processes the lightcurve (single band photometric) and angles (astrometric) data to estimate the orientation, rotational rates, position, and velocity of the space object (SO) along with the scaled inertia parameters. [View Full Paper]

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† Research Engineer, Air Force Research Laboratory, Kirtland AFB, New Mexico 87117, U.S.A. Senior Member AIAA.

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AAS 12-015

SPACE OBJECT AREA-TO-MASS RATIO ESTIMATION USING MULTIPLE MODEL APPROACHES

Richard Linares,[*] Moriba K. Jah[†] and John L. Crassidis[‡]

In this paper two multiple model approaches are applied to estimate the effective area-to-mass ratio of a space object. Both multiple-model adaptive estimation and a new approach called adaptive likelihood mixtures are used in this work. Multiple model approaches have been used extensively used in target tracking applications since they can detect abrupt changes in the models governing the target's motion. Since the area-to-mass ratio is a function of the projected Sun facing area, which is a function of the orientation of the space object, then the effective area-to-mass ratio is time varying. It is difficult to estimate the time varying nature of the area-to-mass ratio using traditional estimators. Therefore multiple model approaches are proposed here. Simulation results are shown for different scenarios and good performance is given to determine the effective area-to-mass ratios as, well as their changes over time. [View Full Paper]

* Graduate Student, Department of Mechanical & Aerospace Engineering, University at Buffalo, State University of New York, Amherst, New York 14260-4400, U.S.A. E-mail: arp27@buffalo.edu, Student Member AAS and AIAA.

† Director, Advanced Sciences and Technology Research Institute for Astrodynamics (ASTRIA), Air Force Research Laboratory, Kirtland AFB, New Mexico, 87117, U.S.A. Member AAS, Associate Fellow AIAA.

‡ Professor, Department of Mechanical & Aerospace Engineering, University at Buffalo, State University of New York, Amherst, New York 14260-4400, U.S.A. E-mail: johnc@buffalo.edu, Member AAS, Associate Fellow AIAA.

AAS 12-016

SPACE DEBRIS REORBITING USING ELECTROSTATIC ACTUATION

Erik A. Hogan[*] and Hanspeter Schaub[†]

The use of an electrostatic force to perform orbital element modifications on a passive space object is investigated. Using inertial thrusters, a space tug approaches and engages a debris object. Once in place, an electrostatic force is created between the two bodies using non-contact charge transfer, enabling the tugging craft to perform an inertial thrusting maneuver to modify the debris' orbit without physical contact. An open-loop performance study is performed where variational equations are used to predict how much various orbital elements may be changed using this electrostatic force over one orbital period for a satellite at geosynchronous altitude. Because the electrostatic forces are small in magnitude (mN or less) and assumed to be piecewise constant in direction, the variational equations can be integrated analytically. The issues associated with repositioning the tug craft during orbit modifications to achieve desired tug directions are also investigated. Ranges of craft voltages are considered, as well as varying masses, illustrating promising debris maneuverability. [View Full Paper]

* Graduate Student, Aerospace Engineering Sciences, University of Colorado, Boulder, Colorado 80309, U.S.A.

† Associate Professor, H. Joseph Smead Fellow, Aerospace Engineering Sciences, University of Colorado, Boulder, Colorado 80309, U.S.A. Chief Technologist, Wacari Group, Boulder, Colorado, U.S.A.

DESIGN OF SPACECRAFT MISSIONS TO REMOVE MULTIPLE ORBITAL DEBRIS OBJECTS

Brent W. Barbee,* Salvatore Alfano,† Elfego Piñon,‡ Kenn Gold§ and David Gaylor**

The amount of hazardous debris in Earth orbit has been increasing, posing an ever-greater danger to space assets and human missions. In January of 2007, a Chinese ASAT test produced approximately 2600 pieces of orbital debris. In February of 2009, Iridium 33 collided with an inactive Russian satellite, yielding approximately 1300 pieces of debris. These recent disastrous events and the sheer size of the Earth orbiting population make clear the necessity of removing orbital debris. In fact, experts from both NASA and ESA have stated that 10 to 20 pieces of orbital debris need to be removed per year to stabilize the orbital debris environment. However, no spacecraft trajectories have yet been designed for removing multiple debris objects and the size of the debris population makes the design of such trajectories a daunting task. Designing an efficient spacecraft trajectory to rendezvous with each of a large number of orbital debris pieces is akin to the famous Traveling Salesman problem, an NP-complete combinatorial optimization problem in which a number of cities are to be visited in turn. The goal is to choose the order in which the cities are visited so as to minimize the total path distance traveled. In the case of orbital debris, the pieces of debris to be visited must be selected and ordered such that spacecraft propellant consumption is minimized or at least kept low enough to be feasible. Emergent Space Technologies, Inc. has developed specialized algorithms for designing efficient tour missions for near-Earth asteroids that may be applied to the design of efficient spacecraft missions capable of visiting large numbers of orbital debris pieces. The first step is to identify a list of high priority debris targets using the Analytical Graphics, Inc. SOCRATES website and then obtain their state information from Celestrak. The tour trajectory design algorithms will then be used to determine the itinerary of objects and Δv requirements. These results will shed light on how many debris pieces can be visited for various amounts of propellant, which launch vehicles can accommodate such missions, and how much margin is available for debris removal system payloads. [View Full Paper]

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‡ Senior GN&C Engineer, Emergent Space Technologies, Inc., 6411 Ivy Lane, Suite 303, Greenbelt, Maryland 20770, U.S.A.

§ Director of R&D, Emergent Space Technologies, Inc., 6411 Ivy Lane, Suite 303, Greenbelt, Maryland 20770, U.S.A.

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AAS 12-018

OPERATIONS CONCEPT FOR THE ROBOTIC CAPTURE OF LARGE ORBITAL DEBRIS

Richard Rembala,[*] Frank Teti[†] and Patrice Couzin[‡]

The growing population of expired satellites and space debris has become a global concern. Nearly 29,000 objects larger than 10 cm have been identified, any of which could cause a catastrophic collision and on-orbit break-up of an operating satellite. As postulated by Donald J. Kessler in 1978, the debris field is expected to increase through collisions with existing orbiting objects until a critical level is reached where a cascading collision effect will pollute Earth orbit with small fragments in a phenomenon known as the "Kessler Syndrome." The presence of debris has and will continue to put at risk the safe operation of satellites in high value orbits. One remedy proposed by Kessler in 2009: "The control of future debris requires, at a minimum, that we not leave future payloads and rocket bodies in orbit after their useful life and might require that we plan launches to return some objects already in orbit." This paper examines an active debris removal mission whereby a robotic Orbital Debris Removal Vehicle (ODRV) removes large derelict objects from high value regions in low earth orbit. The operations concept and key functional requirements for the tracking and capture systems necessary to address the unprepared nature and possibly tumbling behavior of the debris will be presented. [View Full Paper]

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† Manager, Autonomous Robotics, MDA Space Mission, 9445 Airport Road, Brampton, Ontario, Canada.

‡ Systems Engineering, Thales Alenia Space, 100 boulevard du midi - BP 99 - 06156 Cannes, France.

SPACE WEATHER TUTORIAL

SESSION III

Understanding near-Earth space and atmospheric effects are critical to satellite design and effective on-orbit operation of spacecraft and payload systems (including RF and scientific payloads). Atmospheric density impacts Orbital Determination (OD) in the Low Earth Orbit (LEO) regime. Ionospheric and proto-ionospheric physics result in RF signal delays and scintillation. The spacecraft in-situ environment will drive on-orbit impacts that include electrostatic discharge events, single-event upsets and other effects resulting from trapped radiation and other solar particle events. This session will include a tutorial of the current state of space and upper-atmospheric physics and provide an overview of its impact to orbital missions.

National Chairpersons:

Tim Walsh
National Oceanic and
Atmospheric Administration –
Goddard Space Flight Center
(NOAA/GSFC)

Bob Rutledge
National Oceanic and
Atmospheric Administration –
Space Weather Prediction
Center (NOAA/SWPC)

Doug Biesecker
National Oceanic and
Atmospheric Administration –
Space Weather Prediction
Center (NOAA/SWPC)

Local Chairpersons:

Shawn McQuerry
Lockheed Martin
Space Systems Company

Lee Barker
Lockheed Martin
Space Systems Company

The following papers were not available:

AAS 12-031
“Introduction to Space Weather,” Bob Rutledge, NOAA/NWS (Presentation Only)

AAS 12-032
“Space Weather Considerations for Spacecraft/Instrument Design,” Paul Richards, NASA/GSFC (Presentation Only)

The following paper numbers were not assigned:
AAS 12-036 to -040

SPACE WEATHER HAZARDS IN THE INNER MAGNETOSPHERE

Josef Koller*

Space weather refers to the conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and endanger human life or health. The purpose of this presentation is to review the processes and effects on space hardware with relevance to real world applications. We will focus on the inner magnetosphere and in particular on the radiation belt environment. We will describe the impact of space weather on hardware as a function of orbit and discuss the current modeling efforts that take into account real-time radiation belt observations and a physics-based model. [View Full Paper]

* Space Science and Applications, ISR-1, PO Box 1663, D466, Los Alamos, New Mexico 87545, U.S.A.

AAS 12-034

ADDRESSING THE INFLUENCE OF SPACE WEATHER ON AIRLINE NAVIGATION

Lawrence Sparks*

The advent of satellite-based augmentation systems has made it possible to navigate aircraft safely using radio signals emitted by global navigation satellite systems (GNSS) such as the Global Positioning System. As a signal propagates through the earth's ionosphere, it suffers delay that is proportional to the total electron content encountered along the raypath. Since the magnitude of this total electron content is strongly influenced by space weather, the safety and reliability of GNSS for airline navigation requires continual monitoring of the state of the ionosphere and calibration of ionospheric delay. This paper examines the impact of space weather on GNSS-based navigation and provides an overview of how the Wide Area Augmentation System protects its users from positioning error due to ionospheric disturbances. [View Full Paper]

* Jet Propulsion Laboratory / California Institute of Technology, 4800 Oak Grove Drive, Pasadena, California 91109-8099, U.S.A.

AAS 12-035

TUTORIAL: THE NEUTRAL ATMOSPHERE AND THE SATELLITE DRAG ENVIRONMENT

Geoff Crowley,[*] Marcin Pilinski[†] and Irfan Azeem[‡]

Satellite drag is the primary non-gravitational force acting on satellites below 500 km altitudes and continues to be an important orbital perturbation up to 800-1000 km altitudes. Recent developments in the understanding of upper atmospheric physics as well as the availability of high-resolution satellite drag data are motivating a transition from empirical models to physics based assimilative models as the primary tools for satellite drag specification. The motivation, current progress and future challenges associated with this effort are described in this paper. First principles models, such as TIMEGCM are described and their ability to specify satellite drag is demonstrated. Since the prediction of satellite ballistic coefficients limits the ability to forecast satellite drag almost as much as atmospheric density, physics-based atmospheric models will likely be coupled with physics-based ballistic and drag coefficient specification. This complete approach to the satellite drag problem has the potential to be the first system to achieve the 5% drag specification goal prescribed by the Air Force Space Command.
[View Full Paper]

* Chief Scientist and CEO, Atmospheric and Space Technology Research Associates (ASTRA), Boulder, Colorado 80301, U.S.A. Tel: 210-834-3475.

† Postdoctoral Researcher, Atmospheric and Space Technology Research Associates (ASTRA), Boulder, Colorado 80301, U.S.A. Tel: 210-834-3475.

‡ Chief Engineer, Atmospheric and Space Technology Research Associates (ASTRA), Boulder, Colorado 80301, U.S.A. Tel: 210-834-3475.

ADVANCES IN GUIDANCE, NAVIGATION AND CONTROL

SESSIONS IV and V

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

National Chairpersons:	Brent Robertson NASA Goddard Space Flight Center
	Tim Crain NASA Johnson Space Center
Local Chairpersons:	David Chart Lockheed Martin Space Systems
	Ian Gravseth Ball Aerospace & Technologies Corp.

The following paper numbers were not assigned:

AAS 12-046 to -050 and AAS-058 to -060

ATTITUDE DETERMINATION FOR A SMALL SATELLITE MISSION

Michael D'Angelo,[*] Richard Linares[†] and John L. Crassidis[‡]

This paper describes a path toward the development of theory for using a low noise high frame rate camera as a star tracker for spacecraft attitude estimation. The benefit of using a low noise high frame rate camera is that star data can be sampled at a faster rate while allowing one to measure very dim stars, increasing the number of stars available for attitude estimation. The development of a noise model is discussed and an algorithm to process raw data is shown. An attitude estimation method is discussed and simulated data is shown. A simulated star tracker for attitude estimation is shown and attitude estimation results are shown. [View Full Paper]

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AAS 12-042

ALIGNMENT BETWEEN IMU AND STAR TRACKER USING THE NIGHT SKY AND AN ON-BOARD NAVIGATION SYSTEM

Stephen R. Steffes,* Malak A. Samaan† and Stephan Theil‡

When developing a navigation system with an IMU and star tracker, the attitude alignment between the two sensors (relative pose) must be estimated so that measurements from both sensors can be converted to a common reference frame. Often such navigation systems use an on-board computer to combine the IMU's gyro and accelerometer measurements with the star tracker's attitude measurements using a Kalman filter. The proposed alignment method adds three states to this navigation filter to estimate the error in a given coarse alignment quaternion. On ground, the alignment quaternion can be accurately measured by navigating with the on-board system while the star tracker points towards the night sky and takes measurements. The vehicle is rotated in several positions to image the night sky from different angles. Each change of orientation provides the navigation system with additional measurements of gravity, Earth rate, angle slews and star tracker quaternions, all of which help improve the filter's estimate of the alignment quaternion. Alignment can also be done during the mission, however gravity and Earth rate measurements may not be available. Alignment accuracy depends on the IMU's error characteristics and the star tracker's accuracy. This technique is used for the Hybrid Navigation System and is compared to a traditional indoor alignment method which uses a checkerboard optical target. [View Full Paper]

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SMALL SATELLITE ATTITUDE CONTROL FOR TRACKING RESIDENT SPACE OBJECTS

Dylan Conway,[*] Richard Linares[†] and John L. Crassidis[‡]

This paper addresses the attitude determination and control problem for the University at Buffalo's GLADOS mission. The main objective of the mission is to collect multi-band photometric data of resident space objects to improve space situational awareness. The team plans to use two optical payloads, a wide-field camera and a spectrometer, to achieve this goal. The attitude control system uses feedback from the wide-field camera in order to track targets and allow the collection of spectral data. The development of this novel approach which is suitable for low-cost small satellites is presented. A numerical simulation of a modeled mission including environmental disturbances, reaction wheel limitations, and sensor errors and delays is outlined. Results of this simulation are then presented. The ability of this approach to effectively track targets within the narrow field-of-view of the spectrometer is demonstrated.

[View Full Paper]

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GPS AT GEO: A FIRST LOOK AT GPS FROM SBIRS GEO1*

Lee Barker† and Chuck Frey‡

On May 7, 2011, Lockheed Martin successfully launched the first of a new series of Space-Based Infrared System (SBIRS) satellites, SBIRS GEO1. SBIRS is intended primarily to provide enhanced strategic and theater ballistic missile warning capabilities. Part of the SBIRS GEO1 design is the inclusion of a dual frequency GPS receiver to support spacecraft navigation requirements. Launch of GEO1 is significant in that it makes use of GPS in the geosynchronous orbit regime, providing a unique look at the GPS environment, expectation of performance, and new challenges in GPS applications as seen from above the GPS constellation.

New user navigation accuracy and robustness requirements for GEO satellites have spurred interest in developing GPS navigation systems designed to operate in the sparse measurement environment. Understanding that environment is key to designing a successful system.

Several published papers have described the well understood geometric constraints of the GPS system when operating receivers above the GPS constellation. A few operators have reported on actual data collected by receivers operating at or above the GPS constellation. Finally, several papers have been authored regarding proposed systems showing simulation results for high altitude GPS based navigation systems. These simulation results are based on modeling assumptions that are critical to the analysis. SBIRS GEO1 data offers the first look at actual observations from GEO, and an opportunity to validate or improve upon models.

The purpose of this paper is to present and discuss observations, postulate phenomena, and identify areas where future research or work would be useful in the exploitation of GPS in the geosynchronous orbit environment. This paper will (1) briefly summarize some earlier work in the use of GPS above the terrestrial and LEO regime, (2) present and discuss analysis of observed GPS signal from the GEO regime. These observations include a look at ionosphere delay as seen from GEO, GPS L1 antenna group delay as seen from large angles off the GPS satellite beam center, and GPS signal strength at GEO relative to link predictions. [View Full Paper]

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AAS 12-045

SAFEHOLD ATTITUDE DETERMINATION APPROACH FOR GPM

Henry Fitzpatrick* **and Keith DeWeese***

Spacecraft safing designs generally have minimal goals with loose pointing requirements. Safe pointing orientations for three-axis stabilized spacecraft are usually chosen to put the spacecraft into a thermally safe and power-positive orientation. In addition, safe mode designs are required to be simple and reliable. This simplicity lends itself to the usage of analog sun sensors, because digital sun sensors will add unwanted complexity to the safe hold mode.

The Global Precipitation Measurement (GPM) Mission Core Observatory will launch into lower earth orbit (LEO) at an inclination of 65 degrees. The GPM instrument suite consists of an active radar system and a passive microwave imager to provide the next-generation global observations of rain and snow. The complexity and precision of these instruments along with the operational constraints of the mission result in tight pointing requirements during all phases of the mission. To ensure the instruments are not damaged during spacecraft safing, thermal constraints dictate that the solar pointing orientation must be maintained to better than 6.5 degrees. This requirement is outside the capabilities of a typical analog sun sensor suite, primarily due to the effects of Earth's albedo. To ensure mission success, a new analog sensor, along with the appropriate algorithms, is needed.

This paper discusses the design issues involving albedo effects on spacecraft pointing and the development of a simple, low-cost analog sensor and algorithm that will address the needs of the GPM mission. In addition, the algorithms are designed to be easily integrated into the existing attitude determination software by using common interfaces. The sensor design is based on a heritage, commercial off-the-shelf analog sun sensors with a limited field-of-view to reduce the effects of Earth's albedo. High fidelity simulation results are presented that demonstrate the efficacy of the design.

[View Full Paper]

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AAS 12-051

VISION NAVIGATION SENSOR (VNS) RESULTS FROM THE STORRM MISSION

Ian J. Gravseth, Reuben Rohrschneider and Jim Masciarelli*

The VNS was developed as the final docking sensor for Orion and is intended to provide range and bearing data which can be used to calculate relative pose between the sensor and the docking target from a range of in excess of 5 km down to docking. The sensor measures time of flight of reflected laser pulses and returned intensity off of retroreflectors on the target vehicle. As part of the Orion program's development, this sensor was designed, built and tested at Ball Aerospace and was flown on STS-134 to mitigate the risk of differences between ground test and spaceflight for relative navigation sensors. This paper will discuss centroiding results from the Sensor Test for Orion RelNav Risk Mitigation (STORRM) flight of the VNS sensor as a science payload on STS-134. Centroiding results will be compared against the Best Estimated Trajectory for the shuttle flight. [View Full Paper]

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FULL SCALE FLIGHT DEMONSTRATION OF LIDAR-BASED HAZARD DETECTION AND AVOIDANCE

David Neveu,* Jean-François Hamel,† Mike Alger,† Jean de Lafontaine,† Jeff Tripp,‡ Marwan Hussein,‡ Brian Hill,‡ Allen Taylor,§ Peter Dietrich,§ Chris Langley§ and Andrew Kerr§

International space agencies want to maximise the scientific return of planetary exploration missions with the minimum level of risk. This goal can be achieved by implementing the capability of landing spacecrafts with high precision and safety nearby known surface targets of interest such as craters, boulders and hills. Innovative guidance, navigation and control technologies are needed to achieve that goal. It requires the capability to identify boulders and slopes on the surface of the celestial body and react rapidly in order to guide the spacecraft toward a safe region. This capability is known in the literature as Hazard Detection and Avoidance (HDA). In previous papers presented at various conferences, the design of a Lidar-based autonomous planetary landing system and its validation using software simulators and scaled hardware-in-the-loop simulators were presented. This paper is a continuation of this work and presents the demonstration at full scale of this technology using helicopter flight test experiments, with Lidar measurements processing and HDA software functions operated in real time using a flight representative Lidar instrument. The first flight test experiments of this program were performed with success during the month of October 2010 and additional flight test campaigns were conducted during September 2011 using an upgraded and consolidated version of the design. This paper begins with a description of the latest design version of the Lidar-based autonomous planetary landing system. Then, the paper presents the methodology adopted to validate the interfaces and the performance of the landing system in a scaled and repeatable environment using a robotic test bench, the so-called Landing Dynamic Test Facility (LDTF). This laboratory environment enables the efficient, low-cost and low-risk validation of the complex landing system before proceeding to the more expensive and more risky flight experiments. The paper then presents the flight test validation methodology using a helicopter on a steep descent (Mars-like) and shallow descent (Moon-like) trajectory toward terrains with representative slopes, rocks and boulders. The paper concludes with the presentation of the flight experiment results and a detailed analysis of the achieved performance.

[View Full Paper]

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AAS 12-053

SIMULATION RESULTS OF RENDEZVOUS AND DOCKING WITH THE INTERNATIONAL SPACE STATION USING ONLY 3D RANGE IMAGES

Reuben R. Rohrschneider,* William Tandy,†
Jeff Bladt* and Ian J. Gravseth*

NASA's future plans for space vehicles call for the ability to automatically rendezvous and dock (AR&D) with the International Space Station (ISS) and other targets. This requires sensors and algorithms capable of determining the relative position and orientation (pose) between the target and chase vehicles under the drastically varying lighting conditions of low Earth orbit and beyond.

To this end, Ball Aerospace has developed algorithms to produce six degree-of-freedom navigation data from 3D point clouds. The algorithms require a-priori knowledge of the target vehicle geometry and a range image of the target vehicle for in-flight pose determination (no visible or reflective targets are needed). The algorithms have been incorporated into a simulation that includes a flash LIDAR model, orbital dynamics, vehicle thrust control, and a three-dimensional model of the ISS. The flash LIDAR is used as the only relative navigation sensor during AR&D. In this paper we present the results of the docking simulation, including the accuracy of the pose determination algorithms during a successful approach and docking with ISS.

[View Full Paper]

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AAS 12-054

MONOCULAR 3D SLAM USING A VISUAL LANDMARK DATABASE FOR AUTONOMOUS NAVIGATION NEAR SMALL CELESTIAL BODIES

Cedric Cocaud* and Takashi Kubota†

Close proximity operations near small celestial bodies adds a new range of problems requiring more autonomy, more precision and more flexibility from the navigation software. Addressing these problems, this paper focuses on a 3D monocular SLAM based on the Rao-Blackwellized Particle Filter approach using a hybrid mapping module combining binary search trees acting as a visual landmark signature catalog, and an octree occupancy grid meant to offer a spatial representation of the landmark uncertainty distribution. SLAM motion estimation is performed at the beginning of each time step according to a probabilistic scheme based on fast linear visual pose estimation algorithms, sampling probable motion estimates from subgroups of visual features matched across pairs of subsequent navigation camera images. The autonomous SLAM-based navigation scheme estimates the spacecraft position and attitude – or pose – at each time step by picking the most probable pose from a sample population of particles representing different hypotheses on the spacecraft path and the landmark distribution conditioned on it. A low-pass filter processes the raw output of the SLAM to provide a smoother response that can be used by a conventional trajectory tracking controller. [View Full Paper]

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EPOXI FINE GUIDANCE ARCHITECTURE AND OPERATION

Dustin Putnam*

The Deep Impact spacecraft was launched January 2005 and has subsequently executed close flybys of two comets: 9P/Tempel and 103P/Hartley. The Deep Impact spacecraft is equipped with three science instruments: a high resolution visible imager (HRI), a medium resolution visible imager (MRI), and a high resolution infra-red spectrometer. This paper describes the software architecture being put in place to use the MRI to provide high accuracy stellar inertial reference measurements. Combining these "Fine Guidance" measurements with the Scalable Space Inertial Reference Unit (SSIRU) yields a pointing stability of 0.5 μrad 1σ and a pointing accuracy of approximately 5 μrad 3σ. [View Full Paper]

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GOES-R MAGNETIC FIELD ESTIMATION

Chris Chastain,* Donald Chu† and Doug Westbury‡

GOES-R is the next satellite in the series of NOAA geostationary operational environmental satellites (GOES) and will be launched in 2015. This paper discusses the design and estimation approach being implemented for the GOESR Series Magnetometer mission which will provide highly accurate estimates of the magnetic field in Geostationary Earth Orbit (GEO). These estimates are used to determine the level of geomagnetic activity, detect magnetopause crossings, storm sudden commencements, and map the space environment that controls charged particle dynamics in the outer region of the magnetosphere. [View Full Paper]

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AAS 12-057

GIMBAL CONTROL ALGORITHMS FOR THE GLOBAL PRECIPITATION MEASUREMENT CORE OBSERVATORY

Gary Welter,[*] Kuo Chia (Alice) Liu[†] and Carl Blaurock[‡]

There are two gimbaled systems on the Global Precipitation Measurement Core Observatory: two single-degree-of-freedom solar arrays (SAs) and one two-degree-of-freedom high gain antenna (HGA). The guidance, navigation, and control analysis team was presented with the following challenges regarding SA orientation control during periods of normal mission science: (1) maximize solar flux on the SAs during orbit day, subject to battery charging limits, (2) minimize atmospheric drag during orbit night to reduce frequency of orbit maintenance thruster usage, (3) minimize atmospheric drag during orbits for which solar flux is nearly independent of SA orientation, and (4) keep array-induced spacecraft attitude disturbances within allocated tolerances. The team was presented with the following challenges regarding HGA control during mission science periods: (1) while tracking a ground-selected Tracking Data and Relay Satellite (TDRS), keep HGA control error below about 4’, (2) keep array-induced spacecraft attitude disturbances small, and (3) minimize transition time between TDRSs subject to constraints imposed by item 2. This paper describes the control algorithms developed to achieve these goals and certain analysis done as part of that work.

[View Full Paper]

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GUIDANCE, NAVIGATION AND CONTROL: THE FUTURE

SESSION VI

Advances in technology and engineering capabilities have continued to facilitate increasingly-sophisticated space-based platforms for a variety of purposes. However it is clear that new GN&C concepts, architectures, systems, algorithms, and components, will be required to meet the emerging needs of the more demanding, complex and highly dynamic missions currently envisioned for Earth observation, space science, human exploration beyond low Earth orbit, and national defense. Some of the GN&C functions driven by advanced mission concepts and payload requirements include autonomy, adaptability, high stability, rapid slew and settle times, high-accuracy pointing and precise vehicle position/attitude knowledge. This session considers foreseeable system requirements and their flow to future GN&C requirements.

National Chairpersons:

Neil Dennehy
NASA Goddard
Space Flight Center

David Richie
U.S. Air Force Academy

Local Chairpersons:

Michael Drews
Lockheed Martin Space Systems

Bill Frazier
Ball Aerospace &
Technologies Corp.

The following paper numbers were not assigned:

AAS 12-066 to -070

AAS 12-061

TECHNICAL CHALLENGES AND FUTURE TECHNOLOGY NEEDS FOR NASA'S GUIDANCE, NAVIGATION AND CONTROL ENGINEERING DISCIPLINE

Cornelius J. Dennehy*

Currently the United States (U.S.) National Aeronautics and Space Administration (NASA) is experiencing some significant changes, particularly in the human exploration arena. Notable among the changes that have recently occurred within NASA is the retirement of the space shuttle, the emergence of commercial crew transport to the International Space Station (ISS), the development of architectures for human exploration beyond low-Earth orbit (LEO), affordability constraints on robotic spaceflight missions, and a renewed emphasis on and commitment to space technology development/demonstration. These new changes within the Agency will have impacts on the Guidance, Navigation and Control (GN&C) discipline. This paper will summarize an independent NASA Engineering and Safety Center (NESC) assessment of the GN&C technical challenges and barriers currently faced by the three NASA Mission Directorates. Technical challenges and future technological need for NASA's GN&C engineering discipline will be summarized. In particular, three key GN&C challenge areas will be discussed in this paper. The first challenge concerns the fact that advanced GN&C capabilities (e.g., the application of robust/optimal or adaptive control) are not being exploited as much as they could be due to perceived risk of implementation. The second challenge addresses the need for meaningful investments in the next generation of GN&C component-level technologies. The third challenge arises from the lack of consistent NASA-wide top-level guidelines for GN&C system Design, Development, Test and Evaluation (DDT&E). Specific steps, many involving the efforts of the NESC GN&C Technical Discipline Team (TDT), to mitigate these three challenges will be identified and described. This paper will also discuss the need for sustained investments to sufficiently mature the several classes of GN&C technologies required to implement NASA crewed exploration missions beyond LEO, to address future aeronautical system needs, and to conduct robotic spaceflight missions for attaining Earth and Space scientific goals.
[View Full Paper]

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AAS 12-062

OPTIMAL SPACE EFFECTS: DRIVING FUTURE MILITARY GN&C TECHNOLOGY NEEDS

William W. Saylor* and David J. Richie†

This work builds on current exquisite performance in a variety of spacecraft components, subsystems, and algorithms in very demanding guidance, navigation, and control applications through flowing future national interest goals into satellite platform technology requirements within plausible constellation constructs identified along the way. Rather than hypothesizing new developments at the component and algorithm level, the paper focuses on the underlying rationale and methods for pushing the state-of-the-art GNC subsystems for space, from identifying future military challenges, to meeting planned threats with robust space effects (i.e. precise navigation and timing; intelligence, surveillance, and reconnaissance collection), the carefully designed, analyzed, integrated, and tested satellite systems usually work as well as expected on orbit and generally demonstrate robust performance in the presence of space environmental uncertainties. However, the latest complication is that each satellite must continually calculate power, energy, bandwidth, memory storage and thermal constraints – and then "play forward" in, for example, a receding horizon optimal control construct that calculates the next move in an infinite game of space chess. The remainder of this work, then, initiates this investigation through identifying constellation constructs, addressing the utility optimal algorithms have on advancing the state-of–the-art while still leveraging today's hardware with minimal changes, demonstrates how this all works with a single ISR small satellite slewing maneuver, and presents future tasks needed to adequately evolve these steps from concept to reality, noting that each optimization step, however simplified, places new GNC requirements upon space mission designers and developers. [View Full Paper]

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FUTURE US LAUNCH VEHICLE GN&C TECHNOLOGY NEEDS*

John G. Reed†

With the exciting changes looming in the United States launch vehicle market, this is an appropriate time to examine the emerging needs of commercial crew and the evolution of range safety. This paper addresses the changing face of GN&C in the US Launch Vehicle Segment, addressing the impact of crewed vehicle operations on the architecture, systems and components of the Atlas and Delta launch vehicles, with special attention paid to those aspects driving evolution of the GN&C systems. It is also timely to address the integration of the GPS Metric Tracking effort into the fleet and assess the future impacts of this evolving system and the intersection with crewed launch vehicle operations. Consideration is also given to the evolving role of the FAA in launch vehicle operations and their intersection with fault tolerant GN&C. Given the increasing focus on affordability and the importance of maximizing the launch benefits, additional topics include the impacts of secondary mission's requirements on GN&C evolution. Finally, no assessment would be complete without touching on the challenges and opportunities afforded with the development of the SLS and reusable concepts like the fly-back booster efforts by the USAF and some of the new Launch Vehicle entrants.
[View Full Paper]

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GUIDANCE, NAVIGATION AND CONTROL REQUIREMENTS FOR FUTURE REMOTE SENSING SPACE SYSTEMS

Michael Santina,[*] Bruce C. Chesley[†] and Gregory R. Johnston[‡]

As the role of space-based intelligence, surveillance and reconnaissance continues to grow, military users will demand higher image quality, faster delivery of image products, and improved target location accuracy in order to pinpoint locations of events of interest and for precise situational awareness. Such demands have a significant impact on the space vehicle Guidance, Navigation and Control (GNC) subsystem. GNC requirements are ultimately driven by key performance parameters (KPPs) for the overall system which include image quality, quantity, timeliness, and geolocation accuracy. Consequently, an important task in the initial phase of the system development is to convert these KPP requirements into GNC requirements and then flow down these requirements into drivers of GNC performance. We focus on a process to derive GNC requirements from KPPs for electro-optical and synthetic aperture radar remote sensing systems. Error budgets for the pointing knowledge and pointing control will be presented and the error contributors that affect the pointing control system performance will also be discussed. [View Full Paper]

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AAS 12-065

AUTONOMOUS RPOD TECHNOLOGY CHALLENGES FOR THE COMING DECADE

Bo J. Naasz and Michael C. Moreau*

Rendezvous Proximity Operations and Docking (RPOD) technologies are important to a wide range of future space endeavors. This paper will review some of the recent and ongoing activities related to autonomous RPOD capabilities and summarize the current state of the art. Gaps are identified where future investments are necessary to successfully execute some of the missions likely to be conducted within the next ten years. A proposed RPOD technology roadmap that meets the broad needs of NASA's future missions will be outlined, and ongoing activities at GSFC in support of a future satellite servicing mission are presented. The case presented shows that an evolutionary, stair-step technology development program, including a robust campaign of coordinated ground tests and space-based system-level technology demonstration missions, will ultimately yield a multi-use mainstream autonomous RPOD capability suite with cross-cutting benefits across a wide range of future applications. [View Full Paper]

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CURRENT AND FUTURE ADVANCED EUROPEAN PROGRAMS

SESSION VII

This session aims to provide an overview of GN&C developments and direction within Europe. All aspects of GN&C, from system design and new equipment feasibility studies through on-orbit experiences, are covered via the presentation of selected topics representative of the current state of the art in Europe.

National Chairpersons:	Stephen P. Airey European Space Agency
	Jacques Busseuil Thales Alenia Space
Local Chairpersons:	Jim Chapel Lockheed Martin Space Systems
	James McQuerry Ball Aerospace & Technologies Corp.

The following paper numbers were not assigned:

AAS 12-078 to -080

AAS 12-071

SPACEBUS 4000: FROM EARTH SENSORS TO 3-AXIS STAR TRACKERS CONTROL OF TELECOMMUNICATION SPACECRAFT

E. Brouillard,[*] B. Célérier[†] and C. Boddaert[‡]

Spacebus 4000 telecommunication spacecraft are now operated without Earth sensor. It took a long way to achieve this configuration. It was only possible thanks to the high records of Star Trackers and their careful and step by step introduction in the AOCS control loop. The paper will retrace the main milestones of the STR introduction on Spacebus 4000 that finally ended with the earth sensor removal. Flight records showing the great superiority of stellar pointing versus direct earth pointing will be provided. [View Full Paper]

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AAS 12-072

THE PRISMA FORMATION FLYING DEMONSTRATOR: OVERVIEW AND CONCLUSIONS FROM THE NOMINAL MISSION

Per Bodin,[*] Ron Noteborn,[*] Robin Larsson,[*] Thomas Karlsson,[*] Simone D'Amico,[†] Jean Sebastien Ardaens,[†] Michel Delpech[‡] and Jean-Claude Berges[‡]

The PRISMA in-orbit testbed was launched on June 15, 2010 to demonstrate strategies and technologies for formation flying and rendezvous. OHB Sweden (OHB-SE) is the prime contractor for the project which is funded by the Swedish National Space Board with additional support from the German Aerospace Center (DLR), the French National Space Center (CNES), and the Technical University of Denmark (DTU). In August 2011, PRISMA completed its nominal mission and during the fall of 2011, several additional activities have been performed under a mission extension program. The mission qualifies a series of sensor and actuator systems including navigation using GPS, Vision Based and RF technology as well as a propulsion system based on environmentally friendly propellant technology. The mission also includes a series of GNC experiments using this equipment in closed loop. Separate experiments are implemented by OHB-SE, DLR, and CNES and the paper provides an overview and conclusions from the nominal mission flight results from these experiments. [View Full Paper]

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AAS 12-073

FROM THE BRIGHT SUN TO THE FAINTEST STARS: THE EUROPEAN ROUTE TO STATE OF THE ART MINIATURIZED ATTITUDE SENSORS

Paolo Fidanzati,* Riccardo Gabrieli,* Egidio Pucci,* Franco Boldrini,* Dorico Procopio* and Stephen P. Airey†

Following the recent trend for miniaturization and the latest innovation steps in the CMOS technology, the integration on the same chip of a detector pixel array as well as the driving & processing logic has become mature for applications in the space field. In the star tracker application a real optics is needed to image the stars on the detector, but the relevant telescope cannot be integrated directly on the chip. However, the processing logic can be embedded on the silicon and, with a suitable optics, a miniaturized star sensor optical head can be realized. The design of a suitable miniaturized optics is therefore necessary to perform a step forward in the sensor miniaturization. A contract was then awarded to SELEX Galileo by ESA to carry out a preliminary study on a miniaturized optics suitable to be used for a future STAR TRACKER ON CHIP (STRoC). This paper describes in detail the design of such optics for a star tracker application, developed keeping in mind the need for small dimensions and low recurring cost, mandatory for such kind of application to gain attractiveness on a wide range of applications and market opportunities, not only limited to micro and nano satellites. The analyses show encouraging results both in terms of optics performance and stability of the assembly in temperature given the proposed radiative thermal design. A prototype will be manufactured early in 2012 and tested on an optical test bench using an image detector used for star tracker products. The next step in the miniaturized sensor road map is the design of a dedicated chip and supporting off chip electronics. The latter will take advantage of the work realized for the development of a miniaturized Sun Sensor on Chip by SELEX Galileo, like '4T' pixel design, on chip signal processing, thresholding and clustering, algorithms for cluster identification and unwanted objects rejection, feasibility of a true on chip DC/DC converter. [View Full Paper]

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EUROPEAN ASTRIX™ FOG IN-ORBIT HERITAGE

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In the early 2000s, ASTRIUM SAS, in collaboration with iXBlue (formerly IXSEA), a French SME, developed with CNES and ESA support, an inertial reference unit (IRU) family for a wide range of space applications. These fully European products, called "ASTRIXTM", are based on solid-state (FOG) technology. The first flight models were delivered in 2006 and 2007, and production is now running smoothly. These IRUs have been selected by a range of applications as varied as PLANCK, PLEIADES, AEOLUS, GAIA, EUROSTAR, GALILEO IOV, SENTINEL 1&2, JPSS_1 etc. covering the different orbit types (LEO, MEO, GEO and Lagrange). They fully benefit from the unequalled potential of FOG technology and from its particularly good suitability to high performance space applications requirements. The ASTRIX family currently comprises three fully qualified products, namely ASTRIX200, ASTRIX120 and ASTRIX120HR, which are shortly presented in this paper.

A total of 22 FOG channels, cumulating to date 170 000 operating hours, are currently in orbit (latest being with PLEIADES ASTRIX200 launched on Soyouz, Kourou, on Dec. 11). Up to Feb. 2012, the PLANCK (L2) ASTRIX120 has continuously been in operation for two and half years and the COMS (GEO) ASTRIX120HR for one and half year. After having briefly introduced the origin of the product development, the paper presents the observed in-orbit performances of these gyros in detail. The differences between these two missions, their different orbits and use of gyros give a particularly interesting feedback on the excellent behavior of this technology. One of the 4 PLANCK FOGs is oriented perpendicularly to the spin axis, making it possible to accurately characterize its measurement noise, and confirming that this remains unchanged with regard to ground acceptance test results. The COMS gyros are part of the spacecraft AOCS control loop, and thus are a major contributor to the excellent mission performances. During their use in the transfer phase, their high accuracy gave unprecedented visibility of micro-vibration and flexure in the various equipments and instruments, as well as the effects of spacecraft outgassing. Very positive lessons learnt from this in-orbit heritage are discussed. The paper concludes by briefly presenting the ASTRIX family latest development, the ASTRIX3M2, a promising three-axis, cost-competitive, high-performance IMU. [View Full Paper]

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FLASH OPTICAL SENSORS FOR GUIDANCE, NAVIGATION AND CONTROL SYSTEMS

A. Pollini*

This paper described the project “Flash Optical Sensor for TErrain Relative NAVigation (FOSTERNAV)”, an activity funded by the European Commission through its seventh research programme framework (FP7) space call.

The orientations of the project are three folds: to review space exploration missions’ requirements with landing or rendezvous phases for which the use of Light Detection And Ranging (LiDAR) is foreseen, to design and build a three-dimensional (3D) imaging flash LiDAR prototype and to test the prototype on test-benches for soft-landing and rendezvous applications.

The flash imaging LiDAR architecture studied in the frame of the project is a system solution addressing the intrinsic disadvantage of flash compared with flying-spot LiDAR. In the case of flash LiDAR the scene of interest – or the target – is illuminated completely in one shot. Consequently, the limited available optical power has to be diffused in a larger solid angle for flash imaging LiDAR than for flying-spot LiDAR, and hence a lower optical density is available on the photo-detector’s sensitive surface. When the signal-to-noise ratio (SNR) of the detected light is sufficient, the two-dimensional photo-detector array of a flash imaging LiDAR captures in one snapshot a 3D image or a Digital Elevation Map (DEM) of the target.

If the lower relative optical power density disadvantage can be compensated for, then the flash architecture offers advantages for system miniaturization and simplification over the flying-spot architecture.

In the frame of FOSTERNAV to compensate for the intrinsic disadvantage, the illumination source of the LiDAR is a controllable laser head that can generate either several beams with low relative divergence or one single beam with a large relative divergence. For the receiver, an Active Pixel Sensor (APS) made of demodulation pixels is used. This detector or imager generates DEM by measuring the Time-Of-Flight (TOF) of the modulated light hitting each pixel.

FOSTERNAV started in January 2011and will last three years. So far, the project’s team has gone through the first phase of the project focusing at identifying and analyzing several missions’ term of requirements for soft-landing and rendezvous, and to derive from the results, system and subsystems specifications of the flash 3D imaging LiDAR. The second phase will concentrate on the sensor prototype design and the third on the assessment of the prototype. [View Full Paper]

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NPAL EVOLUTIONS APPLIED TO ESA'S LUNAR LANDER MISSION

D. Fischer,* E. Zaunick,* B. Polle† and E. Kervendal‡

In 2010, The European Space Agency has kicked off the phase B1 of Lunar Lander: a mission aiming to autonomously, safely, softly and precisely landing a spacecraft at the lunar South Pole by 2018. Astrium, in charge of mission analysis and spacecraft design, is actively involved in the design of the GNC system for which innovative solutions had to be implemented in order to meet stringent landing requirements. Built upon work performed during the Lunar Lander phase A, Astrium proposes a navigation system based on the NPAL solution developed with ESA, and improved through internal studies at Astrium. Compatible with the very sequence of lunar descent and landing as well as needs for Hazard Detection and Avoidance, this navigation solution is designed to meet both real time and CPU load challenges inherent to such a lunar endeavor. Recent test campaigns with computer-generated and data acquired with a helicopter have also confirmed that navigation solution is compatible with soft and precision landing requirements. [View Full Paper]

Astrium Satellites, AOCS & GNC, Flight Dynamics Department, Transnational Unit in Central Engineering:

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AAS 12-077

EUROPEAN SPACE AGENCY (ESA): NEW REACTION WHEEL CHARACTERISATION TEST FACILITY (RCF)

Mark Wagner,[*] Stephen Airey,[†] Gaetan Piret[‡] and Phuoc Le[§]

Future scientific and Earth observation space missions call for stringent requirements with regard to the micro-vibration environment on-board of a spacecraft. The experimental verification of the compliance to such requirements on a fully assembled spacecraft on ground e.g. during an environmental test campaign is hardly feasible because of the complexity to establish representative boundary conditions and the difficulty to realize a satisfying decoupling from the disturbing surrounding. The unit level measurement of the micro-vibration environment induced by a unit under operation e.g. mechanisms or reaction wheel is much more straight forward to be set up. The data measured on the unit can be used as input to dynamic simulation models of the overall spacecraft system in order to assess the severity of induced perturbations on critical performance parameters such as pointing accuracy.

The European Space Agency (ESA) initiated the development of a new test facility with the objective to quantify very low level forces and moments in six degrees of freedom induced by spacecraft units under operation. The design of this new test facility was driven by the need to characterize the interface dynamics of reaction wheels at different speeds. Thus facility was named Reaction Wheel Characterization Facility (RCF). Pre-studies and market survey revealed that commercially available dynamometers and force tables were not able to satisfy the demanding requirements. The most challenging task was to establish a design able to acquire very low amplitude levels (<10mN to 200N) in a frequency regime of interest from 5Hz up to 1kHz and making use of as many commercial off the shelf equipment as possible.

This paper introduces the principle design of ESA's Reaction Wheel Characterization Facility. In addition, the results of the test campaign conducted to demonstrate its performance are addressed. [View Full Paper]

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IMAGE NAVIGATION AND REGISTRATION FROM UNMANNED AERIAL VEHICLES

SESSION VIII

This session will focus on hardware and software systems for the Image Navigation and Registration (INR) from Unmanned Aerial Vehicles (UAVs).Talks will cover UAV systems that can be used for INR of sensors installed on the UAV platform and will also report on instruments with an autonomous INR capability. Applications will include both defense and civilian applications and will apply both to the remote collection of image data and to image guidance systems for the UAV.

National Chairpersons:

Gary Bullock
Naval Surface Warfare Center

Matt Fladeland
NASA Ames Research Center

Local Chairpersons:

Bill Emery
University of Colorado

Scott Francis
Lockheed Martin Space Systems

The following papers were not available for publication:

AAS 12-086
(Paper Withdrawn)

The following paper numbers were not assigned:

AAS 12-088 to -090

POPULATION OF A RANGE BEARING MAP FOR LOCAL OBSTACLE AVOIDANCE USING MONOCULAR VISION

Sean Quinn Marlow[*] and Jack W. Langelaan[†]

This paper presents a method for navigation of a small unmanned aerial vehicle (UAV) through an unsurveyed static environment using a single forward pointing camera and a GPS corrected inertial measurement unit. The size and maneuverability of small UAVs allows for low altitude flights in complex environments. Without accurate estimates of obstacle locations, successful navigation is not possible. Using camera measurements of bearing and optical flow and estimates of vehicle motion, a range bearing map is created. The range bearing map stores estimates of the closest obstacle in a particular region, the information necessary to perform local obstacle avoidance. By discretizating the area around the vehicle by angle and forcing each region to contain an estimated range, complex environments can be modeled. Results of two-dimensional simulations are presented using a potential field method for obstacle avoidance and navigation. [View Full Paper]

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CLOUD COMPUTING ON WINGS: APPLICATIONS TO AIR QUALITY

H. Chen,*
R. Hansen,* J. Huang,* E. Pereira,* R. Swick,* D. Vizzini,* R. Sengupta,†
C. M. Kirsch,‡ F. Landolt,‡ M. Lippautz,‡ A. Rottmann‡ and R. Trummer‡

We extend the concept of cloud computing developed in the cyber–world to sensors mounted on aircraft, creating a new paradigm called the Cloud on Wings. Under the proposed framework, a server hosted on an airplane is allowed to move in space and perform sensing and actuation. The analog of cloud computing's virtual machine, in the Cloud on Wings, is the "virtual vehicle." Virtual vehicles are hosted by real vehicles, such as commercial flights or unmanned air vehicles. We explore air quality monitoring as a service enabled by the Cloud on Wings. We describe a low cost, low liability measurement aircraft built and tested by us for measurement in close proximity to people, our server design and implementation for the Cloud on Wings, and algorithms to operate the cloud efficiently. [View Full Paper]

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AAS 12-083

THREE DIMENSIONAL GEOLOCATION FROM UAS IMAGERY: INVESTIGATING AN INVERSE STRUCTURE-FROM-MOTION MODEL

Keith W. Cunningham and Rayjan Wilson[*]

We discuss an inverse approach to Structure-from-Motion that enables the geolocation of an unmanned aerial system using a single, two-dimensional image correlated to a digital surface model. This approach allows the calculation of airborne xyz position coordinates as well as the orientation parameters of omega (ω), phi (φ), and kappa (κ). This theoretical investigation with idealized models seems promising.
[View Full Paper]

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FROM WEATHER SATELLITES TO AERIAL IMAGING: BRINGING IMAGE NAVIGATION AND REGISTRATION DOWN TO EARTH

James L. Carr,*† Nate Allen,* Joseph Fox-Rabinovitz,* Christopher Miller,* Norman Lo,* Stephen J. Fujikawa‡ and Lanny Herron§

Image Navigation and Registration (INR) is an engineering term used with geostationary weather satellites. INR technology enables accurate determination of geo-locations ("navigation") for sensed objects. In weather satellite applications, image geometric distortions with respect to a standard fixed-grid projection are either compensated by onboard Image Motion Compensation (IMC) or by on-ground remapping ("registration"). Repeated acquisitions of the same image frame will then be registered to each other, which enables movie making. The use of geometric observations made through the aperture of the sensor itself is a general characteristic of such INR solutions. The current generation of Geostationary Operational Environmental Satellites (GOES) uses star senses and landmarks from which IMC model coefficients are determined. The next generation of GOES weather satellites will augment this capability with GPS from geostationary orbit. Current capabilities navigate and register imagery to the sub-pixel level. The INR problem is more challenging from an aerial platform as its flight dynamics are less predictable and consideration of the three-dimensional geometry of the scene is required. We describe our work in this area and the application of INR technology from GOES to the FalconScan commercial imaging venture. Low-cost FalconScan payloads fly on single engine airplanes, but they are well suited to UAVs once regulations permit such flights in national airspace. FalconScan processed almost 200 collections in 2011 for customers in the U.S. and Canada. Product mosaics are at 10cm to 50cm resolution and cover large areas that may include up to one billion pixels. Meter-level INR accuracies are achieved over these large survey spaces. We describe these products and some of the challenges in verification of their INR.

Key words: INR, Aerial Remote Sensing, GOES, Landmarks, Mosaic, UAV.

[View Full Paper]

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COSTAL SURVEY USING UNMANNED AERIAL SYSTEMS

Gregory Walker*

Generating high-resolution 3-dimensional costal imagery from imagery collected on small-unmanned aircraft is opening many opportunities to study marine wildlife and its use of costal habitats as well as climate change effects on northern coasts where storm surges are radically altering the coastline. Additionally, the technology is being evaluated for oil spill response planning and preparation. The University of Alaska Fairbanks works extensively with small-unmanned aircraft and recently began evaluating the aircraft utility for generating survey grade mapping of topographic features. When generating 3-D maps of coastal regions however there are added challenges that the University have identified and are trying to address. Recent projects with Alaska fisheries and BP Exploration Alaska have demonstrated that small-unmanned aircraft can support the generation of map-based products that are nearly impossible to generate with other technologies. [View Full Paper]

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AAS 12-087

OPTICAL TERRAIN NAVIGATION FOR PINPOINT LANDING: IMAGE SCALE AND POSITION-GUIDED LANDMARK MATCHING

Jeff Delaune,[*] Guy Le Besnerais,[†] Martial Sanfourche,[†] Thomas Voirin,[‡] Clément Bourdarias[§] and Jean-Loup Farges[**]

Map-based accurate navigation is a requirement for future planetary missions requiring a pinpoint landing capability. Based on an Extended Kalman Filter tight fusion architecture between a camera and inertial sensors, this paper proposes a new method to match descent image landmarks with orbital ones down to very low altitude while being robust to 3D terrain topography and illumination changes. It is based on the idea that image scale can be used as an additional description for a landmark. Filter estimates are used to predict the research area and scale of the landmarks in the descent image. A Monte Carlo analysis using software simulation shows its compliance with pinpoint landing requirements. [View Full Paper]

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RECENT EXPERIENCES IN GUIDANCE AND CONTROL

SESSION IX

Lessons learned through experience prove most valuable when shared with others in the GN&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.

National Chairpersons:	Kyle Henderson Air Force Research Laboratory
	Mimi Aung NASA Jet Propulsion Laboratory
Local Chairpersons:	Brian Clapp Lockheed Martin Space Systems
	Larry Germann Left Hand Design

The following paper number was not assigned:

AAS 12-099

IMPLEMENTING THE MARS SCIENCE LABORATORY TERMINAL DESCENT SENSOR FIELD TEST CAMPAIGN

James F. Montgomery,* James H. Bodie,* Joseph D. Brown,† Allen Chen,* Curtis W. Chen,* John C. Essmiller,* Charles D. Fisher,† Hannah R. Goldberg,‡ Steven W. Lee* and Scott J. Shaffer§

The Mars Science Laboratory (MSL) will deliver a 900 kg rover to the surface of Mars in August 2012. MSL will utilize a new pulse-Doppler landing radar, the Terminal Descent Sensor (TDS). The TDS employs six narrow-beam antennas to provide unprecedented slant range and velocity performance at Mars to enable soft touchdown of the MSL rover using a unique sky crane Entry, Descent, and Landing (EDL) technique. Prior to use on MSL, the TDS was put through a rigorous verification and validation (V&V) process. A key element of this V&V was operating the TDS over a series of field tests, using flight-like profiles expected during the descent and landing of MSL over Mars-like terrain on Earth. Limits of TDS performance were characterized with additional testing meant to stress operational modes outside of the expected EDL flight profiles. The flight envelope over which the TDS must operate on Mars encompasses such a large range of altitudes and velocities that a variety of venues were necessary to cover the test space. These venues included an F/A-18 high performance aircraft, a Eurocopter AS350 AStar helicopter and 100-meter tall Echo Towers at the China Lake Naval Air Warfare Center. Testing was carried out over a five year period from July 2006 to June 2011. TDS performance was shown, in general, to be excellent over all venues. This paper describes the planning, design, and implementation of the field test campaign plus results and lessons learned. [View Full Paper]

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ORION MULTI-PURPOSE CREW MODULE PAD ABORT FLIGHT TEST OVERVIEW AND SUMMARY

Richard R. Burt, William D. Pratt and Michael E. Begley*

The NASA Orion Multi-Purpose Crew Vehicle (MPCV) program conducted the first flight test of the active ascent abort system on May 6th, 2010. The flight test was executed at the White Sands Missile Range (WSMR) in New Mexico with the objective to demonstrate the capability of the Launch Abort Vehicle (LAV) to successfully perform an abort from the launch pad. This paper will provide an overview of the Pad Abort 1 (PA-1) mission, an overview of the flight vehicle and GNC system, a review of the flight performance in contrast to the pre-flight predictions, and some GNC findings from the test. [View Full Paper]

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NIGERIASAT-2 AOCS: RESULTS FROM THE FIRST 90 DAYS IN ORBIT

Andrew Carrel,[*] Tony Holt,[†] A. Gavin Y. Johnston,[‡] Gokhan Yuksel,[§] Allon Jameson,[§] Yoshi Hashida,[**] Andrew Cawthorne[††] and Guy Richardson[‡‡]

The NigeriaSat-2 mission is a high resolution imaging system launched on 17th August, 2011. The 300 kg satellite will provide high-resolution (2.5m) imagery to support Nigeria natural resource management. The Attitude and Orbit Control Subsystem (AOCS) provides the stability required by the imager, a geolocation accuracy of 45m and an agile off-nadir targeting capability which can support a range of imaging modes. This paper discusses the evolution of the AOCS design from SSTL's existing heritage, which enables operational high-resolution imagery to be captured by a small satellite and reports on the performance of the system during the initial commissioning phase during the 90 days after launch. Finally, the paper discusses how the lessons learned during the commissioning process are already being fed into the design of future missions, in particular, the DMC3 Earth observation constellation. [View Full Paper]

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AAS 12-094

DEMETER – IN-ORBIT RESULTS OF DEORBITATION*

Christine Fallet and Jérôme Maureau†

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

DEMETER is the first application of the MYRIADE micro-satellite program. Launched in 2004 with a two years expected lifetime, DEMETER was designed neither for a fluidic passivation nor an electric one. Since 2008, the European code concerning the space debris mitigation requires to limit to 25 years the orbital lifetime after the end of operational mission for LEO spacecrafts and the passivation of all components with risks of explosion or creation of debris. In 20l0, after seven years of successful operational lifetime, it has been decided to stop the DEMETER mission and to realize the fluidic and electric passivation of the spacecraft to comply with the European code. The paper will introduce the DEMETER spacecraft. It will present the deorbitation strategy adapted to the spacecraft architecture. Then, it will focus on the G&C studies performed to demonstrate the adequacy of the control spacecraft subsystem with the strategy. It will also describe the tools developed to follow the deorbitation. After the description of the on-ground strategy validation, it will present the in-orbit results of the fluidic and electric passivation of the spacecraft. [View Full Paper]

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AAS 12-095

INITIAL GN&C PERFORMANCE ON THE JUNO SPACECRAFT

Jay A. St. Pierre,* Kristen M. Francis,† Jason A. Wynn‡ and Christopher T. Voth§

Juno, part of the NASA New Frontiers Program, is a spin stabilized, solar-powered spacecraft launched on August 5th, 2011 and destined to arrive at Jupiter in July, 2016. The attitude determination sensors consist of two Stellar Reference Units, two Inertial Measurement Units, and two Spinning Sun Sensors. Attitude control is achieved through twelve one pound thrusters and one main engine, supplemented by a passive nutation damper. The principal axis of the vehicle has been aligned to the High Gain Antenna boresight by actuating the solar panels. This paper will discuss the initial performance of the GN&C subsystem. The Juno spacecraft is managed by the Jet Propulsion Laboratory in Pasadena, California, and was built and is operated by Lockheed Martin Space Systems in Denver, Colorado. [View Full Paper]

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GUIDANCE AND CONTROL CHALLENGES TO THE MESSENGER SPACECRAFT IN ACHIEVING AND OPERATING FROM ORBIT AT MERCURY

Sarah H. Flanigan,[*] Daniel J. O'Shaughnessy[†] and Eric J. Finnegan[‡]

Next to the launch of the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft, the Mercury orbit insertion (MOI) maneuver was the most critical activity of the mission. The MOI maneuver was the largest of the mission by nearly a factor of three and required extensive planning and simulation to ensure insertion into the desired science orbit. The criticality of the MOI maneuver also prompted a unique fault management schema. Once in orbit about Mercury, a series of orbit-correction maneuvers was required in the year-long primary mission to ensure that the orbit continued to meet the science requirements. These maneuvers capitalized on the flexibility in the guidance and control (G&C) system, as they required operational strategies unforeseen at the time the G&C software was designed. [View Full Paper]

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UNDERSTANDING SPACECRAFT AGILITY FOR ORBIT TRANSFERS ON THE DAWN LOW-THRUST MISSION*

Brett A. Smith,† C. Anthony Vanelli‡ and Allan Y. Lee§

Dawn is a low-thrust interplanetary spacecraft currently orbiting the asteroid Vesta. The spacecraft launched in September 2007 on a mission to better understand the early creation of the solar system, and recently arrived at Vesta in May of 2011. Three solar electric ion-propulsion engines provide the primary thrust for the Dawn spacecraft. Ion engines very efficiently produce a small thrust magnitude, and therefore must thrust almost continuously for long periods to realize the necessary change in velocity to reach Vesta, and eventually Ceres.

The amount of time that must be spent thrusting presents unique challenges to executing orbit transfers on low-thrust missions. The necessary delta-V cannot be easily decomposed into a subset of fixed inertial attitudes, leading to the need to use time-varying thrust attitudes. Changing spacecraft orientation while thrusting imposes dynamic constraints on orbit transfer thrust designs, in addition to geometric pointing constraints. The dynamic constraints increase the coupling between the navigation design and the attitude control system, further challenging the design of flyable orbit transfers. Additionally, software commanding limitations and the need to maintain positive solar array power made developing simplified constraints for the navigation team a very non-linear problem. Post-launch development of new tools and processes was necessary to aid in the design of flyable orbit transfer trajectories.

This paper briefly discusses the general attitude control issues with orbit transfers on a low thrust mission, and details their specific resolution on the Dawn mission. The discussion presents the tools and strategies developed to ensure successful design of orbit transfer thrust trajectories that remain safely within the capabilities of the Dawn attitude control system. With Dawn having recently completed a significant percentage of the orbit transfers at Vesta, this paper compares predicted performance and capabilities with actual spacecraft performance during orbit transfers. Being NASA's first ion-propulsion mission to orbit an asteroid provided numerous lessons that will be beneficial to all future low thrust missions. [View Full Paper]

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AAS 12-098

STARDUST-NEXT: LESSONS LEARNED FROM A COMET FLYBY MISSION*

Aron A. Wolf,† Timothy Larson,‡ Paul Thompson,§ Timothy McElrath,§ Shyam Bhaskaran, Steven Chesley,§ Kenneth P. Klaasen†† and Allan Cheuvront‡‡**

The Stardust-NExT (New Exploration of Tempel) mission, a follow-on to the Stardust prime mission, successfully completed a flyby of comet Tempel-1 on 2/14/11. However there were many challenges along the way, most significantly low propellant margin and detection of the comet in imagery later than anticipated. These challenges and their ramifications forced the project to respond with flexibility and ingenuity. As a result, the flyby at an altitude of 178 km was nearly flawless, accomplishing all its science objectives. Lessons learned on Stardust-NExT may have relevance to other spacecraft missions. [View Full Paper]

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POSTER SESSION

POSTER SESSION

Local Chairperson: Kyle Miller
Ball Aerospace &
Technologies Corp.

The following paper numbers were not assigned:

AAS 12-009 to -010

AAS 12-001

IN-SITU SUB-MILLIMETER SPACE DEBRIS DETECTION USING CUBESATS

Katharine M. Brumbaugh,[*] Henri C. Kjellberg,[*] E. Glenn Lightsey,[†] Alexander Wolf[‡] and Rene Laufer[§]

Space debris is a major concern for both government and industry space assets. With more debris posing a danger to vital communications, scientific and military satellites, cataloguing the space debris environment is a growing problem. The existing ground-based technology, however, is limited to sensing space debris particles which are larger than 1 cm. While the up-and-coming "Space Fence" will have the ability to detect smaller particles, it will primarily use this information to warn satellite operators if their satellite is in danger. However, there is an unmet need to provide in-situ data for scientists in order to characterize the space debris environment to a higher fidelity.

In particular, there is a significant gap in knowledge about particles smaller than 1 cm. These particles may cause damage to operational satellites: hits from space dust and debris particles of only 0.01 cm in diameter have required that Space Shuttle windows be replaced; 0.02 cm particles have penetrated astronaut EVA suits. Unfortunately, not much is known about this particle size range other than experiments which are analyzed once they have returned to Earth (such as LDEF and MISSE). There has not, to this time, been an in-situ small particle measurement method which provides data collection of sub-millimeter particles while on orbit.

The University of Texas at Austin (UT-Austin) is developing a 3U CubeSat to satisfy this in-situ data collection need. CubeSats are relatively inexpensive compared to larger nano- or micro-satellites and have a higher ability to launch quickly. This paper explores the importance of studying small space debris particles in general as well as the ability of CubeSats to provide this service. A case study of a current satellite project at UT-Austin is presented which employs a 3U CubeSat to study the sub-millimeter space debris size range and provide in-situ data collection using a piezoelectric dust detector. The case study concludes with a grassroots cost analysis of 3U CubeSat production costs as compared to traditional cost models used in the aerospace industry. This comprehensive case study shows the 3U CubeSat as a viable platform for missions studying space debris. [View Full Paper]

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MEETING ORBIT DETERMINATION REQUIREMENTS FOR A SMALL SATELLITE MISSION

Adonis Pimienta-Peñalver,[*] Richard Linares[†] and John L. Crassidis[‡]

A study is conducted with the goal of utilizing estimation techniques on measurements obtained from various onboard resources such as a Sun sensor, a magnetometer and a commercial GPS unit in order to approximate the true trajectory of the vehicle in realtime and minimize the error associated with the process. This carries significant relevance to the field of orbit determination, where a small mission could operate a relatively cheap system for tracking purposes. This paper models a GPS sensor to become available only 5 minutes each day, which approximates a worst-case scenario where sparse pseudorange data is only possible due to suboptimal operating conditions for commercial GPS receivers taken to the space environment. Using a dynamic propagation model, which includes effects of Earth's gravity, J_2 zonal harmonics, and atmospheric drag, a sequential filtering method is used in order to estimate the states (position and velocity) of the vehicle with respect to time. This study demonstrates the capability of this system to achieve an error of approximately 15 meters, which is greatly influenced by the inclusion of a low-cost GPS module as an alternative to high end units that may be unaffordable for low-budget small satellite missions. [View Full Paper]

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AAS 12-003

HELIOGYRO SOLAR SAIL BLADE TWIST CONTROL

Daniel Guerrant,[*] Dale Lawrence[†] and W. Keats Wilkie[‡]

The heliogyro is an ultra-lightweight, high performance, spinning solar sail architecture. The sail is divided into long blades supported by the centripetal acceleration of the spacecraft's spin alone. The heliogyro's attitude and thrust vector are controlled by changing the cyclic and collective blade pitch similar to a helicopter. The heliogyro's reflective sail membranes are packaged and unspooled from rolls, greatly simplifying deployment operations compared with square-rigger solar sail designs. The heliogyro also easily scales to the huge dimensions required for many applications enabled by solar sail propulsion. One principal concern for the feasibility of heliogyros is the ability to adequately control the dynamic response of their long, unsupported blades, and in particular, to damp disturbances caused by maneuvering transients. First, the finite element equations of motion for a thin membrane are developed and validated for a single blade in twist. A Proportional/Derivative/Feed-Forward controller is implemented at the root. The control gains are optimized both through the stiffness analysis and parametrically. It is found that the blade vibrations from all maneuvers of interest can be damped in less than eight minutes using root actuation alone. This is a significant improvement over previous work in the area and is sufficiently rapid for even the most demanding heliogyro missions. [View Full Paper]

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AAS 12-004

MULTIOBJECTIVE GENETIC ALGORITHM FOR STABILITY ANALYSIS OF FLEXIBLE ARTICULATED PLANTS

Ashley Moore,* Marcus R. George† and Davin K. Swanson‡

Flexible spacecraft with multiple articulated degrees of freedom result in model complexity and configuration space size that can render typical stability verification methods computationally infeasible. Therefore, this work explores the use of a multiobjective genetic algorithm for an automated stability search tool that aims to identify plant configurations that lead to poor stability. The genetic algorithm is applied to an example plant with one articulated degree of freedom and quickly locates the global minima for all specified stability margins. The real power of the genetic algorithm emerges when applied to a system with multiple articulated degrees of freedom. A lumped parameter plant with two solar arrays and two articulated payloads is fabricated to exhibit poor stability behavior in certain configurations. The genetic algorithm successfully identifies these problematic configurations. [View Full Paper]

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AAS 12-005

ANALYSIS OF THE TOUCH-AND-GO SURFACE SAMPLING CONCEPT FOR COMET SAMPLE RETURN MISSIONS*

Milan Mandić, Behçet Açıkmeşe, David S. Bayard and Lars Blackmore†

This paper studies the Touch-and-Go (TAG) concept for enabling a spacecraft to take a sample from the surface of a small primitive body, such as an asteroid or comet. The idea behind the TAG concept is to let the spacecraft descend to the surface, make contact with the surface for several seconds, and then ascend to a safe location. Sampling would be accomplished by an end-effector that is active during the few seconds of surface contact. The TAG event is one of the most critical events in a primitive body sample-return mission. The purpose of this study is to evaluate the dynamic behavior of a representative spacecraft during the TAG event, i.e., immediately prior, during, and after surface contact of the sampler. The study evaluates the sample-collection performance of the proposed sampling end-effector, in this case a brushwheel sampler, while acquiring material from the surface during the contact. A main result of the study is a guidance and control (G&C) validation of the overall TAG concept, in addition to specific contributions to demonstrating the effectiveness of using nonlinear clutch mechanisms in the sampling arm joints, and increasing the length of the sampling arms to improve robustness. [View Full Paper]

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AAS 12-006

SMART GN&C COMPONENTS FOR SMART SATELLITES

Anja Nicolai,* Antje Deckert,* Christian Raschke* and Stephan Stoltz*

For future satellite design, smart components play an important role. They are easy to integrate, time saving and require less complex GN&C software on board the satellite. With smart components, a modular satellite is possible, where integration and on board software development time is greatly reduced. A smart component does not only have a digital interface, it can also provide telemetry information and includes software models that model and control disturbing influences like temperature gradients or friction. With the for the component required software being developed by the manufacturer, it is especially adapted to the physical properties of the smart component and thus tends to enhance the precision of the component much more than a software developed by the satellite design team. The knowledge once created in designing that software is not lost, but is available for other future satellite projects and lessons learned from previous projects can be used to enhance the smart component even further. If an interface standard is defined, smart components could have plug & play capabilities, making their integration even easier. This paper describes the efforts and successes of creating smart GN&C components by Astro- und Feinwerktechnik as well as lessons learned from the BIRD satellite project. [View Full Paper]

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AAS 12-007

GNC DESIGN AND VALIDATION FOR PRECISION LANDING AT THE MOON AND MARS

Jean-François Hamel,[*] David Beaudette,[†] Vincent Simard-Bilodeau,[†] Jean de Lafontaine,[†] Emanuele Di Sotto,[‡] Nuno Paulino,[‡] Joao Branco,[‡] Guy Johns[§] and Diego de Rosa[**]

Precision landing is a critical and challenging requirement for future planetary exploration landing missions. In order to meet these requirements, a GNC architecture is proposed for autonomous planetary landing applications. The GNC design proves to meet a 200 m landing accuracy at the Moon and a 10 km landing accuracy at Mars, relying on vision-based navigation technologies (for Moon), guided entry (for Mars) and innovative navigation concepts. Performance of the GNC is validated through Monte-Carlo simulations campaigns, in closed-loop in a high-fidelity simulation environment. [View Full Paper]

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SPACECRAFT ATTITUDE AND BODY RATE ESTIMATION WITH MULTI-HEAD STAR SENSOR: CONCEPT, DESIGN AND ON-ORBIT RESULTS

Shoji Yoshikawa,* Katsumasa Miyatake,† Hiroyuki Kawano,† Haruhiko Shimoji,‡ Takeshi Suzuki,§ Yoshinori Kunii,§ Kazumori Hama and Noriaki Oka††**

We have developed a star sensor system with four heads as a prototype of a future small and low-priced satellite attitude controller. To reduce size and cost of the controller, we integrate attitude sensors into star sensors with medium resolution and medium sensitivity and adopt Commercial Off-The-Shelf (COTS) electrical parts for key parts such as CPU and CCD. After its basic design was verified by on-orbit tests, the proposed star sensor system was installed on the 2nd verification satellite of the Space Environment Reliability Verification Integrated System (SERVIS-2) as a primary attitude information source. The SERVIS-2 was launched on June 2nd, 2010 and had been operated smoothly until it ended its mission on June 3rd, 2011. We summarize the concept and design of the proposed star sensor system and report some highlights from the on-orbit results. [View Full Paper]

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TECHNICAL EXHIBITS

SESSION II

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

Local Chairpersons:

Kristen Francis
Lockheed Martin Space Systems

Zach Wilson
Lockheed Martin Space Systems

For most of the Technical Exhibits there was no formal written text available, and therefore most of the papers for this session were not available for publication. The following papers and paper numbers were not available for publication, or were not assigned:

AAS 12-023 to -030

Participants in Technical Exhibits

Company:

a.i. Solutions, Inc.

ACUTRONIC USA Inc.

Astro- und Feinwerktechnik Adlershof GmbH

Ball Aerospace & Technologies Corp.

BEI Precision Systems & Space Company

EADS-Astrium SAS

EADS Sodern

Emergent Space Technologies Inc.

Jena-Optronik GmbH

Lockheed Martin Space Systems Company

MathWorks, Inc.

MIT Space Systems Laboratory

Monarch High School

Rockwell Collins

SELEX Galileo

Sierra Nevada Corporation

SimuLogix

SSBV Space and Ground Systems

Surrey Satellite Technology US LLC

EUROPEAN ASTRIX™ FOG IN-ORBIT HERITAGE*

G. Cros, Ph. Loubières, I. Lainé,† Ph. Guay‡ and S. Ferrand§

In the early 2000s, ASTRIUM SAS, in collaboration with iXBlue (formerly IXSEA), a French SME, developed with CNES and ESA support, an inertial reference unit (IRU) family for a wide range of space applications. These fully European products, called "ASTRIX™", are based on solid-state (FOG) technology. The first flight models were delivered in 2006 and 2007, and production is now running smoothly. These IRUs have been selected by a range of applications as varied as PLANCK, PLEIADES, AEOLUS, GAIA, EUROSTAR, GALILEO IOV, SENTINEL1&2, JPSS_1 etc. covering the different orbit types (LEO, MEO, GEO and Lagrange). They fully benefit from the unequalled potential of FOG technology and from its particularly good suitability to high performance space applications requirements. The ASTRIX family currently comprises three fully qualified products, namely ASTRIX200, ASTRIX120 and ASTRIX120HR, which are shortly presented in this paper.

A total of 22 FOG channels, cumulating to date 170 000 operating hours, are currently in orbit (latest being with PLEIADES ASTRIX200 launched on Soyouz, Kourou, on Dec 11). Up to Feb. 2012, the PLANCK (L2) ASTRIX120 has continuously been in operation for two and half years and the COMS (GEO) ASTRIX120HR for one and half year. After having briefly introduced the origin of the product development, the paper presents the observed in-orbit performances of these gyros in detail. The differences between these two missions, their different orbits and use of gyros give a particularly interesting feedback on the excellent behavior of this technology. One of the 4 PLANCK FOGs is oriented perpendicularly to the spin axis, making it possible to accurately characterize its measurement noise, and confirming that this remains unchanged with regard to ground acceptance test results. The COMS gyros are part of the spacecraft AOCS control loop, and thus are a major contributor to the excellent mission performances. During their use in the transfer phase, their high accuracy gave unprecedented visibility of micro-vibration and flexure in the various equipments and instruments, as well as the effects of spacecraft outgassing. Very positive lessons learnt from this in-orbit heritage are discussed. The paper concludes by briefly presenting the ASTRIX family latest development, the ASTRIX3M2, a promising three-axis, cost-competitive, high-performance IMU.

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* This paper appears in full in this volume as paper AAS 12-074, pp. 481–502.

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AAS 12-022

2012 WITH THE SHAZBOTS

Aida Castillo, Taylor Andrews, Will Searight, Dylan Cassidy, David Sahud, Rebecca Minari, Noah Rosenthal and Daniel Early*

FIRST (For Inspiration and Recognition of Science and Technology) is an organization created with the purpose of encouraging and challenging students of all ages and nationalities to employ engineering, programming, web design, business, and management skills while working together in real-world circumstances. FIRST holds the FRC tournament for high school students, in which Monarch Shazbots has participated in since 2003, and our team will compete in the 2012 Colorado FIRST Regional, with the help of our sponsors, including the AAS Rocky Mountain Section. Throughout the season we do so many things, and we would like to take this opportunity to show you a bit more about not only the building process, basic design, and robot functions, but also our experiences from build season and the lessons we learned as a FRC team.
[View Full Paper]

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