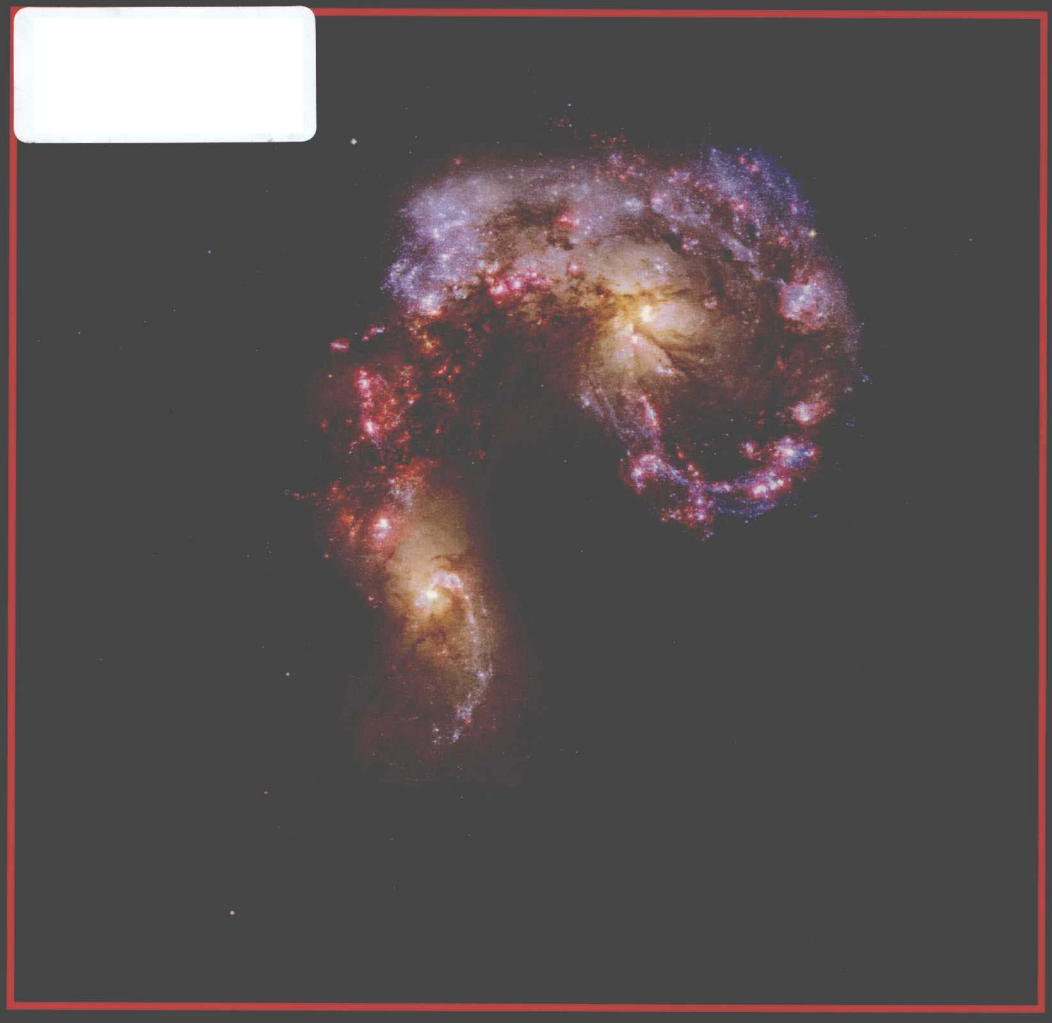
GUIDANCE AND CONTROL 2013

Edited by
Lisa R. Hardaway



Volume 149

ADVANCES IN THE ASTRONAUTICAL SCIENCES

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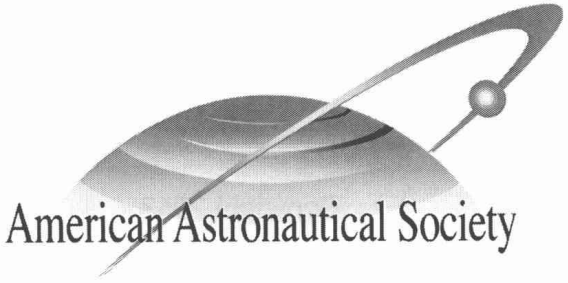

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FOREWORD

HISTORICAL SUMMARY

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

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

Back in Denver, Bud and Don approached the AAS Section Chair, Bob Culp, with their proposal. In 1977, Bud Gates, Don Parsons, and Bob Culp organized the first conference, and began the annual series of meetings the following winter. Dan and Lou were delighted to see their concept brought to reality and joined enthusiastically from afar. In March 1978, the First Annual Rocky Mountain Guidance and Control Conference met at Keystone, Colorado. It met there for eighteen years, moving to Breckenridge in 1996 where it has been for the last 18 years. The 2013 Conference was the 36th Annual AAS Rocky Mountain Guidance and Control Conference.

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

The style was established at the first Conference, and has been adhered to strictly until 2013. No parallel sessions, three-hour technical/tutorial sessions at daybreak and late afternoon, and a six-hour ski break at midday are the biblical constraints. For the first fifteen Conferences, the weekend was filled with a tutorial from a distinguished researcher from academia. The Conferences developed a reputation for concentrated, productive work that more than justified the hard play between sessions.

After the 2012 conference, it was clear that overall industry budget cuts and a mis-conception by industry and government leaders that this conference was a ski trip with a few side conversations were leading to reduced attendance and support. In an effort to meet the needs of the constituents, several changes were suggested that did not meet the original

founding style. The first implementation of these changes was to add parallel sessions for 3 of the 8 sessions on a trial basis during the 2013 conference and was welcomed by most attendees.

A tradition from the beginning and retained in 2013 has been the Conference banquet. It is an elegant feast marked by informality and good cheer. A general interest speaker has been a popular feature. The banquet speakers have been:

Banquet Speakers

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

2006 Mary E. Kicza, Deputy Assistant Administrator for Satellite and Information Services, NASA, "NOAA: Observing the Earth from Top to Bottom."

2007 Patrick Moore, Consulting Senior Life Scientist, SAIC and the Navy Marine Mammal Program, "Echolocating Dolphins in the U.S. Navy Marine Mammal Program."

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

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

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

2011 Joe Tanner, Former NASA Astronaut, 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*."

2013 Thomas J. "Dr. Colorado" Noel, Ph..D., Professor of History and Director of Public History, Preservation & Colorado Studies at University of Colorado Denver, "Welcome to the Highest State: A Quick History of Colorado."

OBSERVATIONS: CHALLENGES AND RESPONSIBILITIES

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

Tutorials

1978 Professor Dan DeBra, Stanford University, "Navigation."

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

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

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

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

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

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

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

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

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

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

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

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

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

After 1991 there were no more tutorials, but special sessions or featured invited lectures served as focal points for the Conferences. In 1992 the theme was "Mission to Planet Earth" with presentations on all the large Earth Observer programs. In 1993 the feature was "Applications of Modern Control: Hubble Space Telescope Performance Enhancement Study" organized by Angie Bukley of NASA Marshall. In 1994 Jason Speyer of UCLA discussed "Approximate Optimal Guidance for Aerospace Systems." In 1995 a special session on "International Space Programs" featured programs from Canada, Japan, Europe, and South America. In 1996, and again in 1997, one of the most popular features was Professor Juris Vagners, of the University of Washington with "A Control Systems Engineer Examines the Biomechanics of Snow Skiing." In 2005, Angie Bukley chaired a tutorial session "University Work on Precision Pointing and Geolocation." In 2006, a special day for U.S. Citizens only was inserted at the beginning of the Conference to allow for topics that were limited due to ITAR constraints. In 2007, two special invited sessions were held: "Lunar Ambitions—The Next Generation" and "Project Orion—The Crew Exploration Vehicle." In 2008, a special panel addressed "G&C Challenges in the Next 50 Years." The 2009 Conference featured a special session on "Constellation Guidance, Navigation, and Control." In 2013, the nail-biting but successful landing of *Curiosity* on Mars inspired a special session on "Entry, Descent and Landing Flight Dynamics."

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

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

Scholarship Winners

Academic Year	Aerospace Engr Sciences	Electrical and Computer Engr
1981–1982	Jim Chapel	
1982–1983	Eric Seale	
1983–1984	Doug Stoner	John Mallon
1984–1985	Mike Baldwin	Paul Dassow
1985–1886	Bruce Haines	Steve Piche
1986–1987	Beth Swickard	Mike Clark
1987–1988	Tony Cetuk	Fred Ziel
1988–1989	Mike Mundt	Brian Olson
1989–1990	Keith Wilkins	Jon Lutz
1990–1991	Robert Taylor	Greg Reinacker
1991–1992	Jeff Goss	Mark Ortega
1992–1993	Mike Goodner	Dan Smathers
1993–1994	Mark Baski	George Letey
1994–1995	Chris Jensen	Curt Musfeldt
1995–1996	Mike Jones	Curt Musfeldt
1996–1997	Karrin Borchard	Kirk Hermann
1997–1998	Tim Rood	Ui Han
1998–1999	Erica Lieb	Kris Reed
1999–2000	Trent Yang	Adam Greengard
2000–2001	Josh Wells	Catherine Allen
2001–2002	Justin Mages	Ryan Avery
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

In 2013, in an effort to obtain more student involvement, a special Student Paper Session was added to the program. This session embraces the wealth of research and innovative projects related to spacecraft GN&C being accomplished in the university setting. Papers in this session address hardware and software research as well as component, system, or simulation advances. Papers submitted must have a student as the primary author and presenter. Papers are adjudicated based on level of innovation, applicability and fieldability to near-term systems, clarity of written and verbal delivery, number of completed years of schooling and adherence to delivery schedule. The SpaceX Grand Prize Award for Excellence in the field of GN&C by a Student was awarded.

Student Paper Winners

2013 ***1st Place***: Nicholas Truesdale, Kevin Dinkel, Jedediah Diller, Zachary Dischnew, "Daystar: Modeling and Testing a Daytime Star Tracker for High Altitude Balloon Observatories."
2nd Place: Christopher M. Pong, Kuo-Chia Liu, David W. Miller, "Angular Rate Estimation from Geomagnetic Field Measurements and Observability Singularity Avoidance during Detumbling and Sun Acquisition."
3rd Place: Gregory Eslinger, "Electromagnetic Formation Flight Control Using Dynamic Programming."

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

	Conference Chair	Attendance
1978	Robert L. Gates	83
1979	Robert D. Culp	109
1980	Louis L. Morine	130
1981	Carl Henrikson	150
1982	W. Edwin Dorroh, Jr.	180
1983	Zubin Emsley	192
1984	Parker S. Stafford	203
1985	Charles A. Cullian	200
1986	John C. Durrett	186
1987	Terry Kelly	201
1988	Paul Shattuck	244
1989	Robert A. Lewis	201
1990	Arlo Gravseth	254
1991	James McQuerry	256
1992	Dick Zietz	258
1993	George Bickley	220
1994	Ron Rausch	182
1995	Jim Medbery	169
1996	Marv Odefey	186
1997	Stuart Wiens	192
1998	David Igli	189
1999	Doug Wiemer	188
2000	Eileen Dukes	199
2001	Charlie Schira	189
2002	Steve Jolly	151
2003	Ian Gravseth	178
2004	Jim Chapel	137

2005	Bill Frazier	140
2006	Steve Jolly	182
2007	Heidi Hallowell	206
2008	Michael Drews	189
2009	Ed Friedman	160
2010	Shawn McQuerry	189
2011	Kyle Miller	161
2012	Michael Osborne	140
2013	Lisa Hardaway	181

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

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

On behalf of the Conference Committee and the Section,

Lisa R. Hardaway, Ph.D.
Ball Aerospace & Technology Corp.
Boulder, Colorado

PREFACE

This year marked the 36th anniversary of the AAS Rocky Mountain Section's Guidance and Control Conference. It was held in Breckenridge, Colorado at the Beaver Run Resort on February 1-6, 2013. This year was also the first year of an expected several years of reformatting to be more in-line with industry expectations and government budgets. The planning committee and the national chairs took this in stride and created an excellent conference experience. I thank all deeply for their hard work and flexibility. Despite the looming threat of Sequestration and several cancellations by government employees, the attendance kept steady at 181, most likely due the parallel sessions and increased student attendance.

The conference formally began on the morning of February 2nd with a new session of student papers chaired by Dr. Tim Crain, the Morpheus Flight Dynamics Lead at NASA's Johnson Space Center. This session was designed to embrace the wealth of research and innovative projects related to spacecraft GN&C being accomplished in the university setting. Papers submitted had a student as the primary author and presenter and were adjudicated based on level of innovation, applicability and fieldability to near-term systems, clarity of written and verbal delivery, number of completed years of schooling and adherence to delivery schedule. The SpaceX Grand Prize Award for "Excellence in the Field of GN&C by a Student" was awarded.

Due to scheduling conflicts, our keynote speaker took the stage in the late afternoon instead of the traditional morning slot. Mr. Gentry Lee of the Jet Propulsion Laboratory spoke to "From Viking to Curiosity: Reflections on the Exploration of Mars." Closely following the successful landing of *Curiosity*, the GN&C community appreciated the inside looks at entry, descent and landing capabilities through the years.

To cap off the day, the *Technical Exhibits* session was held in the afternoon. Twenty-four companies participated in the technical exhibits with many hardware demonstrations as well as fostering excellent technical interchanges between conferees, vendors, and family. Students from Monarch High School in Louisville, Colorado and from several universities also participated. The session was accompanied by an excellent buffet dinner. Many family members and children were present, greatly enhancing the collegiality of the session. The highly experienced team of Kristen Scott and Meredith Larson did an outstanding job organizing the vendors and exhibits.

February 3rd began with the first ever parallel sessions, *Advances in GN&C Software* and *Advances in GN&C Hardware*. The response to the request for papers for both sessions was enormous and both sessions were well attended. After an educational workshop presented by Math Works, Inc. entitled "Model-based Design of Satellite Dynamics" for those interested in the development and implementation of a satellite spin-stabilized control method, the afternoon session continued in the parallel vein with *Human Spaceflight GN&C*,

addressing the new paradigms of GN&C concepts applied to human spaceflight and *Position Navigation and Timing*, which concentrated on global positioning systems.

Monday morning the 4th of February was devoted to a long but exciting session *Entry, Descent and Landing Flight Dynamics*. Topics ranged from Mars landers to closed-looped test beds. Prior to the banquet in the evening, a foreshortened but fun afternoon session addressed possible future developments in *GN&C Beyond 2022*.

Thomas J. "Dr. Colorado" Noel, Ph.D., Professor of History and Director of Public History, Preservation & Colorado Studies at University of Colorado Denver entertained the attendees with a presentation entitled "Welcome to the Highest State: A Quick History of Colorado." The banquet food was excellent, as usual, thanks to the great staff at Beaver Run and the conference's own Kristen Scott.

Tuesday, February 5th continued with a warm trend outside while inside attendees were treated to several excellent papers about *GN&C Operations Around Asteroids and Comets*. Four missions were discussed as well as some advanced technologies. The afternoon brought another set of parallel sessions, *Rendezvous, Proximity Operations and Docking* and *Nested Control Loops Leveraging Payload Capabilities*. Both sessions provided insight into these important GN&C topics.

The conference wrapped up on the morning of the 6th with the ever popular *Recent Experiences* session. The valuable lessons purveyed in this session by our most experienced colleagues will go a long ways toward creating successful missions in the future.

Overall, the 36th annual conference was interesting and engaging, with many unique experiences. Technically, we are maintaining the high standards set by our predecessors while welcoming a new generation of conferees to continue the traditions of our founders. The technical committee, session chairs, and national chairs were a pleasure to work with. Special thanks go to both Carolyn O'Brien of Lockheed Martin and Liz Garret from Ball Aerospace for their abilities to herd the engineers, physicists, and mathematicians in the right direction, as well as keep me on-track and sane throughout the process.

Lisa Hardaway, Ph.D., Conference Chairperson
2013 AAS Guidance and Control Conference

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