

44th AEROSPACE MECHANISMS SYMPOSIUM

Cleveland, Ohio
May 16-18, 2018

Hosted by NASA Glenn Research Center and Lockheed Martin Space
Organized by the Mechanisms Education Association

SYMPOSIUM OBJECTIVES

This symposium is concerned with the problems of design, fabrication, test, and operational use of aerospace mechanisms. Emphasis is on hardware developments. The symposium provides a social and technical forum for personnel active in the field of mechanisms technology, as well as providing a source of information for others interested in this field. The symposium rotates among eight NASA Centers and attracts papers and attendees from all over the world.

SYMPOSIUM LOCATION

The Hilton Cleveland Downtown in Cleveland, Ohio is the site for all technical sessions.

SYMPOSIUM ACTIVITIES

The planned technical and social activities provide an opportunity for attendees to become professionally and personally acquainted. Dress attire is business casual unless otherwise noted.

MECHANISMS COURSES - On Monday and Tuesday, May 14-15, three separate courses will be offered in the same hotel as the AMS. ***Be sure to use the hotel booking link below when you make your hotel reservations.*** Registration for the Aerospace Mechanisms Symposium is not included in any class price.

Space Mechanisms Course (May 14-15)

Launchspace is providing a special edition of its internationally popular Space Vehicle Mechanisms course. This course explores the technologies required for successful space mechanisms design and offers a detailed look at many of the key components common to most mechanisms. The materials necessary to achieve high performance are discussed. Examples of the many types of mechanisms are included for illustration. In addition, the mechanisms relationships and interfaces with other vehicle systems are explored. The course includes design and analysis examples to demonstrate principles involved in understanding how mechanisms should work and how design margins should be evaluated during the evolution of a program.

Register at: <https://launchspace.com/ams-registration/>

The special symposium price for this course is \$895. Due to the special pricing (list price for this course is \$1595), the textbook, "Space Vehicle Mechanisms: Elements of Successful Design", edited by P.L. Conley, will not be provided but can be purchased commercially by attendees.

ESTL Space Tribology Course (May 14th and 15th)

The European Space Tribology Laboratory presents this course which draws heavily from experimental data generated during its 45 years as Europe's independent center of excellence for space tribology. Attendees will receive a comprehensive overview of the many issues relating to friction, lubrication and wear of spacecraft mechanisms, presented in 4 parts:

Fundamentals of Tribology - in which tribological concepts are introduced and the special considerations for space and vacuum tribology highlighted.
Tribo-component Design and Performance - in which an overview of the different types, characteristics and performances of tribo-components (ball bearings, gears, plain and ball/rollerscrews, etc.) used in spacecraft applications is provided. This includes a detailed presentation of considerations for design, selection and load capacity verification of ball bearings for space applications.
Lubrication of Spacecraft Components - in which the application-driven considerations for selection of fluid and dry (solid) lubricants are provided. This part includes the considerations and typical performances of dry (solid) and fluid lubricants, respectively. Some practical issues concerning application, handling and preloading of ball bearings are also presented.
Lessons Learned - presenting a selection of the (sometimes painful!) lessons learned on various programs.

Summarizing test data not widely accessible outside Europe, the course, whose two presenters have almost 40 years of space tribological experience, will be valuable both for younger engineers entering the industry and for the more experienced who may wish to refresh or challenge their tribological understanding. Attendees will receive personal paper and electronic format copies of presentation handouts (around 300 slides in total). The symposium price for the course is \$1000 and a minimum of 25 delegate registrations is required for the class to be held.

Register via the ESR website:
<http://www.esrtechnology.com/centres/estl/Pages/default.aspx>.

Shape Memory Alloys - Designing Your Next Mechanism Workshop (May 15)

Sixty years after the discovery of shape memory alloys (SMAs), many actuation and structural applications using these materials have been conceived and developed. SMAs are a unique class of multifunctional materials that have the ability to recover large deformations and generate high stresses in response to thermal, mechanical and/or electromagnetic stimuli. These abilities have made them a viable option for actuation/structural systems in aerospace applications, amongst others. However, designing with SMAs is a paradigm shift from the conventional way we look at metals and mechanisms.

In this course, you will learn how the unique properties of SMAs can be applied to designing mechanisms and the associated benefits. Basic primer will be provided on what they are and why they work with examples of the most successful applications that have been imagined. Common design tool and properties-database will be discussed.

Price is \$550 with breakfast included. Register in the registration module of the AMS.

CHECK-IN - On Tuesday evening, May 15, from 6:00-8:00 PM, check in and registration will be in the Hilton Cleveland Downtown Eliot's Lounge located on the second floor. Symposium materials, including symposium proceedings, will be available, along with light refreshments.

RECEPTION - On Wednesday evening, May 16, a reception will be held in the Hilton Cleveland Downtown. Supplier and poster paper displays will be exhibited during the evening along with demonstrations by local high school FIRST Robotics teams. A light buffet dinner will be served. The exhibits will be open for the enjoyment of all attendees and guests.

SYMPOSIUM BANQUET - On Thursday evening, May 17, the symposium dinner will be at the Rock and Roll Hall of Fame. The museum documents the entire history of rock

and roll and is alive with the energy, passion and the spirit of music. The museum features seven floors, four theaters for films and ever-changing exhibits.

FACILITY TOURS - On Friday afternoon, May 18, there will be opportunities to go on a tour of NASA Glenn Research Center or NASA Plum Brook Station. The tours are open to all attendees and guests; space is limited on all tours so register early. **Non-US citizens wishing to attend a tour must register for the symposium by March 15.** Bus transportation will be provided.

GUEST ACTIVITIES - Cleveland is a major city in Ohio on the shores of Lake Erie. Landmarks dating to its days as a turn-of-the-20th-century manufacturing center include the Steamship William G. Mather, now part of the Great Lakes Science Center. It's also known for the stately Cleveland Museum of Art. The popular Crawford Auto-Aviation Museum features an excellent private collection of antique cars and airplanes. Close by is Cedar Point amusement park, the roller coaster capital of the world.

PRESENTERS' MEETINGS - Presenting authors are required to attend a complimentary breakfast on the day of their presentation. (Note - only the presenters, not all authors of the paper.) This gathering gives the session participants an opportunity to meet their Session Chair and each other, and to review the session arrangements. The Symposium AV help will be available to discuss presentation requirements.

SYMPOSIUM INFORMATION

REGISTRATION - Advance registration is requested to facilitate planning and commitments. Please register on www.aeromechanisms.com. The registration fee is \$750 (\$350 for full-time professors, \$300 for full-time students and \$250 for retirees). **Non-US citizens wishing to attend either of the tours must register by March 15.** Late registration for the symposium may be done at the hotel on Tuesday evening, May 3, and each day of the symposium. **NOTE: If the registration payment is received after 11:59pm EDT (GMT-4) April 13, 2018 the registration fee is \$850 for all.** This fee covers all sessions, proceedings, break refreshments, reception, symposium banquet, tour, lunch for three days, and specified bus transportation. Guest tickets are \$35 for the reception and \$70 for the banquet (Late registration, \$45 reception, \$80 banquet).

HOTEL RESERVATIONS - A block of rooms has been reserved at the Hilton Cleveland Downtown (<http://www3.hilton.com/en/hotels/ohio/hilton-cleveland-downtown-CLEDOHH/index.html>). The hotel features wireless internet, 24-hour fitness center, business center, pool and restaurant on site. Rooms at the Hilton Cleveland Downtown are offered at a special rate of \$134 (which is the government per diem) for stays from May 12 to May 19 for attendees. Attendees must make their own reservations directly with the hotel. Use the link below (preferred method) or if you call the hotel, mention the 44th Aerospace Mechanisms Symposium. **Make your reservations by April 13, 2018 to ensure the special rate.** After April 13, reservations may be made at the prevailing hotel rate. Reservation link:

<https://aws.passkey.com/gt/214327830?gtid=fed68f263df8d10fe08682fc63823bd1>

Hilton Cleveland Downtown
100 Lakeside Ave East
Cleveland OH 44114 USA
(216) 413-5000

TRANSPORTATION - Cleveland is served by Cleveland Hopkins International Airport (CLE) (12 miles away). Taxi/Ridesharing service, car rentals and a train to downtown are at the airport. The train stops at Downtown Cleveland's Tower City Station, which is about a 10-minute walk to the hotel (<http://www.riderta.com/airportservice>).

DR. GEORGE HERZL AWARD - At each symposium, an award is given to the author(s) of the "Best Paper." The award is based on paper content, presentation delivery, and visual aids. This award was established in honor of Dr. George Herzl of Lockheed Martin, a co-founder of the Aerospace Mechanisms Symposium.

DR. CHARLES COALE AWARD - Each year MEA sponsors a child to attend Space Camp in honor of Dr. Charles Coale of Lockheed Martin. Dr. Coale was the leader of the symposium for more than 20 years and had a special interest in helping children.

GRANTS - Each year MEA awards grants to several high school FIRST Robotics teams. MEA may also provide an AMS attendance stipend to student authors.

TUESDAY, 15 MAY 2018

6:00-8:00 CHECK-IN - Eliot's Lounge

WEDNESDAY, 16 MAY 2018

7:00 Wednesday Presenters' Breakfast - Veterans Room B

7:00 CHECK-IN AND REFRESHMENTS - 5th Floor Lobby

8:15 INTRODUCTORY REMARKS - Superior Ballroom, Section A

Damon Delap, Host Chairman, NASA Glenn Research Center, Cleveland, OH
Edward Boesiger, General Chairman, Lockheed Martin Space, Sunnyvale, CA
Engineering Director, NASA Glenn Research Center, Cleveland, OH

8:30 SESSION I - INSTRUMENTS
Session Chair

- Scroll Compressor for Mars Atmospheric Acquisition, John Wilson et al., Air Squared, LLC, Broomfield, CO

- The Regolith and Ice Drill for Exploration of New Terrains (TRIDENT); a One-Meter Drill for the Lunar Resource Prospector Mission, Gale Paulsen et al., Honeybee Robotics Spacecraft Mechanisms Corp, Pasadena, CA

- Tools for Robotic Servicing of Spacecraft with Failed Deployables, Alejandro Rivera & Thomas McBirney, NASA Goddard Space Flight Center, Greenbelt, MD

- Environmental Chamber Testing of the VISAGE Rock Sampling Drill, Fredrik Rehnmark et al., Honeybee Robotics Spacecraft Mechanisms Corp, Pasadena, CA

10:10 SESSION II - BEARINGS & LUBRICATION

Session Chair

- A Discussion of Friction Anomaly Signatures in Response to Electrical Discharge in Ball Bearings, William Bialke, Lochridge Farm LLC, Trumansburg, NY
- Efficacy of Lead Napthenate for Wear Protection in Mixed Lubrication Regime, Jason Galary, NYE Lubricants Inc, Fairhaven, MA
- Dynamic Behavior and Modelling of Preloaded Ball Bearings Under Axial Vibration, Virgil Hinqué, Ronan Le Letty & René Seiler, European Space Agency/ESTEC, Noordwijk, The Netherlands
- Lessons Learned in the Design & Development of the Ocean Color Instrument Precision Hybrid Bearing Cartridge, Joseph Schepis et al., NASA Goddard Space Flight Center, Greenbelt, MD

11:50 LUNCH

Lunch for AMS Attendees in the Superior Ballroom, Section D

12:40 SESSION III - DEPLOY

Session Chair

- Lessons Learned in the Flight Qualification of the S-NPP and JPSS Deployable Solar Arrays, Dan Helfrich, NASA Goddard Space Flight Center, Greenbelt, MD & Adam Sexton, Ball Aerospace, Boulder, CO
- Spacecraft Viscous Damper Design and Prototype Testing for Common Deployable Boom, Paul Lytal, NASA Jet Propulsion Laboratory, Pasadena, CA
- Deployment Boom for Antenna Reflectors, Matthieu Robroek & Martin Kroon, Airbus Defence & Space, Leiden, The Netherlands
- Precision High-Strain Composite Hinges for Deployable Space Telescopes, Mark Silver et al., MIT Lincoln Laboratory, Lexington, MA
- An Improved Synchronization Mechanism for Optimizing Solar Array Deployment, Yan Zehong, Beijing Institute of Spacecraft System Engineering, Beijing, China

2:45 BREAK

3:00 SESSION IV: "OH THE NOISE! NOISE! NOISE!"

Session Chair

- Solving a performance limiting resonance frequency problem of the SOFIA Secondary Mirror Mechanism by Structural Modifications, Yannick Lammen, Andreas Reinacher & Alfred Krabbe, Deutsches SOFIA Institut (DSI), Palmdale, CA
- Enhanced Vibration Isolation using a Magnetic Linear Gear for Highly Demanding Aerospace Applications, Jose Luis Perez-Diaz et al., Universidad de Alcalá, Alcalá de Henares, Spain
- A Mechanisms Perspective on Microvibration - Good Practices and Lessons Learned, Geert Smet, European Space Agency/ESTEC, Noordwijk, The Netherlands

4:15 SESSION V - POTPOURRI OF POSTERS

Session Chair

- Investigation of Bolt Preload Relaxation for JWST Thermal Heat Strap Assembly Joints with Aluminum-1100 and Indium Gaskets, Andrew Bartoszyk et al., NASA Goddard Space Flight Center, Greenbelt, MD

- Development and Validation of a 2.5D PCB Technology for Slip Ring Assembly, Mélanie Henry, RUAG Space Switzerland, Nyon, Switzerland

- Quantifying Threaded Fastener Locking, Daniel Hess, University of South Florida, Tampa, FL

- Reliability Calculation Methodologies for Mechanisms and Actuators, Tanner Horne & Evan Herrington, Avior Control Technologies, Inc, Longmont, CO

- NEA Miniature Release Mechanism, Geoff Kaczynski & John Sudick, Ensign Bickford Aerospace - NEA Electronics, Inc, Moorpark, CA

- Compliant Mechanisms Re-Design, Lionel Kiener et al., Centre Suisse d'Electronique et de Microtechnique S.A., Neuchatel, Switzerland

- Non-Pyrotechnic Multi-point Release Mechanisms for Spacecraft Release, Ambrosio Mejia, John Sudick, and Geoffrey Kaczynski, Ensign Bickford Aerospace - NEA Electronics, Inc, Moorpark, CA

- ORION - Crew Module / Service Module Retention & Release Mechanism - Custom Split Race Spherical Bearing, Swapnil Patel, Lockheed Martin Space, Denver, CO

- Innovation in Large Angle Flexible Pivot Design & Material Accelerated Fatigue Screening Test Results, Yoel Puyol, Lausanne, Switzerland

- Validation of a Novel High Performance Magnetic Gearbox for Space, Ignacio Valiente-Blanco et al., Mag SOAR S.L., Valdemoro, Spain

- Qualification of a Networked Pyrotechnic Initiation System for the CST-100 Starliner Crew Capsule, David Novotney, Ensign Bickford Aerospace, Simsbury, CT

6:30 -10:00 RECEPTION - Hilton Cleveland Downtown

Invited component suppliers display current products and provide tutorials along with FIRST Robotics Team demonstrations and a light buffet meal.

THURSDAY, 17 MAY 2018

7:00 Thursday Presenters' Breakfast - Veterans Room B

8:00 SESSION VI - ACTUATORS

Session Chair

- KaRIn Alignment Mechanism Design, Testing, and Lessons Learned, John Wolff, NASA Jet Propulsion Laboratory, Pasadena, CA

- Use and Advantages of Direct-Drive Brushless DC Actuators for Precision Instrument Pointing of the Total and Spectral Solar Irradiance Sensor (TSIS), Pat Brown, Andrew Engelmann & Ryan Lewis, University of Colorado, Boulder, CO

- SADA Lessons Learned, Jonathan Wood, Lockheed Martin Space, Sunnyvale, CA

- Detection of Root Cause and Direct Imaging of Actuator Internal Failures - No Disassembly Required, Michael Johnson, NASA Jet Propulsion Laboratory, Pasadena, CA

9:40 BREAK

9:50 SESSION VII - CUBESATS

Session Chair

- Testing and Development of NEA Scout Solar Sail Deployer Mechanism, Alex Few et al., NASA Marshall Space Flight Center, Huntsville, AL

- Mechanism Design & Flight Build of Furled High Strain Composite Antenna for CubeSats, Bruce Davis et al., Rocco, Longmont, CO

- Use of the Eaton-Cooper Non-Explosive Actuator on the NanoRacks CubeSat Deployer, Michael Lewis & C Brown, NanoRacks, LLC, Webster, TX

- The Evolution of Deployment Mechanisms for a Ka-band Deployable Antenna for CubeSats, Jonathan Sauder et al., NASA Jet Propulsion Laboratory, Pasadena, CA

- Testing and Maturing a Mass Translating Mechanism for a Deep Space CubeSat, Alex Few et al., NASA Marshall Space Flight Center, Huntsville, AL

- Design and Development of Cubesat Solar Array Deployment Mechanisms Using Shape Memory Alloys, Allen Guzik & Othmane Benafan, NASA Glenn Research Center, Cleveland, OH

12:20 LUNCH

Lunch for AMS Attendees in the Superior Ballroom, Section D

1:05: SPECIAL PRESENTATION: NASA GODDARD ROBOTIC LSAT-7 REFUELING MISSION

Ben Reed: Deputy Division Director, Satellite Servicing Projects Division NASA Goddard Space Flight Center

Hear about the mission to robotically refuel Landsat 7 in low earth orbit. Learn about the novel robotic hardware being developed to grab and refuel this satellite that was never designed to be refueled.

2:05 SESSION VIII - DOCKING

Session Chair

- Capture Latch Design, Development, and Qualification for the NDSB1, Brandon Dick, The Boeing Company, Huntsville, AL

- Design, Development, and Testing of the Dragon 2 Docking System, Jaret Matthews et al., SpaceX, Hawthorne, CA

- NASA Docking System Block 1: NASA's new direct electric Docking System Supporting ISS and Future Human Space Exploration, Karl Keiser et al., The Boeing Company, Huntsville, AL

3:20 BREAK

3:30 SESSION IX -SOLID LUBRICATION
Session Chair

- Hybrid Lubrication of PFPE fluids and Sputtered MoS₂, Michael Buttery et al., ESR Technology Ltd. - European Space Tribology Laboratory, Warrington, United Kingdom

- Evaluation of Friction Characteristics and Low Friction Mechanism of Tungsten Disulfide for Space Solid Lubricant at Elevated Temperature in a Vacuum, Ayaka Takahashi et al., Chiba University, Chiba, Japan

- A Study of Humidity Effects on MoS₂ Coated Gears, Tim Krantz, S NASA Glenn Research Center, Cleveland, OH

- An Improved Solid Lubricant for Bearings Operating in Space and Terrestrial Environments, Harpal Singh et al., University of Akron, Akron, OH

5:10 INVITED PRESENTATION -Doug Wheelock, Aerospace Engineer and Astronaut Doug has been launched into space via the Space Shuttle Discovery and Soyuz TMA-19, and spent more than 5 months in space aboard the Space Station. He has made multiple spacewalks to repair equipment and will have stories to tell.

7:00-11:00 BANQUET - Rock and Roll Hall of Fame
Dinner, entertainment and exhibits celebrating music history.

FRIDAY, 18 MAY 2018

7:00 Friday Presenters' Breakfast - Veterans Room B

8:00 SESSION X - TESTING, TRANSPORTATION & THE FUTURE
Session Chair

- Development of the Multi-Purpose Transportation System for the Space Launch System (SLS) Core Stage (CS) Flight Article, Sarah Sandridge et al., NASA Marshall Space Flight Center, Huntsville, AL

- High Speed Bearing Wear Rate Measurements for Spacecraft Active Thermal Control Fluid Pumps with a Novel Pin on Disk Apparatus, Robert Bruckner, NASA Glenn Research Center, Cleveland, OH

- Accelerated Testing of Tribological Components - Uncertainties and Solutions, Simon Lewis, Michael Buttery & Oliver Poyntz-Wright, ESR Technology Ltd. - European Space Tribology Laboratory, Warrington, United Kingdom

- Developmental Bearing and Bushing Testing for Mars Gearboxes, Dave Suffern & Jonathan Parker, Sierra Nevada Corp, Durham, NC

9:40 BREAK

- Experimental Method for Determining Ball Bearing Lubricant Quantity Factor, Yoshimi Takeuchi, Peter P Frantz & Tim Woodard, The Aerospace Corporation, Los Angeles, CA

- Ultra-Low Shock Separation Nut Source Shock Test and Data Reduction Methodology, Victor Kiuhan, Northrop Grumman Aerospace Systems, Redondo Beach, CA

- Deployment Tracking System, Matthieu Robroek, Airbus Defence & Space, Leiden, The Netherlands

- Mechanisms and New Space, Bill Purdy, Purdy Engineering, Poolesville, MD

11:30 SPECIAL PRESENTATION ON NASA GLENN RESEARCH CENTER

12:15 TECHNICAL SESSIONS CONCLUSION

Stu Loewenthal, Deputy Chairman, Lockheed Martin Space, Sunnyvale, CA

• Herzl Award Presentation

12:30 LUNCH

Lunch for AMS Attendees in the Superior Ballroom, Section D

1:15 - 5:00 TOURS

Attendees may go on a special tour of either NASA Glenn Research Center or NASA Plum Brook Station.

1:15 Buses depart hotel for tours

5:00 Approximate time buses return to hotel

SYMPOSIUM ORGANIZING COMMITTEE

Host Chair - Damon C. Delap, NASA GRC

Co-Host Chair - Steven W. Bauman, NASA GRC

General Chairman - Edward A. Boesiger, Lockheed Martin Space

Deputy Chairman - Stuart H. Loewenthal, Lockheed Martin Space

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