

Rohan Sood

Curriculum Vita

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Professional Summary

Dr. Rohan Sood is a tenured Associate Professor in the Department of Aerospace Engineering at the University of Alabama. He has successfully secured over \$1.67M (1.25M+ as Dr. Sood's) to support his lab's research activities, graduate students and in support of University of Alabama's first spacecraft, BAMA-1, and subsequent mission, BAMA-2.

The success of his Aerodynamics and Space Research Laboratory is also evident from achievements of his graduate and undergraduate students at international, national, state, and university level. Under his mentorship, two of his graduate students have received the prestigious National Science Foundation Graduate Research Fellowships. His students are also the recipients of the University of Alabama's highly coveted David A. Francko Fellowship (awarded to only one student per year), Capstone Graduate Council Fellowship, multiple Alabama Space Grant Graduate Fellowships and UA's Graduate Council Fellowships. He is currently mentoring 8 students (5 PhD, 1 MS, 2 UG), and has successfully mentored 6 students (2 PhD, 4 MS) to degree completion. Dr. Sood has 60+ publications (20+ referred journal articles, all in well-respected journals, including *Nature* and *Icarus*, 40+ conference papers, and 2 bulletins for NASA's Decadal Survey in *American Astronomical Society*).

In 2018, NASA Marshall Space Flight Center (MSFC) selected Dr. Sood's Technical Excellence proposal on Advanced Trajectory Design. In 2019, Dr. Sood was awarded the Aerodynamics in Support of Icy World Missions grant by NASA HQ. He is also the recipient of the Center innovation Funds from NASA-Jet Propulsion Laboratory for two consecutive years (2019-2021). His ongoing collaboration with MSFC involves exploring solutions for NASA's Near Earth Asteroid Scout mission. Additionally, in 2021, he was actively involved with NASA's Solar Cruiser trajectory design in collaboration with MSFC's Mission Design and Navigation Team to find innovative solutions to meet mission specifications. More recently, his work is exploring trajectories that leverage multibody dynamics and additional sail parameters to enable Solar Polar Imager mission to explore the poles of the Sun, something that has never been done before. In partnership with small business, Dr. Sood has been awarded NASA SBIR (2019-2020) and DOD – Air Force STTR (2022-2023). Dr. Sood has also collaborated with NASA Goddard Space Flight Center, NASA Ames Research Center, and small businesses on emerging technologies in space flight.

Since his appointment at UA, Dr. Sood has taught 25 sections of 9 different courses ranging from service courses, undergraduate professional courses, and graduate courses. As the demand for more space-oriented courses increased, he introduced new topics (Advanced Aerodynamics, Spacecraft Attitude Dynamics) and updated Orbital Mechanics to better prepare the graduates based on current state-of-the-art in the field of space exploration. Dr. Sood also employs a variety of hardware and software to enhance visualization (*3-D* and *Virtual Reality*, and *Augmented Reality*) of spacecraft trajectories, mission architecture, and to improve student classroom experience.

Dr. Sood's scientific discoveries of lunar lava tubes and buried craters has received widespread coverage by the BBC and National Geographic that led to collaboration with the Japanese Space Agency, JAXA. He is an active member of the American Institute of Aeronautics and Astronautics (AIAA) Aerodynamics Technical Committee and the American Astronautical Society (AAS). In recognition of his professional standing and successful practice, he is a senior member of AIAA. Dr. Sood has chaired multiple conference sessions at the AIAA/AAS conferences and was the General Conference Chair for the 33rd AAS/AIAA Space Flight Mechanics Meeting in January 2023. He has reviewed numerous national/international journals and has served on NASA and Dutch proposal review committees.

Research Interests

Astrodynamics and space applications, spacecraft attitude dynamics & control, orbital mechanics, interplanetary trajectory design, motion in the vicinity of asteroids, icy worlds, and other celestial bodies, multi-body dynamics, small-body dynamics, artificial intelligence in astrodynamics, remote sensing – Earth and space based observations, human exploration and habitation, extraterrestrial lava tubes

Education

Purdue University, Aeronautics and Astronautics **Ph.D., 2016**

Astrodynamics and Space Applications, Minor: Dynamics and Control

Advisors: **Dr. Kathleen C. Howell**, *Hsu Lo Distinguished Professor of Aeronautics & Astronautics*

Dr. Henry (Jay) Melosh, *Distinguished Professor of Earth, Atmospheric & Planetary Sciences*

Dissertation: *Significance of specific force models in two applications: solar sails to Sun-Earth L₄/L₅ and Grail data analysis suggesting lava tubes and buried craters on the Moon*

Purdue University, Aeronautics and Astronautics **M.S., 2012**

Astrodynamics and Space Applications, Minor: Dynamics and Control

Advisor: **Dr. Kathleen C. Howell**, *Hsu Lo Distinguished Professor of Aeronautics & Astronautics*

Thesis: *Solar sail applications for mission design in sun-planet systems from the perspective of the circular restricted three-body problem*

University at Buffalo SUNY, Department of Mechanical and Aerospace Engineering **B.S., 2009**

Double major: Aerospace Engineering and Mechanical Engineering, **Summa Cum Laude**

Professional Experience

Aug. 2022 – Present *Associate Professor, Dept. of Aerospace Engineering & Mechanics*, University of Alabama

Feb. 2017 – Aug. 2022 *Assistant Professor, Dept. of Aerospace Engineering & Mechanics*, University of Alabama

2012 – 2016

Research Assistant, School of Aeronautics and Astronautics, Purdue University

2009 – 2012

Teaching Assistant, School of Aeronautics and Astronautics, Purdue University

Current Research

Director: Astrodynamics and Space Research Laboratory (asrl.ua.edu)

- Astrodynamics, space exploration and applications
- Spacecraft trajectory design and attitude dynamics
- Remote sensing – Earth and space based observations
- Human exploration and habitation on extraterrestrial bodies – empty lava tubes on Moon and Mars
- Artificial intelligence – applications of neural network to spacecraft trajectory design
- 3D visualization, virtual reality (VR) and augmented reality (AR) for applications in astrodynamics

Upcoming/Past Mission Involvement

- **Solar Cruiser and Solar Polar Imager** in collaboration with NASA Marshall Space Flight Center
 - Innovation trajectory design solution to ensure mission success
 - Explore future missions enabled by Solar Cruiser's sail technology to explore the Sun's poles
 - Engage students in challenging activities to characterize sail performance
- **BAMA-1** NASA selected University of Alabama's first satellite launched in February 2022
 - Drag sail technology demonstration mission as innovative solution to satellite deorbit strategy
 - Launch vehicle issue during ascent – spacecraft not delivered to orbit
 - NASA has offered a new launch, **BAMA-2**
- **Near-Earth Asteroid Scout** in collaboration with NASA MSFC, to be launched NET June 2022
 - Contingency trajectory design and analysis
 - Target assessment (as a secondary payload on Artemis I)
 - Solar sail application to multiple asteroid flyby

Rohan Sood

*Curriculum Vitae
(continued)*

- **Mars Sample Return** in collaboration with NASA Jet Propulsion Laboratory (JPL)
 - Mars to Earth sample return trajectory design
 - Application of reinforcement learning to missed thrust events
- **GRAIL Science Team** in collaboration with MIT and NASA JPL
 - Gravity data analysis
 - Lava tube exploration as potential sites for human habitats
 - Buried lunar craters

Awarded and Pending Grants and Research Support

Awarded

| | Agency, Title | Role | Duration | Total | Sood Share |
|---|--|-----------------------|----------------------------|--------------------|--------------------|
| 1. | DoD – Air Force , Kessler Run | Collaborator UA-PI | 11/05/2022 – 12/31/2023 | \$250,000 | \$125,000 |
| 2. | NASA-HQ , Astrodynamics in Support of Icy Worlds Missions | PI | 11/15/2019 – 12/31/2023 | \$300,000 | \$300,000 |
| 3. | NASA-JPL , Designing Trajectories Resilient to Missed Thrust Events | PI | 01/01/2021 – 12/31/2021 | \$72,000 | \$72,000 |
| 4. | NASA-JPL , Application of Reinforcement Learning: Trajectories Resilient to Missed Thrust Events | PI | 01/06/2020 – 12/31/2020 | \$72,000 | \$72,000 |
| 5. | NASA-MSFC , University of Alabama Support of Solar Cruiser Mission* | Collaborator UA-PI | 07/16/2021 – 07/15/2024 | \$150,000 | \$150,000 |
| 6. | NASA-MSFC , Technical Excellence (Revery Enhancement) | PI | 07/01/2019 – 08/31/2020 | \$25,000 | \$25,000 |
| 7. | ASGC/UAH , UA/ASGC Workforce Development (UA/ASGC WFD) Program | Co-PI | 04/23/2020 – 03/22/2024 | \$103,000 | \$4,120 |
| 8. | NASA , Development of Metasurface Reflectors to Enable Future Sail Missions | Co-PI | 01/06/2020 – 12/31/2021 | \$38,921 | \$11,676 |
| 9. | NASA , Alabama Space Grant Consortium – Ari Rubinsztein; William Ledbetter, Jared Sikes, Kyra Bryan; Will Lage, | Co-PI | 08/16/2021 – 05/15/2023 | \$41,500 | \$20,750 |
| 10. | NASA , Electrically Tunable Liquid Crystal to Enable Future Sail Mission | Co-PI | 01/01/2022 – 12/31/2023 | \$65,185 | \$19,556 |
| 11. | NASA SBIR , Sail Trimming Actuator for Targeted Reentry (STARTR) – Roccor | Collaborator UA-PI | 09/16/2019 – 02/18/2020 | \$150,000 | \$25,000 |
| Total | | | | \$1,267,606 | \$825,105 |
| 12. | NSF GRFP , Solar Sail Trajectory Design for Heliophysics Missions – James Pezent | PI , Advisor | 08/16/2019 – 08/15/2022 | \$138,000 | \$138,000 |
| 13. | NSF GRFP , Expected Thrust to Solar Sailing Trajectory Design – Carrie Sandel [†] | PI , Advisor | 08/16/2021 – 08/15/2024 | \$138,000 | \$138,000 |
| Faculty Success Total | | | | \$1,543,606 | \$1,101,105 |
| 14. | NASA/Industry/Private Foundation , BAMA-1 and BAMA-2 CubeSat Program | Advisor | 02/22/2020 12/31/2023 | \$449,000 | 149,666 |
| Grand Total | | | | \$1,672,606 | \$1,250,896 |
| *Dr. Sood assisted the Solar Cruiser team (led by PI Les Johnson of NASA MSFC, Huntsville AL.) with the proposal. The Solar Cruiser investigation is budgeted for \$65 million. | | | | | |

Publications and Presentations:

Underline indicates students advised by me.

Peer Reviewed Journals

- [26] Pezent, J. B., **Sood, R.**, Heaton, A., and Johnson, L., “Solar Polar Imaging Mission Design and Trajectory Analysis Leveraging Venus Flyby,” 2023 (in preparation).
- [25] Sikes, J. D., Rubinsztein, A., **Sood, R.**, Everett, J., and Heaton, A., “Overburn and Underburn Analysis for NASA’s Solar Cruiser Mission,” 2023 (in preparation).
- [24] Rubinsztein, A., **Sood, R.**, Laipert, F., and Imkem, T., “Missed Thrust Requirements for Deep Space Missions: Specification, Analysis, and Mitigation,” 2023 (in preparation).
- [23] Ledbetter, W.G., and **Sood, R.**, “Novel Solution to Differential Games Applied to Pursuer-Evader Problems in Multibody Systems,” 2023 (in preparation).
- [22] Sandel C., and **Sood, R.**, “Natural and Forced Spacecraft Loitering in a Near Rectilinear Halo Orbit,” *Special Issue: Cislunar Space Operations, The Journal of the Astronautical Sciences*, 2023 (submitted).
- [21] Blumenthal, B., and **Sood, R.**, “Local Lyapunov Exponents Augmented Differential Corrections Process for Cislunar Trajectory Targeting,” *Special Issue: Cislunar Space Operations, The Journal of the Astronautical Sciences* 2023 (submitted).
- [20] Pezent, J. B., and **Sood, R.**, “New Solution to Euler’s Equations for Asymmetric Bodies: Applications to Spacecraft Reorientation,” *AIAA Journal of Guidance, Control, and Dynamics*, 2022. DOI: 10.2514/1.G006747
- [19] Sikes, J., Pezent, J.B., Sandel, C., Rubinsztein, A., and **Sood, R.**, “GTOC 11 –Results from the University of Alabama Team,” *Special Issue Acta Astronautica*, 2022. DOI: 10.1016/j.actaastro.2022.06.038
- [18] Rubinsztein, A., **Sood, R.**, and Laipert, F., “Missed Thrust Resilient Trajectory Design Applied to the Earth Return Orbiter,” *Acta Astronautica*, 2022 (submitted, minor edits).
- [17] Elkins, J., **Sood, R.**, and Rumpf, C., “Bridging Reinforcement Learning and Online Learning for Spacecraft Attitude Control,” *AIAA Journal of Aerospace Information Systems*, Sep. 2021. DOI: 10.2514/1.I010958
- [16] Rubinsztein, A., Sandel, C. G., **Sood, R.**, and Laipert, F., “Designing Trajectories Resilient to Missed Thrust Events Using Expected Thrust Fraction,” *Aerospace Science and Technology*, vol. 115, Aug. 2021. DOI: 10.1016/j.ast.2021.106780
- [15] Pezent, J., **Sood, R.**, Heaton, A., Miller, K., and Johnson, L., “Preliminary Trajectory Design for NASA’s Solar Cruiser: A Technology Demonstration Mission,” *Acta Astronautica*, vol. 183, pp. 134-140, June 2021. DOI: 10.1016/j.actaastro.2021.03.006
- [14] Ledbetter, W.G., **Sood, R.**, Keane, J.T., and Stuart, J., “SmallSat swarm gravimetry: Revealing the interior structure of asteroids and comets,” *Astrodynamics*, Feb. 2021. DOI: 10.1007/s42064-020-0098-1
- [13] Song, P., Gogineni, S.P., Galkin, I.A., Volakis, J.L., Soderblom, J.M., Hayes, A.G., Reinisch, B.W., Giles, R.H., **Sood, R.**, Zhang, H., Braaten, D., Melosh, H.J., Bruzzone, L., Venkatakrishnan, S.B., Yan, S.J., and O’Neill, C., “Feasibility Study of a High-Resolution Shallow Surface Penetration Radar for Space Application,” *Radio Science*, vol. 56, issue 2, Feb. 2021. DOI: 10.1029/2020RS007118
- [12] Pezent, J.B., **Sood, R.**, and Heaton, A., “Configuration Space and Stability Analysis of Solar Sail Near-Vertical Earth-Trailing Orbits,” *Advances in Space Research, Special Issue: Solar Sailing Advances*, vol. 67, issue 9, pp. 2981-2994, Oct. 2020. DOI: 10.1016/j.asr.2020.10.011
- [11] Pezent, J.B., **Sood, R.**, and Heaton, A., “Innovative Solar Sail Earth-Trailing Trajectories Enabling Sustainable Heliophysics Missions,” *The Journal of the Astronautical Sciences*, vol. 67(4) pp.1249-1270, June 2020. DOI: 10.1007/s40295-020-00214-3
- [10] Rubinsztein, A., **Sood, R.**, and Laipert, F., “Neural Network Optimal Control in Astrodynamics: Application to the Missed Thrust Problem,” *Acta Astronautica*, vol. 176, pp. 192-203, Nov. 2020. DOI: 10.1016/j.actaastro.2020.05.027
- [9] Pezent, J.B., **Sood, R.**, and Heaton, A., “Contingency Target Assessment, Trajectory Design, and Analysis for NASA’s NEA Scout Solar Sail Mission,” *Advances in Space Research, Special Issue: Solar Sailing Advances*, vol. 67, issue 9, pp. 2890-2898, Feb. 2020. DOI: 10.1016/j.asr.2020.02.004

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- [8] Pezent, J.B., Sood, R., and Heaton, A., “High-Fidelity Contingency Trajectory Design and Analysis for NASA’s Near-Earth Asteroid (NEA) Scout Solar Sail Mission,” *Acta Astronautica*, vol. 159, pp. 385-396, June 2019. DOI: 10.1016/j.actaastro.2019.03.050
 - [7] Sood, R., and Howell, K., “Solar Sail Transfers and Trajectory Design to Sun-Earth L₄, L₅: Solar Observations and Potential Earth Trojan Exploration,” *The Journal of the Astronautical Sciences*, vol. 66, pp. 247-281, Feb. 2019. DOI: 10.1007/s40295-018-00141-4
 - [6] Guzzetti, D., Sood, R., Chappaz, L., and Baoyin, H., “Stationkeeping Analysis for Solar Sailing the L4 Region of Binary Asteroid Systems,” *Journal of Guidance, Control, and Dynamics*, pp. 1–13, Jan. 2019. DOI: 10.2514/1.g003994
 - [5] Ullery, D.C., Soleymani, S., Heaton, A., Orphee, J., Johnson, L., Sood, R., Kung, P., and Kim, S.M., “Strong Solar Radiation Forces from Anomalous Reflecting Metasurfaces for Solar Sail Attitude Control,” *Nature, Scientific Reports*, vol. 8, no. 1, July 2018. DOI: 10.1038/s41598-018-28133-2
 - [4] Kaku T., Haruyama J., Miyake W., Kumamoto A., Ishiyama K., Nishibori T., Yamamoto K., Crites S. T., Michikami T., Yokota Y., Sood, R., Melosh, H. J., Chappaz L., and Howell K. C., “Detection of Intact Lava Tubes at Marius Hills on the Moon by SELENE (Kaguya) Lunar Radar Sounder,” *Geophysical Research Letters*, vol. 44, no. 20, pp. 10,155–10,161, Oct. 2017. DOI: 10.1002/2017gl074998
 - [3] Sood, R., Chappaz, L., Melosh, H.J., Howell, K.C., Milbury, C., Blair, D.M., and Zuber, M.T., “Detection and characterization of buried lunar craters with GRAIL data,” *Icarus*, vol. 289, pp. 157–172, June 2017. DOI: 10.1016/j.icarus.2017.02.013
 - [2] Chappaz, L., Sood, R., Melosh, H.J., Howell, K.C., Blair, D.M., Milbury, C., and Zuber, M.T., “Evidence of large empty lava tubes on the Moon using GRAIL gravity,” *Geophysical Research Letters*, vol. 44, no. 1, pp. 105–112, Jan. 2017. DOI: 10.1002/2016gl071588
 - [1] Blair, D.M., Chappaz, L., Sood, R., Milbury, C., Bobet, A., Melosh, H.J., Howell, K.C., and Freed, A.M., “The structural stability of lunar lava tubes,” *Icarus*, vol. 282, pp. 47–55, Jan. 2017. DOI: 10.1007/978-3-319-05546-6_52-1

Peer Reviewed Conference Publications and Presentations

- [42] Blumenthal, B., and Sood, R., “Application of Local Lyapunov Exponents for NASA’s Artemis-1 Trajectory Design and Maneuver Planning,” *33rd AAS/AIAA Space Flight Mechanics Meeting*, AAS 23-182, Austin, TX, Jan. 2023.
- [41] Pezent, J. B., Sood, R., Heaton, A., and Johnson, L., “Mission Design for Near-Future Solar Polar Imaging Mission Leveraging Venus Flyby,” *33rd AAS/AIAA Space Flight Mechanics Meeting*, AAS 23-284, Austin, TX, Jan. 2023.
- [40] Sikes, J. D., Rubinsztein, A., Sood, R., Everett, J., and Heaton, A., “Overburn and Underburn Analysis for NASA’s Solar Cruiser Mission,” *33rd AAS/AIAA Space Flight Mechanics Meeting*, AAS 23-283, Austin, TX, Jan. 2023.
- [39] Sandel C., and Sood, R., “Low-Thrust Rendezvous and Proximity Operations in a Near Rectilinear Halo Orbit,” *33rd AAS/AIAA Space Flight Mechanics Meeting*, AAS 23-296, Austin, TX, Jan. 2023.
- [38] Blumenthal, B., and Sood, R., “Application of Local Lyapunov Exponents for Autonomous Trajectory Targeting and Generation,” *33rd AAS/AIAA Space Flight Mechanics Meeting*, AAS 23-183, Austin, TX, Jan. 2023.
- [37] Houin, A., and Sood, R., “Optimal Launch Windows for Artemis III and Beyond Leveraging Contour Map,” *International Astronautical Congress*, IAC-22-C1.IP.35, Paris, France, Sept. 2022.
- [38] Rubinsztein, A., Sood, R., and Laipert, F., “Designing Multiple Missed Thrust Event Resilient Trajectories using Virtual Swarms,” *2022 AAS/AIAA Astrodynamics Specialist Conference*, 22-179, Charlotte, NC, Aug. 2022.
- [35] Rubinsztein, A., Sood, R., and Laipert, F., “Chaining Moon-to-Moon Trajectories Using Network Analysis,” *32nd AIAA/AAS Space Flight Mechanics Meeting (2022 AIAA SciTech Forum)*, San Diego, CA, Jan. 2022 (p. 0858). DOI: <https://doi.org/10.2514/6.2022-0858>.
- [34] Pezent, J.B., Sikes, J.D., Ledbetter, W.G., Sood, R., Howell, K.C., and Stuart, J., “ASSET: Astrodynamics Software and Science Enabling Toolkit,” *32nd AIAA/AAS Space Flight Mechanics*

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- Meeting (2022 AIAA SciTech Forum), San Diego, CA, Jan. 2022 (p. 1131). DOI: <https://doi.org/10.2514/6.2022-1131>.*
- [33] Rubinsztein, A., Sandel, C.G., Pezent, J.B., Sood, R., Laipert, F., Heaton, A., and Johnson, L., “Design of Solar Sailing Trajectories Resilient to Safe Mode Events,” *2021 AAS/AIAA Astrodynamics Specialist Conference*, 21-621, Big Sky, MT, Aug. 2021.
- [32] Gogineni, S.P., Yan, S., Song, P., Volakis, J.L., Deshpande M., Galkin, I.A., Soderblom, J.M., Hayes, A.G., Reinisch, B.W., Giles, R.H., **Sood, R.**, Zhang, H., Braaten, D., Bruzzone, L., Venkatakrishnan, S.B., Yan, S.J., Taylor, D., “UWB MIMO Radars for Sounding and Imaging of Ice on the Earth and Other Celestial Bodies,” *IEEE International Geoscience and Remote Sensing Symposium*, 4467, Brussels, July 2021.
- [31] Rubinsztein, A., Sood, R., and Laipert, F., “Measuring Resilience of Autonomous Controllers to Spacecraft Missed Thrust Events,” *ESA GNC*, June 2021.
- [30] Rubinsztein, A., Sood, R., and Laipert, F., “Expected Thrust Fraction: Resilient Trajectory Design Applied to the Earth Return Orbiter,” *AAS Space Flight Mechanics*, 21-232, Feb. 2021.
- [29] Elkins, J.G., Sood, R., and Rumpf, C., “Autonomous Spacecraft Attitude Control Using Deep Reinforcement Learning,” *IAC 2020 CyberSpace Edition*, IAC–20–C1.9.8, Oct. 2020.
- [28] Pezent, J., Sood, R., Heaton, A., Miller, K., Johnson, L., “Preliminary Trajectory Design for NASA’s Solar Cruiser: A Technology Demonstration Mission,” *2020 AAS/AIAA Astrodynamics Specialist Conference*, 20-653, Lake Tahoe, CA, Aug. 2020.
- [27] Elkins, J., Sood, R., and Rumpf, C., “Adaptive Continuous Control of Spacecraft Attitude Using Deep Reinforcement Learning,” *2020 AAS/AIAA Astrodynamics Specialist Conference*, 20-475, Lake Tahoe, CA, Aug. 2020.
- [26] Rubinsztein, A., Sandel, C.G., Sood, R., and Laipert, F., “Designing Trajectories Resilient to Missed Thrust Events Using Expected Thrust Fraction,” *2020 AAS/AIAA Astrodynamics Specialist Conference*, 20-452, Lake Tahoe, CA, Aug. 2020.
- [25] Schoenwetter, L., Sood, R., and Barbee, B., “Optimal Intercept of Evasive Spacecraft,” *2020 AAS/AIAA Astrodynamics Specialist Conference*, 20-540, Lake Tahoe, CA, Aug. 2020.
- [24] Rubinsztein, A., Bryan, K., Sood, R., and Laipert, F., “Using Reinforcement Learning to Design Missed Thrust Resilient Trajectories,” *2020 AAS/AIAA Astrodynamics Specialist Conference*, 20-453, Lake Tahoe, CA, Aug. 2020.
- [23] Sikes, J., Sood, R., Medina, K., and Turse, D., “Keeping Low Earth Orbit Clean: Deorbit and Stability Analysis for an Articulating Boom Drag Sail,” *2020 AAS/AIAA Astrodynamics Specialist Conference*, 20-629, Lake Tahoe, CA, Aug. 2020.
- [22] Heaton, A. and **Sood, R.**, “Space Launch System Departure Trajectory Analysis for Cislunar and Deep-Space Exploration,” *2020 AAS/AIAA Astrodynamics Specialist Conference*, 20-604, Lake Tahoe, CA, Aug. 2020.
- [21] Rubinsztein, A., Sood, R., and Laipert, F., “Neural Network Based Optimal Control: Resilience to Missed Thrust Events for Long Duration Transfers,” *2019 AAS/AIAA Astrodynamics Specialist Conference*, 19-773, Portland, ME, Aug. 2019.
- [20] Pezent, J.B., Sood, R., and Heaton, A., “Contingency Target Assessment, Trajectory Design and Analysis for NASA’s NEA Scout Solar Sail Mission,” *5th International Symposium on Solar Sailing*, 19050, Aachen, Germany, July 2019.
- [19] Pezent, J.B., Sood, R., and Heaton, A., “Solar Sail Enabled Near-Vertical Earth-Trailing Orbits,” *5th International Symposium on Solar Sailing*, 19049, Aachen, Germany, July 2019.
- [18] Kaku, T., Haruyama, J., Miyake, W., Kumamoto, A., Ishiyama, K., Nishibori, T., Iwata, T., Crites, S. T., Michikami, T., Yokota, Y., Ohno, T., **Sood, R.**, Melosh, H. J., Chappaz, L., and Howell, K. C., “Global Distribution of Possible Lava Tubes from Near-Surface to a Hundred Meter Depth on the Moon,” *Lunar and Planetary Science Conference*, vol. 50, no. 2205, Houston, TX, Mar. 2019.
- [17] Pezent, J., Heaton, A., and **Sood, R.**, “Innovative Solar Sail Earth-Trailing Trajectories Enabling Sustainable Heliophysics Missions,” *29th AAS/AIAA Space Flight Mechanics*, 18-541, Ka’anapali, Maui, HI, Jan. 2019.

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- [16] Ledbetter, W.G., Sood, R., and Stuart, J., “Expected Accuracy of Density Recovery using Satellite Swarm Gravity Measurements,” *29th AAS/AIAA Space Flight Mechanics*, 18-529, Ka'anapali, Maui, HI, Jan. 2019.
- [15] Ledbetter, W.G., Sood, R., and Keane, J.T., “SmallSat Swarm Gravimetry: Revealing the Interior Structure of Asteroids and Comets,” *AAS/AIAA Astrodynamics Specialist Conference*, 18-225, Snowbird, UT, Aug. 2018.
- [14] Gogineni, P., Simpson, C. R., Yan, J., O'Neill, C. R., Sood, R., Gurbuz, S. Z., Gurbuz, A. C., “A CubeSat Train for Radar Sounding and Imaging of Antarctic Ice Sheet,” *IGARSS 2018 - IEEE International Geoscience and Remote Sensing Symposium Conference*, Valencia, Spain, July 2018.
- [13] Sood, R., Pezent, J., and Heaton, A., “NEA Scout-X: A Cost-Effective Mission Performing Flybys of Multiple Near-Earth Asteroids and Rendezvous,” *Lunar and Planetary Science Conference*, vol. 49, no. 2217, Houston, TX, Mar. 2018.
- [12] Ledbetter, W.G., Sood, R., and Keane, J.T., “The Interior Structure of Asteroids and Comets Revealed by ChipSat Swarm Gravimetry,” *Lunar and Planetary Science Conference*, vol. 49, no. 2136, Houston, TX, Mar. 2018.
- [11] Kaku T., Haruyama J., Miyake W., Kumamoto A., Ishiyama K., Nishibori T., Yamamoto K., Iwata, T., Crites, S. T., Michikami T., Yokota Y., Sood, R., Melosh, H. J., Chappaz, L., Howell K. C., “Existence of a Lunar Lava Tube West of Rima Mairan Suggested by SELENE LRS,” *Lunar and Planetary Science Conference*, vol. 49, no. 1830, Houston, TX, Mar. 2018.
- [10] Pezent, J.B., Sood, R., and Heaton, A., “Near Earth Asteroid (NEA) Scout Solar Sail Contingency Trajectory Design and Analysis,” *2018 Space Flight Mechanics Meeting*, Orlando, FL, Jan. 2018. DOI: 10.2514/6.2018-0199
- [9] Haruyama J., Kaku T., Shinoda R., Miyake W., Kumamoto A., Ishiyama K., Nishibori T., Yamamoto K., Kurosawa K., Suzuki A.I., Crites S.T., Michikami T., Yokota Y., Sood, R., Melosh, H. J., Chappaz L., Howell K. C., “Detection of Lunar Lava Tubes by Lunar Radar Sounder Onboard SELENE (Kaguya),” *Lunar and Planetary Science Conference*, vol. 48, no. 1711, Mar. 2017.
- [8] Sood, R., Chappaz, L., Melosh, H.J., Howell, K.C. and Milbury, C., “Detection of Buried Empty Lunar Lava Tubes Using GRAIL Gravity Data,” *Lunar and Planetary Science Conference*, vol. 47, no. 1509, Houston, TX, Mar. 2016.
- [7] Sood, R., and Howell, K., “L₄, L₅ Solar Sail Transfers and Trajectory Design: Solar Observations and Potential Earth Trojan Exploration,” *26th AAS/AIAA Space Flight Mechanics Meeting*, vol. 158, no. 16-467, Napa, CA, Feb. 2016.
- [6] Sood, R., Melosh, H. J. and Howell, K., “Lunar advanced radar orbiter for subsurface sounding (LAROSS): lava tube exploration mission,” *26th AAS/AIAA Space Flight Mechanics Meeting*, vol. 158, no. 16-464, Napa, CA, Feb. 2016.
- [5] Sood, R., Chappaz, L., Melosh, H.J., Howell, K.C., Blair, D.M. and Milbury, C., “Detection of Buried Empty Lunar Lava Tubes Using GRAIL Gravity Data,” *2nd Planetary Caves Conference*, no. 9016, Flagstaff, AZ, Oct. 2015.
- [4] Blair, D.M., Chappaz, L., Sood, R., Milbury, C., Bobet, A., Melosh, H.J., Howell, K.C. and Freed, A.M. “Modeling the Structural Stability of Lunar Lava Tubes,” *2nd Planetary Caves Conference*, no. 9014, Flagstaff, AZ, Oct. 2015.
- [3] Sood, R., Chappaz, L., Milbury, C., Blair, D.M., Melosh, H.J. and Howell, K.C., “A Large, Previously Unknown Lunar Nearside Crater Revealed by GRAIL Gradiometry,” *Lunar and Planetary Science Conference*, vol. 46, no. 1883, Houston, TX, Mar. 2015.
- [2] Blair, D.M., Chappaz, L., Sood, R., Milbury, C., Bobet, A., Melosh, H.J., Howell, K.C. and Freed, A.M., “Determining the structural stability of lunar lava tubes,” *Lunar and Planetary Science Conference*, vol. 46, no. 2174, Houston, TX, Mar. 2015.
- [1] Chappaz, L., Sood, R., Melosh, H. and Howell, K., “Buried empty lava tube detection with GRAIL data,” *AAS/AIAA Astrodynamics Specialist Conference*, vol. 45, no. San Diego, CA, Aug. 2014.

Decadal Survey Bulletins

- [1] Keane, J., Ahern, A. A., Bagenal, F., Barr-Mlinar, A. C., Basu, K., Becerra, P., ... Sood, R., ..., and Williams, D. A. The Science Case for Io Exploration. *Bulletin of the American Astronautical Society*, 53(4), 178, Mar. 2021. DOI: 10.3847/25c2cfef.f844ca0e
- [2] Keane, J., Ahern, A. A., Bagenal, F., Barr-Mlinar, A. C., Basu, K., Becerra, P., ... Sood, R., ..., and Williams, D. A. Recommendations for Addressing Priority Science in the Next Decade. *Bulletin of the American Astronautical Society*, 53(4), 179, Mar. 2021. DOI: 10.3847/25c2cfef.3de45b59

Current and Former Research Students

MS and PhD Committee Chair and Undergraduate Scholars

*Names in **bold** indicates graduated students*

| | Name | Degree Year/ Expected | Dissertation/Thesis, Culminating Experience, or Research Area | Job/Internship Placement and Awards/Fellowships |
|-----|--------------------------|----------------------------------|--|--|
| 1. | Russell Solomon | MS, 05/2020 (MS plan II) | Methods of Modelling and Approximating Thrust for Global Navigation Satellite Systems | United States Navy |
| 2. | Jake Elkins | MS, 05/2021 (MS plan II) | Modern Artificial Intelligence and Spacecraft Attitude Control | NDSEG Fellow; Intern at Lockheed Martin and Navy; UAH PhD student |
| 3. | Andrew Sweeten | MS, 05/2021 (MS plan I) | Passive Drag Sail Applications for the Accelerated Deorbit and Targeted Reentry of Spacecraft | United States Space Force |
| 4. | Luke Schoenwetter | MS, 7/2021 (MS plan I) | Game Theory Applications in Astrodynamics and Space Domain Awareness | 2019, 2020, 2021 intern, and hired by a.i. solutions (NASA contractor) |
| 5. | William Ledbetter | PhD, 07/2021 | Applications of Numerical Methods to the Hamilton-Jacobi-Isaacs Equations in Various Dynamical Systems | 2019-21 ASGC Fellow; Intern and hired by Sandia National Laboratories |
| 6. | Ari Rubinsztein | PhD, 05/2022 | Design of Missed Thrust Resilient Trajectories Using Expected Thrust Fraction | 2019, 2020 Intern at NASA JPL; 2021-22 ASGC Fellow; Hired by John Hopkins Applied Physics Laboratory |
| 7. | Abram Aguilar | MS, 12/2023 | Extended Mission Design and Analysis for NASA's Magnetospheric Multiscale Mission (MMS) | Full-time employee at a.i. solutions, NASA GSFC |
| 8. | James Pezent | PhD, 05/2024 | New Solutions to Euler's Equations for Spacecraft Reorientation and Cost-Effective Trajectory Design | NSF GRFP and David A. Francko Fellow 20-2024; 2019 intern NASA MSFC |
| 9. | Brennan Blumenthal | PhD, 05/2025 | Local Lyapunov Exponents for Spacecraft Trajectory Design and Maneuver Planning | Full-time employee at NASA Johnson Space Center |
| 10. | Jared Sikes | PhD, 12/2025 | Solar and Dray Sails: Deep Space Exploration and De-Orbit Analysis | NAA Fellow 20-2020; 2020, 2021 intern at The Aerospace Corporation |
| 11. | Carrie Sandel | PhD, 05/2026 | Spacecraft Trajectory Design and Optimization for Rendezvous and Proximity Operations | NSF GRFP and Capstone Graduate Council Fellow 20-2026; 2021 intern at The Aerospace Corporation |
| 12. | Aaron Houin | PhD, 05/2026 | Optimal Spacecraft Launch Windows for Artemis III and Beyond Leveraging Contour Maps | Full-time employee at NASA Marshall Space Flight Center (MSFC) |

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Curriculum Vitae
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|-----|-------------------------|-------------|---|---|
| 13. | Luka Kronzer | BS, 05/2023 | Trajectory Design and Optimization; Simulation and Visualization | 2019 and 2022 intern at Oak Ridge National Laboratory |
| 14. | Ryan Hartmann | BS, 05/2025 | Orbital Mechanics and Flight Design | |
| 15. | Nate McCoun | BS, 05/2019 | Effects of Terrain on Satellite-Based Position Accuracy for Stationary and Moving Targets | Full-time employee at a.i. solutions |
| 16. | Jon Martini | BS, 05/2022 | Guidance Navigation, & Control and Machine Learning | 2022 intern at Aerojet Rocketdyne; Coming back to ASRL for MS Plan II |
| 17. | Kyra Bryan | BS, 05/2022 | Spacecraft Trajectory Optimization and Artificial Intelligence | NASA Pathway Intern |
| 18. | Alexandria Boehm | BS, 05/2022 | Solar Sailing and Guidance Navigation, & Control | NASA Pathway Intern |
| 19. | Will Lage | BS, 05/2022 | Spacecraft Trajectory Design | 2021 intern at Defense Intelligence Agency; Accepted job at Dynetics |

Honors and Awards

- **Estus H. and Vashti L. Magoon Award** for excellence in teaching by School of Aeronautics and Astronautics, Purdue University **Aug 2010 – May 2011**
- **Senior Scholar Award** for excellence in engineering by School of Engineering & Applied Sciences, SUNY Buffalo **Jan 2009 – May 2009**
- **Gustav and Greta Zimmer Research Scholar Award** for continuing work in the field of dynamics and control, SUNY Buffalo **Aug 2008 – Dec 2008**
- **Gustav and Greta Zimmer Special Project Scholarship Award** for research on flight dynamics & control of UAVs, SUNY Buffalo **Jan 2007 – Jan 2009**
- **Gustav and Greta Zimmer Summer Scholar Award** for research in vibration measurements, SUNY Buffalo **May 2006 – Jul 2006**
- **Chuang Family Scholarship** based on academic merit by School of Engineering & Applied Sciences, SUNY Buffalo **Jan 2006 – May 2006**

Invited Speaker

- [10] **Sood, R.**, “Innovative Solutions to Spacecraft Trajectory Design Leveraging Natural Dynamics for Space Exploration,” *Chandigarh University, India*, Feb. 2023.
- [9] **Sood, R.**, “Spacecraft Trajectory Design and Mission Analysis: From Earth to Cislunar and Deep Space Exploration,” *Chandigarh University, India*, Feb. 2023.
- [8] **Sood, R.**, “UA and NASA Marshall Space Flight Center: Ongoing and Future Collaboration,” *NASA Marshall Space Flight Center, Huntsville, AL*, Feb. 2023.
- [7] **Sood, R.**, “Spacecraft Trajectory Design Leveraging Natural Dynamics for Space Exploration: Intertwining Engineering and Science,” *Princeton University, Princeton, NJ*, Mar. 2021.
- [6] **Sood, R.**, “Cost-Effective Spacecraft Trajectory Design Leveraging Natural Multi-Body Dynamics,” *University of California, Davis, CA*, Dec. 2019.
- [5] **Sood, R.**, “Collaboration Initiative for Upcoming NASA Missions and Spacecraft Trajectory Design,” *NASA Marshall Space Flight Center, Huntsville, AL*, Mar. 2019.
- [4] **Sood, R.**, “Road Towards Space Exploration,” *Samuel Ginn College of Engineering, Department of Aerospace, Auburn University, Auburn, AL*, Apr. 2018.
- [3] **Sood, R.**, “Astrodynamics and Space Research Laboratory: Exploring the Unknown,” *Industrial Advisory Board, Aerospace Engineering and Mechanics, The University of Alabama, Tuscaloosa, AL*, Apr. 2018.
- [2] **Sood, R.**, “UA and NASA JPL: Visualization Collaboration and Software Acquisition,” *The Jet Propulsion Laboratory, Pasadena, CA*, Oct. 2017.

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- [1] **Sood, R.**, “Industry/Academia Collaboration: Virtual Reality for Spacecraft Trajectory Design,” *AstroLabs.Space*, Pasadena, CA, July 2017.

Teaching Experience

- **Associate Professor:** Dynamics, Advanced Astrodynamics, Celestial Mechanics, Spacecraft Attitude D&C, University of Alabama **Aug 2022 – Present**
- **Assistant Professor:** Dynamics, Advanced Astrodynamics, Celestial Mechanics, Spacecraft Attitude D&C, University of Alabama **Feb 2017 – Aug 2022**
- **Substitute Instructor:** Spacecraft Attitude Dynamics, Dynamics and Vibrations, and Orbital Mechanics for Professor Kathleen C. Howell, Purdue University **Jan 2010 – May 2015**
- **Instructor:** Spacecraft Modeling and Simulation utilizing Trick and Avizo® Visualization software, Purdue University **Aug 2012 – May 2013**
- **Minority Engineering Program:** Teach, engage, and educate underrepresented students critical engineering skills, Purdue University **Summer 2011**

- **Teaching Assistant:**
 - Honors: Creativity and Innovation in Engineering, Purdue University **Aug 2011 – Dec 2011**
 - Dynamics and Vibrations, Orbital Mechanics, Purdue University **Aug 2009 – May 2011**
 - Statics, Université de Technologie de Troyes, France **Summer 2009**

Service

- **University, College, and Department Service**
 - Graduate student recruitment
 - Trip to India to assist the UA Graduate School recruit talented engineering students
 - Assist department of Aerospace Engineering and Mechanics recruit MS and PhD students
 - Aerospace Engineering and Mechanics seminar organizer 2017-2018
 - Promote STEM education: actively recruit and mentor academically talented students from underrepresented and marginalized groups
 - Establish research collaborations between the Astrodynamics and Space Research Laboratory and:
 - NASA Marshall Space Flight Center
 - NASA Jet Propulsion Laboratory
 - NASA Goddard Space Flight Center
 - NASA Ames Research Center
 - Continuum Space Systems
 - Roccor
 - Volunteer assistant diving coach for the University of Alabama Swimming and Diving Team
- **Service to the Profession**
 - Invited international reviewer for the Dutch Research Council: Innovative Research Incentive Scheme of Science Domain
 - Invited reviewer to NASA proposals
 - Invited reviewer for selected journals:
 - The Journal of the Astronautical Sciences
 - Journal of Spacecraft and Rockets
 - Acta Astronautica
 - Aerospace Science and Technology
 - Advances in Space Research
 - Celestial Mechanics and Dynamical Astronomy
 - Journal of Optimization Theory and Applications
 - Conference Chair, session chair/co-chair and paper reviewer:

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Curriculum Vitae
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- Conference Chair: 33rd AAS/AIAA Space Flight Mechanics Meeting, Austin, TX, January 15-19, 2023, AIAA General Chair
 - 2022 AAS/AIAA Astrodynamics Specialist Conference, Charlotte, NC, August 7-11, 2022, Session: Trajectory, Mission, and Maneuver Design and Optimization VI
 - 32nd AIAA/AAS Space Flight Mechanics Meeting/ AIAA SciTech, San Diego CA, January 3-7, 2022, Session: Space Trajectory Design and Optimization II
 - 2021 AAS/AIAA Astrodynamics Specialist Conference, Virtual, August 8-12, 2021, Session: Space Situation Awareness I
 - 31st AAS/AIAA Space Flight Mechanics Meeting, Virtual, February 1-3, 2021, Sessions: Interplanetary Trajectories; Trajectory Design III
 - AAS/AIAA Astrodynamics Specialist Conference, Virtual, August 9-13, 2020, Session: Trajectory Design and Optimization IV
 - 30th AIAA/AAS Space Flight Mechanics Meeting/AIAA SciTech, Orlando, FL, January 6-10, 2020, Sessions: Asteroid and Non-Earth Orbiting Missions II; Low-Thrust Trajectory Design and Optimization II
 - AAS/AIAA Astrodynamics Specialist Conference, Portland, ME, August 11-15, 2019, Session: Trajectory Design & Optimization VI
 - 29th AAS/AIAA Space Flight Mechanics Meeting, Ka'anapali, Maui, HI, January 13-17, 2019, Session: Astrodynamics
 - AAS/AIAA Astrodynamics Specialist Conference, Snowbird, UT, August 19-23, 2018, Sessions: Astrodynamics-III; Space Situational Awareness-II
 - 28th AIAA/AAS Space Flight Mechanics Meeting/ AIAA SciTech, Kissimmee, FL, January 8-12, 2018, Session: Space Trajectory Design and Optimization II

Certification and Membership

- **Certification**
 - Private pilot: single engine land airplane
- **Membership**
 - Senior Member: American Institute of Aeronautics and Astronautics (AIAA)
 - Astrodynamics Technical Committee: American Institute of Aeronautics and Astronautics (AIAA)
 - Member: American Astronautical Society (AAS)

Selected Media Appearances

- [21] “UA Partners with Air Force to Explore Space Innovation.” January 24, 2023. *News Center, The University of Alabama*. <https://news.ua.edu/2023/01/ua-partners-with-air-force-to-explore-space-innovation/>
- [20] “Bama Grad’s Next Stop? Space.” April 20, 2022. *WVUA 23 Alabama News Station*. <https://www.wvua23.com/stationinfo/about/>
- [19] “Ready for Launch! UA Alumnus to Pilot Space Mission.” April 18, 2022. *News Center, The University of Alabama*. <https://news.ua.edu/2022/04/ready-for-launch-ua-alumnus-to-pilot-space-mission/>
- [18] “How drag sails could help solve our space junk problem.” April 11, 2022. *Astronomy*. <https://astronomy.com/news/2022/04/how-drag-sails-could-help-our-space-junk-problem>
- [17] “Dr. Rohan Sood to Attend NASA Launch.” April 11, 2022. *College of Engineering News, The University of Alabama*. <https://news.eng.ua.edu/2022/04/dr-rohan-sood-to-attend-nasa-launch/#:~:text=Dr.%20Rohan%20Sood%20to%20Attend%20NASA%20Launch%20Dr.,SpaceX%20Crew-4%20mission%20from%20Kennedy%20Space%20Center%2C%20Florida>

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Curriculum Vitae
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- [16] “The solar wind bubble that protects Earth has been mapped for the first time.” July 7, 2021. *MIT Technology Review*. <https://www.technologyreview.com/2021/07/07/1027914/ibex-mapped-boundary-earth-heliosphere/>
- [15] “A Message from the President.” Feb. 18, 2021. *Office of the President, The University of Alabama*. <https://president.ua.edu/news/a-message-from-the-president-february-18-2021/>
- [14] “NASA Mission to Include Contributions from UA Engineering.” Feb. 1, 2021. *News Center, The University of Alabama*. <https://news.ua.edu/2021/02/nasa-mission-to-include-contributions-from-ua-engineering/>
- [13] “University of Alabama satellite team offering virtual space lessons.” Apr. 19, 2020. *Alabama News Center*. <https://www.alabamanewscenter.com/2020/04/19/university-of-alabama-satellite-team-offering-virtual-space-lessons/>
- [12] “Randall Outstanding Undergrad Research Awards Recognize Innovation.” Aug. 8, 2019. *News Center, The University of Alabama*. <https://news.ua.edu/2019/08/randall-outstanding-undergrad-research-awards-recognize-innovation/>
- [11] “UA Recognizes Undergrad Randall Research Award Winners.” Apr. 25, 2018. *News Center, The University of Alabama*. <https://news.ua.edu/2018/04/ua-recognizes-undergrad-randall-research-award-winners/>
- [10] “Purdue professor says lunar lava tubes are key for human habitation.” Jan. 18, 2018. *The Purdue Exponent*. https://www.purdueexponent.org/city/article_d2a23ee9-b9f2-59fb-860d-a93635951abc.html
- [9] “Detection of intact lunar lava tubes in the data from SELENE (Kaguya) radar sounding.” Oct. 18, 2017. *JAXA: Japan Aerospace Exploration Agency*. <http://www.isas.jaxa.jp/en/topics/001159.html>
- [8] “UA Researcher on Team Exploring Potential Lunar Habitats for Humans.” Oct. 18, 2017. *News Center, The University of Alabama*. <https://news.ua.edu/2017/10/ua-researcher-on-team-exploring-potential-lunar-habitats-for-humans/>
- [7] “Lunar shelter: Moon caves could protect astronauts.” May 9, 2016. *Fox News: Science*. <https://www.foxnews.com/science/lunar-shelter-moon-caves-could-protect-astronauts>
- [6] “This strange hole in the moon might become an entrance to a future space colony.” Apr. 6, 2016. *Business Insider*. <https://www.businessinsider.com/lunar-lava-tubes-space-habitats-2016-4>
- [5] “Future Moon Bases Might Be Built in Underground Lava Tubes.” Mar. 29, 2016. *Smithsonian*. <https://www.smithsonianmag.com/smart-news/future-moon-bases-might-be-built-underground-lava-tubes-180958590/>
- [4] “Scientists May Have Spotted Buried Lava Tubes on the Moon.” Mar. 25, 2016. *National Geographic*. <https://www.nationalgeographic.com/science/article/scientists-may-have-spotted-buried-lava-tubes-on-the-moon>
- [3] “Earhart, Hiding in Plain Sight.” Mar. 18, 2015. *National Geographic*. <https://blog.education.nationalgeographic.org/2015/03/18/earhart-hiding-in-plain-sight/>
- [2] “New lunar crater named after aviation pioneer Earhart.” Mar. 17, 2015. *BBC News*. <https://www.bbc.com/news/science-environment-31917302>
- [1] “Purdue team puts Earhart on the moon with discovery of new crater.” Mar. 16, 2005. *Purdue University News*. <https://www.purdue.edu/newsroom/releases/2015/Q1/purdue-team-puts-earhart-on-the-moon-with-discovery-of-new-crater.html>

Hobbies and Extracurricular Activities

- Pianist and music composition
- Oil painting
- Swimming and competitive diving