VITAE
MOBLE BENEDICT

Associate Professor
Aerospace Engineering Department
Texas A&M University
741C H. R. Bright Bldg., College Station, TX 77843
Phone: 979-458-2705 (Office), 240-676-5023 (Cell)
Fax: 979-845-6051
Email: benedict@tamu.edu
Advanced Vertical Flight Laboratory Website

January 2022

SUMMARY VITAE

Moble Benedict is currently an Associate Professor of Aerospace Engineering at Texas A&M University (TAMU). Prior to that, he spent four years as an Assistant Research Scientist at the Rotorcraft Center of Excellence at the University of Maryland (UMD). He obtained his Ph.D. from the University of Maryland in December 2010 and M.S. and B.S. degrees from the Indian Institute of Technology (IIT) Bombay in 2004 and 2003, respectively.

Dr. Benedict conducts inter-disciplinary, fundamental research related to the broad areas of design, development, and autonomous control of high performance next-generation vertical take-off and landing (VTOL) capable aircraft, autonomous rotorcraft for planetary exploration, green aviation, high efficiency wind/tidal turbines, and uncrewed underwater vehicles (UUVs). His approach integrates theory and experiments to advance fundamental understanding and apply that understanding to real-life multi-disciplinary barrier problems. One of his notable contributions has been the development of a novel VTOL concept, called a "Cyclocopter," which is an efficient and agile aerial platform. This accomplishment won him the American Institute of Aeronautics and Astronautics **(AIAA) Young Engineer/Scientist of the Year Award** in 2012. He was awarded the 2016 **François-Xavier Bagnoud Award** from the Vertical Flight Society (VFS) for career-to-date contributions to vertical flight technology under the age of 35. He was also the **Grand Prize winner** of the Lockheed Martin "Innovate the Future" Global Challenge (out of 500 global entries) for his novel idea of a "*cycloidal wind turbine,*" which he experimentally demonstrated to be more than twice as efficient as traditional fixed-pitch vertical axis wind turbines.

Dr. Benedict has carried out cutting-edge pioneering research in a wide range of topics that have impacted disciplines such as rotorcraft, microsystems, wind energy, and even underwater propulsion. His research has produced **39 archival journal papers** (published and accepted)**, 86 papers presented at leading conferences, 9 filed patents, and 12 best paper awards**. Overall, he has supervised/co-supervised 20 graduate students (14 at TAMU, 5 at UMD, and 1 at Purdue). At TAMU, he founded the Advanced Vertical Flight Laboratory, which currently supports 1 post-doc, 7 graduate students, and numerous undergraduate students and has obtained **18 different grants** (14 Army/Navy/Air Force/NASA, 2 NSF and 2 industry grants) totaling **$4.4 million (Benedict's share)** to investigate VTOL flight. His research has been covered in more than 15 news articles by outlets including CNN, Popular Mechanics, Aerospace America, Economist, Houston Chronicle, NY Times, and IEEE Spectrum.

Dr. Benedict is also an enthusiastic educator. In teaching, he has made a difference by introducing courses in new disciplines such as rotorcraft engineering. He has obtained teaching evaluation ratings with an average of 4.4/5 for undergraduate level courses and 4.5 for graduate courses, which is well above the department average. Recently, he led a team of 8 aerospace graduate students to compete in the **Boeing GoFly Prize**, a 2-year, $2 million international competition to build a personal flying vehicle that is safe, quiet, and ultra-compact. In both the first (conceptual design) and second (sub-scale demonstration) phases of this challenge, the team **placed among the top 5, competing with 3,500 innovators from 101 countries**. They were the only U.S. university team to be in the top 5. The team built a full-scale 550-pound prototype to compete for the $1 million grand prize at the final phase fly-offs in February 2020. The prize is still unclaimed.

Dr. Benedict taught three graduate-level helicopter design courses focused on the design of the GoFly prototype. He was also the faculty advisor to the Texas A&M Hyperloop team, which was the only A&M team that proceeded to the final stage of the **SpaceX Hyperloop competition** held in California in January 2017, where the team built and demonstrated a full-scale prototype, which could levitate using a novel air-bearing technology that the team patented. Over the past 5 years he has involved more than 40 undergraduate students in his research, providing them with first-hand exposure to the frontiers of rotorcraft engineering and aerial robotics. These students have won numerous best paper awards in the VFS and AIAA conferences. Dr. Benedict has published 10 journal and 24 conference papers co-authored with undergraduate students. He also introduced a new helicopter track in Camp SOAR 2015-2018, a high school summer camp offered by the Aerospace engineering department.

Dr. Benedict's key service accomplishments include representing the Aerospace department in the TAMU Physics Festival, starting the VFS student chapter, hosting a high school teacher as part of an NSF-RET, and serving on numerous committees at the department, college and university levels. He was invited to chair sessions at multiple VFS and AIAA conferences and is a member of the VFS Advanced Vertical Flight Technical Committee. He has peer-reviewed manuscripts from 12 different highly prestigious journals. He has received the **2017 Dean's Excellence Award** and the **2018 TAMU Young Faculty Fellow Award** for his research, education, and service accomplishments.

Dr. Benedict has filed 9 patents (one already granted) over the past 5 years, out of which 3 are already licensed to different start-up companies. Dr. Benedict, along with his graduate students, founded **Harmony Aeronautics LLC** as a direct spin-off from the Boeing GoFly effort to develop and commercialize the personal flying vehicle mentioned above. The ultimate goal is to foster development of safe, quiet, ultra-compact, VTOL personal flying vehicles, which could be used for a wide range of applications in both commercial and military sectors. The company has thus far raised $0.5 million in both dilutive and non-dilutive funding, including an STTR grant from Air Force. This effort has provided significant technical and entrepreneurial exposure to several graduate students in the Aerospace Engineering department.

EXTENDED VITAE

RESEARCH FOCUS

Generate disruptive and revolutionary innovations through opportunity-driven, inter-disciplinary, fundamental research related to the broad areas of *aeromechanics, design, development, and autonomous control of high performance next-generation vertical flight concepts, green aviation, aircraft concepts for planetary exploration, high efficiency wind/tidal turbines, and uncrewed underwater vehicles*. Integrate experiments and computational analyses to advance fundamental understanding and its application to real-life problems, and to tackle multi-disciplinary barrier problems, generate high-level scholarly work, and create a team environment for research productivity and learning.

EDUCATION

University of Maryland (2004 – 2010)
Ph.D. in Aerospace Engineering
Thesis: "*Fundamental Understanding of the Cycloidal-Rotor Concept for Micro Air Vehicle Applications*"
Thesis Advisor: Prof. Inderjit Chopra

Indian Institute of Technology (IIT) Bombay (2003 – 2004)
Master of Technology in Aerospace Engineering
Master's Thesis: "*Aeroelastic Design and Manufacture of an Efficient Ornithopter Wing*"
Thesis Advisor: Prof. K. Sudhakar

Indian Institute of Technology (IIT) Bombay (1999 – 2003)
Bachelor of Technology in Aerospace Engineering

EMPLOYMENT

Associate Professor of Aerospace Engineering, September 2020 – onward
Texas A&M University, College Station

Assistant Professor of Aerospace Engineering, August 2014 – August 2020
Texas A&M University, College Station

Assistant Research Scientist, July 2012 – August 2014
Alfred Gessow Rotorcraft Center, University of Maryland, College Park

Postdoctoral Research Associate, January 2011 – June 2012
Alfred Gessow Rotorcraft Center, University of Maryland, College Park

Graduate Research Assistant, September 2004 – December 2010
Alfred Gessow Rotorcraft Center, University of Maryland, College Park

HONORS AND AWARDS

- One of the 5 **phase-II winners** globally for the $2M Boeing GoFly Prize (link).
- One of the 10 **phase-I winners** (from 600+ global entries) for the $2M Boeing GoFly Prize (link).
- 2018 university nominee for the Gordon Betty Moore Foundation **Moore Inventor Fellowship**.
- **Best Paper Award** in the Modeling and Simulation session (AIAA Aviation Conference 2019).
- TAMU College of Engineering **2018 Young Faculty Fellow Award**.
- TAMU College of Engineering **2017 Dean's Excellence Award**.
- **2016 François-Xavier Bagnoud Award** from American Helicopter Society (AHS) for career-to-date contributions to vertical flight technology under the age of 35 (link).
- $25K **Grand Prize Winner** of the Lockheed Martin 2012 Innovate the Future Global Challenge for "Cycloidal Wind Turbine" idea (winner was selected out of 500 entries) (link).
- **2012 Young Engineer-Scientist of the Year** Award from AIAA (link).
- **9 Best Paper Awards** at Vertical Flight Society Forums 2011, 14, 16, 17, 18, 19, 20, 21 (2 best papers in 2020).
- **Best Paper Award** at the AIAA SciTech Conference 2019.
- **2 Robert L. Lichten Awards** from American Helicopter Society (one per year) (2016 and 2017).
- **13 AIAA student conference prizes** (8 first places, 4 second places and 1 third place).
- Athena Award 2010.
- Ann Wylie Fellowship 2009.
- University of Maryland Future Faculty Fellow 2008.
- **Best Paper Award** at the International Seminar on Advances in Aerospace Sciences, Bangalore, India, December 2003.

PUBLICATIONS IN ARCHIVAL JOURNALS

JOURNAL PAPERS PUBLISHED

1. *Halder, A., and **Benedict, M.**, "Nonlinear Aeroelastic Coupled Trim Analysis of a Twin Cyclocopter in Forward Flight," *AIAA Journal*, Vol. 59, No.1, 2021, pp. 305 – 319.
2. *McElreath, J., **Benedict, M.**, and Tichenor, N., "Cycloidal Rotor Blade Tip Vortex Analysis at Low Reynolds Number," *AIAA Journal*, Vol. 58, No. 6, 2020, pp. 2560 – 2570.
3. *Walther, C., *Coleman, D., and **Benedict, M.**, "Force and Flowfield Measurements to Understand Unsteady Aerodynamics of Cycloidal Rotors in Hover at Ultra-Low Reynolds Numbers," *International Journal of Micro Air Vehicles*, Vol. 11, March 2019, pp. 1-18.
4. *Runco, C., *Coleman, D., and **Benedict, M.**, "Design and Development of a 30 g Cyclocopter," *Journal of the American Helicopter Society*, Vol. 64, No. 1, January 2019, pp. 1-10.

5. *Walther, C., *Saemi, F., **Benedict, M.**, and Lakshminarayan, V. K., "Aerodynamics of Symmetric versus Asymmetric Pitching of a Cycloidal Rotor Blade in Hover at Ultra-Low Reynolds Numbers," *Journal of Aircraft*, January 2019, pp. 1-22.
6. *Runco, C., *Himmelberg, B., and **Benedict, M.**, "Experimental Studies on a Mesoscale Cycloidal Rotor in Hover," *Journal of Aircraft*, December 2018, pp. 1-10.
7. *Coleman, D., *Gakhar, K., **Benedict, M.**, Tran, J., and Sirohi, J., "Aeromechanics Analysis of a Hummingbird-like Flapping Wing in Hover," *Journal of Aircraft*, Vol. 55, No. 6, July 2018, pp. 2282-2297.
8. *Halder, A., and **Benedict, M.**, "Role of Blade Flexibility on Cycloidal Rotor Hover Performance," *Journal of Aircraft*, Vol. 55, No. 5, July 2018, pp. 1773-1791.
9. *Halder, A., *Walther, C., and **Benedict, M**., "Unsteady Hydrodynamic Modeling of a Cycloidal Propeller," *Ocean Engineering*, Vol. 154, April 2018, pp. 94-105.
10. *Coleman, D., **Benedict, M.**, Hrishikeshavan, V., and Chopra, I., "Development of a Robotic Hummingbird Capable of Controlled Hover," *Journal of the American Helicopter Society*, Vol. 62, No. 3, July 2017, pp. 1 – 9.
11. Shrestha, E., Martz, V., Yeo, D., **Benedict, M.**, and Chopra, I., "Development of a Meso-Scale Cycloidal-Rotor Aircraft for Micro Air Vehicle Application," *International Journal of Micro Air Vehicles*, Vol. 9, No. 3, 2017, pp. 218 – 231.
12. **Benedict, M.**, *Coleman, D., Mayo, D. B., and Chopra, I., "Experiments on a Rigid Wing Undergoing Hover-Capable Flapping Kinematics at MAV-Scale Reynolds Numbers," *AIAA Journal*, Vol. 54, No. 4, October 2016, pp. 1145 – 1157.
13. Elena, S., Hrishikeshavan, V., **Benedict, M.**, Yeo, D., and Chopra, I., "Development of Control Strategies for a Twin-Cyclocopter in Forward Flight," *Journal of the American Helicopter Society*, Vol. 61, No. 4, October 2016, pp. 1 – 9.
14. Winslow, J., **Benedict, M.**, Hrishikeshavan, V., and Chopra, I., "Design, Development and Flight Testing of a High Endurance Micro Quadrotor Helicopter," *International Journal of Micro Air Vehicles*, Vol. 8, No. 3, September 2016, pp. 155 – 169.
15. **Benedict, M.**, Jarugumilli, T., and Chopra, I., "Effects of Asymmetric Blade-Pitching Kinematics on Forward Flight Performance of a Micro-Air-Vehicle-Scale Cycloidal-Rotor," *Journal of Aircraft*, Vol. 53, No. 5, 2016, pp. 1568-1573.
16. Shrestha, R., **Benedict, M.**, Hrishikeshavan, V., and Chopra, I., "Hover Performance of a Small-Scale Helicopter Rotor for Flying on Mars," *Journal of Aircraft*, Vol. 53, No. 4, 2016, pp. 1160-1167.
17. **Benedict, M.**, Mullins, J., Hrishikeshavan, V., and Chopra, I., "Development of a Quad Cycloidal-Rotor Unmanned Aerial Vehicle," *Journal of the American Helicopter Society*, Vol. 61, No. 2, April 2016, pp. 1 – 12.
18. **Benedict, M.**, Lakshminarayan, V. K., Johnathan, P., and Chopra, I., "Aerodynamics of a Small-Scale Vertical Axis Wind Turbine with Dynamic Blade Pitching," *AIAA Journal*, Vol. 54, No. 3, 2016, pp. 924 – 935.
19. **Benedict, M.,** Winslow, J., Hasnain, Z., and Chopra, I., "Experimental Investigation of Micro Air Vehicle Scale Helicopter Rotor in Hover," *International Journal of Micro Air Vehicles*, Vol. 7, No. 3, October 2015, pp. 231 – 255.
20. Mayo, D., Lankford, J., **Benedict, M.**, Chopra, I., "Aeroelastic Analysis of Avian-Based Flexible Flapping Wings for Micro Air Vehicles," *Journal of the American Helicopter Society*, Vol. 60, No. 3, 2015, pp. 1-18.

21. Mayo, D., Lankford, J., **Benedict, M.**, Chopra, I., "Experimental and Computational Analysis of Rigid Flapping Wings for Micro Air Vehicles", *Journal of Aircraft*, Vol. 52, Special Section on Second High Lift Prediction Workshop (2015), pp. 1161-1178.
22. Hrishikeshavan, V., **Benedict, M.**, and Chopra, I., "Identification of Flight Dynamics of a Cyclocopter Micro Air Vehicle in Hover," *Journal of Aircraft*, Vol. 52, No. 1, 2015, pp. 116 – 129.
23. Lind, A. H., Jarugumilli, T., **Benedict, M.**, Lakshminarayan, V. K., Jones, A. R., and Chopra, I., "Flowfield studies on a micro-air-vehicle-scale cycloidal rotor in forward flight," *Experiments in Fluids*, Vol. 55, November 2014, pp. 1 – 17.
24. Jarugumilli, T., **Benedict, M.**, and Chopra, I., "Wind Tunnel Studies on a Micro Air Vehicle-Scale Cycloidal Rotor," *Journal of the American Helicopter Society*, Vol. 59, No. 2, April 2014, pp. 1 – 10.
25. **Benedict, M.**, Jarugumilli, T., Lakshminarayan, V. K., and Chopra, I., "Effect of Flow Curvature on the Forward Flight Performance of a MAV-Scale Cycloidal Rotor," *AIAA Journal*, Vol. 52, No. 6, 2014, pp. 1159 – 1169.
26. **Benedict, M.**, Shrestha, E., Hrishikeshavan, V., and Chopra, I., "Development of a Micro Twin-Rotor Cyclocopter Capable of Autonomous Hover," *Journal of Aircraft*, Vol. 51, No. 2, 2014, pp. 672 – 676.
27. **Benedict, M.**, Gupta, R., and Chopra, I., "Design, Development and Flight Testing of a Twin-Rotor Cyclocopter Micro Air Vehicle," *Journal of the American Helicopter Society*, Vol. 58, No. 4, October 2013, pp. 1 – 10.
28. **Benedict, M.**, Jarugumilli, T., and Chopra, I., "Effect of Rotor Geometry and Blade Kinematics on Cycloidal Rotor Hover Performance," *Journal of Aircraft*, Vol. 50, No. 5, 2013, pp. 1340 – 1352.
29. Seshadri, P., **Benedict, M**., and Chopra, I., "Understanding Micro Air Vehicle Flapping-Wing Aerodynamics Using Force and Flowfield Measurements," *Journal of Aircraft*, Vol. 50, No. 4, July 2013, pp. 1070 – 1087.
30. Zachary, H., A., **Benedict, M.**, Hrishikeshavan, V., and Chopra, I., "Design, Development, and Flight Test of a Small-Scale Cyclogyro UAV Utilizing a Novel Cam-Based Passive Blade Pitching Mechanism," *International Journal of Micro Air Vehicles*, Vol. 5, No. 2, June 2013, pp. 145 – 162.
31. Seshadri, P., **Benedict, M.**, and Chopra, I., "A Novel Mechanism for Emulating Insect Wing Kinematics," *Journal of Bioinspiration and Biomimetics*, Vol. 7, No. 3, September 2012, pp. 1—15.
32. Malhan, R., **Benedict, M.**, and Chopra, I., "Experimental Studies to Understand the Hover and Forward Flight Performance of a MAV-scale Flapping Wing Concept," *Journal of the American Helicopter Society*, Vol. 57, No. 2, April 2012, pp. 022002-1 - 022002-11.
33. **Benedict, M.**, Mattaboni, M., Chopra, I., and Masarati, P., "Aeroelastic Analysis of a Micro-Air-Vehicle-Scale Cycloidal Rotor in Hover," *AIAA Journal*, Vol. 49, No. 11, November 2011, pp. 2430 – 2443.
34. **Benedict, M.,** Jarugumilli, T., and Chopra, I., "Experimental Optimization of MAV-Scale Cycloidal Rotor Performance," *Journal of the American Helicopter Society*, Vol. 56, No. 2, April 2011, pp. 022005-1 - 022005-11.
35. **Benedict, M.**, Ramasamy, M., and Chopra, I., "Improving the Aerodynamic Performance of Micro-Air-Vehicle-Scale Cycloidal Rotor: An Experimental Approach," *Journal of Aircraft*, Vol. 47, No. 4, July-August 2010, pp. 1117 – 1125.

36. **Benedict, M.**, Ramasamy, M., Chopra, I., and Leishman, J. G., "Performance of a Cycloidal Rotor Concept for Micro Air Vehicle Applications," *Journal of the American Helicopter Society*, Vol. 55, No. 2, April 2010, pp. 022002-1 - 022002-14.

JOURNAL PAPERS ACCEPTED

37. **Benedict, M.,** Garber, J., and Lakshminarayan, V. K., "Towards Understanding the Physics of a Small-Scale Cycloidal Wind Turbine," Accepted for publication in the *Renewable Energy Journal.*
38. *Yang, X., *Sudhir, A., *Halder, A., and **Benedict, M.**, "Nonlinear Aeroelastic Analysis for Highly Flexible Flapping Wing in Hover," Accepted for publication in the *Journal of the American Helicopter Society.*
39. *Halder, A., and **Benedict, M.**, "Understanding Upward Scalability of Cycloidal Rotors for Large-Scale UAS Applications," Accepted for publication in the *Journal of the American Helicopter Society*.

PUBLICATIONS IN CONFERENCE PROCEEDINGS

1. *Coleman, D., *Halder, A., *Saemi, F., *Runco, C., *Denton, H., *Lee, B., *Subramanian, V., Greenwood, E., Lakshminarayan, V., and **Benedict, M.**, "Development of Aria, a Compact, Ultra-Quiet Personal Electric Helicopter," Proceedings of the 77th Annual National Forum of the Vertical Flight Society, Virtual Meeting, May 10–14, 2021.
   (Best Paper Award Winner in the Electric VTOL Session)
2. *Lee, B., *Saj, V., and **Benedict, M.**, "Machine Learning Vision and Nonlinear Control Approach for Autonomous Ship Landing of Vertical Flight Aircraft," Proceedings of the 77th Annual National Forum of the Vertical Flight Society, Virtual Meeting, May 10–14, 2021.
3. *Denton, H., *McCurdy, G., **Benedict, M.**, and Kang, H., "System Identification of a Thrust-vectoring, Coaxial-rotor-based Gun-launched Micro Air Vehicle in Hover," Proceedings of the 77th Annual National Forum of the Vertical Flight Society, Virtual Meeting, May 10–14, 2021.
4. *Runco, C., and **Benedict, M.**, "Flight Dynamics Model Identification of a Meso-Scale Twin-Cyclocopter in Hover," Proceedings of the 77th Annual National Forum of the Vertical Flight Society, Virtual Meeting, May 10–14, 2021.
5. *Heimerl, J., *Halder, A., and **Benedict, M.**, "Experimental and Computational Investigation of a UAV-Scale Cycloidal Rotor in Forward Flight," Proceedings of the 77th Annual National Forum of the Vertical Flight Society, Virtual Meeting, May 10–14, 2021.
   (2021 American Helicopter Society Robert L. Lichten Award Runner-Up)
6. Desai, M., Gokhale, R., Halder, A., **Benedict, M.**, and Young, Y.L., "Augmenting Maneuverability of UUVs with Cycloidal Propellers," Proceedings of the 33rd Symposium on Naval Hydrodynamics, Virtual Meeting, October 18–23, 2020.
7. *Denton, H., **Benedict, M.**, Kang, H., and Hrishikeshavan, V., "Design, Development and Flight Testing of a Gun-Launched Rotary-Wing Micro Air Vehicle," Proceedings of the 76th Annual National Forum of the Vertical Flight Society, Virtual Meeting, October 6–8, 2020.
   (Best Paper Award Winner in the Advanced Vertical Flight Session)

8. *Saemi, F., **Benedict, M.**, and Beals, N., "Development of a Brushless DC Motor Sizing Algorithm for a Small UAS Design Framework," Proceedings of the 76th Annual National Forum of the Vertical Flight Society, Virtual Meeting, October 6–8, 2020.
   (Best Paper Award Winner in the Propulsion Session)
9. *Lee, B., Saj, V., **Benedict, M.**, and Kalathil, D., "A Vision-Based Control Method for Autonomous Landing of Vertical Flight Aircraft On a Moving Platform Without Using GPS," Proceedings of the 76th Annual National Forum of the Vertical Flight Society, Virtual Meeting, October 6–8, 2020.
10. Peck, C., Adams, D.W., McElreath, J., Verras, A., *Hiemerl, J., Majji, M., **Benedict, M.**, and Junkins, J., "Autonomous Deployment of Payload Packages to Spinning Rocket Bodies: Approach, Apparatus, and Emulation using Ground Robotics," Proceedings of the AAS conference, Virtual Meeting, 2020.
11. *Halder, A., and **Benedict, M.**, "Understanding Upward Scalability of Cycloidal Rotors for Large-Scale UAS Applications," Proceedings of the Transformative Vertical Flight Meeting, San Jose, CA, January 21-23, 2020.
12. *Yang, X., and **Benedict, M.**, "Computational Studies to Understand Flight Stability and Control of a Robotic Hummingbird," Proceedings of the Transformative Vertical Flight Meeting, San Jose, CA, January 21-23, 2020.
13. *Halder, A., and **Benedict, M.**, "Free-Wake Based Nonlinear Aeroelastic Modeling of UAV scale Cycloidal Rotor," Proceedings of the AIAA Aviation Conference, Dallas, TX, June 17–21, 2019.
    (Best Paper Award Winner in the Modeling and Simulation Session)
14. *Coleman, D., and **Benedict, M.**, "Flight Dynamics Identification, Maneuverability, and Gust Tolerance of a Robotic Hummingbird in Hover," Proceedings of the 75th Annual National Forum of the Vertical Flight Society, Philadelphia, PA, May 13–16, 2019.
15. *Denton, H., **Benedict, M.**, Kang, H., and Hrishikeshavan, V., "Development of a Gun-Launched Rotary-Wing Micro Air Vehicle," Proceedings of the 75th Annual National Forum of the Vertical Flight Society, Philadelphia, PA, May 13–16, 2019.
    (Best Paper Award Winner in the Advanced Vertical Flight Session)
16. *Saemi, F., **Benedict, M.**, and Beals, N., "Semi-Empirical Modeling of Group 1 UAS Electric Powertrains," Proceedings of the 75th Annual National Forum of the Vertical Flight Society, Philadelphia, PA, May 13–16, 2019.
    (2019 American Helicopter Society Robert L. Lichten Award Runner-Up)
17. *Halder, A., *Kellen, A., and **Benedict, M.**, "Aeroacoustic Analysis of UAV-Scale Cycloidal Rotor: An Experimental and Computational Approach," Proceedings of the 75th Annual Forum of the Vertical Flight Society, Philadelphia, PA, May 13–16, 2019.
18. *Yang, X., and **Benedict, M.**, "Coupled CFD-CSD Based Aeroelastic Analysis of a Highly Flexible Flapping Wing in Hover," Proceedings of the Vertical Flight Society Autonomous VTOL Technical Meeting and Electric VTOL Symposium, Meza, AZ, January 29-31, 2019.
19. *Kellen, A., *White, J., and **Benedict, M.**, "Development of a UAV-Scale Cyclocopter," Proceedings of the Vertical Flight Society Autonomous VTOL Technical Meeting and Electric VTOL Symposium, Meza, AZ, January 29-31, 2019.
20. *Coleman, D., and **Benedict, M.**, "A Truly Biomimetic Hover-Capable Flapping Wing Robot," Proceedings of the 74th Annual National Forum of the American Helicopter Society, Phoenix, AZ, May 15–17, 2018.
    (Best Paper Award Winner in the Advanced Vertical Flight Session)

21. *McElreath, J., **Benedict, M**., and Tichenor, N., "Tip Vortex Measurements on a Cycloidal Rotor Blade at Ultralow Reynolds Numbers," Proceedings of the 74th Annual National Forum of the American Helicopter Society, Phoenix, AZ, May 15–17, 2018.
    (2018 American Helicopter Society Robert L. Lichten Award Runner-Up)
22. *Runco, C., and **Benedict, M.**, "Understanding Flight Dynamics of a Meso-Scale Twin-Cyclocopter," Proceedings of the 74th Annual National Forum of the American Helicopter Society, Phoenix, AZ, May 15–17, 2018.
23. *Kellen, A., and **Benedict, M.**, "Experimental Investigation of UAV-Scale Cycloidal Rotor Aerodynamic Performance in Hover," Proceedings of the 74th Annual National Forum of the American Helicopter Society, Phoenix, AZ, May 15–17, 2018.
24. *Halder, A., and **Benedict, M.**, "Nonlinear Aeroelastic Coupled Trim Analysis of a Twin-Cyclocopter in Forward Flight," Proceedings of the 74th Annual National Forum of the American Helicopter Society, Phoenix, AZ, May 15–17, 2018.
25. *Yang, X., Badrya, C., Lankford, J., and **Benedict, M.**, "CFD Analysis for Flexible Flapping Wing in Hover Flight," Proceedings of the 74th Annual National Forum of the American Helicopter Society, Phoenix, AZ, May 15–17, 2018.
26. *Walther, C., *Coleman, D., and **Benedict, M.**, "Understanding Unsteady Aerodynamics of Cycloidal Rotors in Hover at Ultra-low Reynolds Numbers," Proceedings of the AIAA SciTech, Kissimmee, FL, Jan 8–12, 2018.
    (2018 AIAA International Student Conference Winner in graduate category)
27. *Yang, X., and **Benedict, M.**, "Nonlinear Aeroelastic Coupled Trim Analysis of Flapping Wing MAV in Hover," Proceedings of the American Helicopter Society International Technical Meeting on Aeromechanics Design for Transformative Vertical Flight, San Francisco, CA, January 16–18, 2018.
28. *Kellen, A., and **Benedict, M.**, "Experimental Optimization of UAV-Scale Cycloidal Rotor," Proceedings of the American Helicopter Society International Technical Meeting on Aeromechanics Design for Transformative Vertical Flight, San Francisco, CA, January 16–18, 2018.
29. *Halder, A., and **Benedict, M.**, "Nonlinear Aeroelastic Modeling of Cycloidal Rotor in Forward Flight," Proceedings of the American Helicopter Society International Technical Meeting on Aeromechanics Design for Transformative Vertical Flight, San Francisco, CA, January 16–18, 2018.
30. *Walther, C., *Coleman, D., **Benedict, M.**, and Lakshminarayan, V. K., "Experimental and Computational Studies to Understand Unsteady Aerodynamics of Cycloidal Rotors in Hover at Ultra-low Reynolds Numbers," Proceedings of the 73rd Annual National Forum of the American Helicopter Society, Fort Worth, TX, May 9–11, 2017.
    (2017 American Helicopter Society Robert L. Lichten Award Winner)
31. *Yang, X., *Sudhir, A., *Halder, A., and **Benedict, M.**, "Aeroelastic Analysis for Highly Flexible Flapping Wing in Hover," Proceedings of the 73rd Annual National Forum of the American Helicopter Society, Fort Worth, TX, May 9–11, 2017.
    (Best Paper Award Winner in the Modeling and Simulation Session)
32. *Halder, A., *Walther, C., and **Benedict, M.**, "Unsteady Hydrodynamic Modeling of a Cycloidal Propeller," Proceedings of the 5th International Symposium on Marine Propulsion, Helsinki, Finland, June 12 – 17, 2017.

33. *Runco, C., *Himmelberg, B., and **Benedict, M.**, "Performance and Flowfield Measurements of a Meso-Scale Cycloidal Rotor in Hover," Proceedings of the 73rd Annual National Forum of the American Helicopter Society, Fort Worth, TX, May 9–11, 2017.
34. *Kellen, A., and **Benedict, M.**, "Performance Measurements of UAV-Scale Cycloidal Rotor," Proceedings of the 73rd Annual National Forum of the American Helicopter Society, Fort Worth, TX, May 9–11, 2017.
35. *Halder, A., and **Benedict, M.**, "Nonlinear Aeroelastic Coupled Trim Analysis of a Cyclocopter in Hover," Proceedings of the 73rd Annual National Forum of the American Helicopter Society, Fort Worth, TX, May 9–11, 2017.
36. *Coleman, D., *Gakhar, K., **Benedict, M.**, and Tran, J., "Experimental Studies towards Understanding the Aeromechanics of a Flexible Robotic Hummingbird Wing in Hover," Proceedings of the 73rd Annual National Forum of the American Helicopter Society, Fort Worth, TX, May 9–11, 2017.
37. *Himmelberg, B., and **Benedict, M.**, "Performance Measurements of Meso-Scale Cycloidal Rotors in Hover," Proceedings of the AIAA SciTech, Grapevine, TX, Jan 9–13, 2017.
38. *Runco, C., *Coleman, D., and **Benedict, M.**, "Development of a cantilevered rotor-based meso-scale cyclocopter," Proceedings of the 7th American Helicopter Society International Specialists' Meeting On Unmanned Rotorcraft Systems, Meza, AZ, January 24-26, 2017.
39. *Coleman, D., and **Benedict, M.**, "Linearized Flight Dynamics of a Robotic Hummingbird in Hover," Proceedings of the 7th American Helicopter Society International Specialists' Meeting On Unmanned Rotorcraft Systems, Meza, AZ, January 24-26, 2017.
40. *Runco, C., *Coleman, D., and **Benedict, M.**, "Development of the World's Smallest Cyclocopter," Proceedings of the 72nd Annual National Forum of the American Helicopter Society, West Palm Beach, FL, May 17–19, 2016.
(2016 American Helicopter Society Robert L. Lichten Award Winner)
41. *Coleman, D., and **Benedict, M.**, "System Identification of a Robotic Hummingbird in Hovering Flight," Proceedings of the 72nd Annual National Forum of the American Helicopter Society, West Palm Beach, FL, May 17–19, 2016.
(Best Paper Award Winner in the Advanced Vertical Flight Session)
42. *Yang, X., *Sudhir, A., and **Benedict, M.**, "Nonlinear Aeroelastic Model for Highly Flexible Flapping Wings in Hover," Proceedings of the 72nd Annual National Forum of the American Helicopter Society, West Palm Beach, FL, May 17–19, 2016.
43. Shrestha, E., Yeo, D., Hrishikeshavan, V., **Benedict, M.**, and Chopra, I., "Gust Disturbance Rejection Study of a Cyclocopter Micro Air Vehicle," Proceedings of the 72nd Annual Forum of the American Helicopter Society, West Palm Beach, FL, May 17–19, 2016.
44. *Halder, A., and **Benedict, M.**, "Understanding Effect of Blade Flexibility on Cycloidal Rotor Hover Performance," Proceedings of the American Helicopter Society Technical Meeting on Aeromechanics Design for Vertical Lift, San Francisco, CA, January 20–22, 2016.
45. *Runco, C., *Coleman, D., and **Benedict, M.**, "Design and Development of a Meso-Scale Cyclocopter," Proceedings of the AIAA SciTech, San Diego, CA, Jan 4–8, 2016.
46. *Coleman, D., **Benedict, M.**, Hrishikeshavan, V., and Chopra, I., "Design, Development and Flight-Testing of a Robotic Hummingbird," Proceedings of the 71st Annual National Forum of the American Helicopter Society, Virginia Beach, VA, May 5–7, 2015.

47. **Benedict, M.,** Lakshminarayan, V. K., Garber, J., and Chopra, I., "Experimental and Computational Investigation of a Small-Scale Vertical Axis Wind Turbine with Dynamic Blade Pitching," Proceedings of the 71st Annual National Forum of the American Helicopter Society, Virginia Beach, VA, May 5–7, 2015.
48. Shrestha, E., Hrishikeshavan, V., Yeo, D., **Benedict, M.**, and Chopra, I., "Flight Dynamics Modeling and System Identification of a Cyclocopter in Forward Flight," Proceedings of the American Helicopter Society 71st Annual Forum, Virginia Beach, VA, May 5-7, 2015.
49. Shrestha, R., **Benedict, M.**, Hrishikeshavan, V., and Chopra, I., "Performance of a Small-Scale Helicopter Rotor for Martian Applications," Proceedings of the 6th American Helicopter Society International Specialists' Meeting on Unmanned Rotorcraft Systems, Chandler, AZ, January 20-22, 2015.
50. *Coleman, D., **Benedict, M.**, Hrishikeshavan, V., and Chopra, I., "Design and Development of a Hover-Capable Flapping Wing Micro Air Vehicle," Proceedings of the 6th American Helicopter Society International Specialists' Meeting on Unmanned Rotorcraft Systems, Chandler, AZ, January 20-22, 2015.
51. Winslow, J., **Benedict, M.**, Hrishikeshavan, V., and Chopra, I., "Design, Development and Flight Testing of a High Endurance Micro Quadrotor Helicopter," Proceedings of the 6th American Helicopter Society International Specialists' Meeting On Unmanned Rotorcraft Systems, Chandler, AZ, January 20-22, 2015.
52. Shrestha, E., Martz, V., Yeo, D., **Benedict, M.**, and Chopra, I., "Design and Hover Testing of a 60-gram Cyclocopter," Proceedings of the 6th AHS International Specialists' Meeting On Unmanned Rotorcraft Systems, Chandler, AZ, January 20-22, 2015.
53. **Benedict, M.**, Winslow, J., Hasnain, Z., and Chopra, I., "Performance and Flowfield Measurements of a MAV-Scale Helicopter Rotor in Hover," Proceedings of the 70th Annual National Forum of the American Helicopter Society, Montreal, Quebec, Canada, May 20–22, 2014.
54. Elena, S., Hrishikeshavan, V., **Benedict, M.**, Yeo, D., and Chopra, I., "Development of Control Strategies and Flight Testing of a Twin-Cyclocopter in Forward Flight," Proceedings of the 70th Annual National Forum of the American Helicopter Society, Montreal, Quebec, Canada, May 20–22, 2014.
    (Best Paper Award Winner in the Advanced Vertical Flight Session)
55. Mayo, D. B., Lankford, J. L., **Benedict, M.**, and Chopra, I., "Coupled CFD/CSD-Based Aeroelastic Analysis with Flowfield Measurements of Avian-Based Flexible Flapping Wings for MAV Applications," Proceedings of the 70th Annual National Forum of the American Helicopter Society, Montreal, Quebec, Canada, May 20–22, 2014.
56. Mayo, D. B., Lankford, J. L., **Benedict, M.**, and Chopra, I., "Experimental and Computational Aerodynamic Investigation of Avian-Based Rigid Flapping Wings for MAV Applications," Proceedings of the American Helicopter Society Specialists' Meeting on Aeromechanics, San Francisco, CA, Jan 22–24, 2014.
57. Hrishikeshavan, V., **Benedict, M.**, and Chopra, I., "Flight Dynamics System Identification and Control of a Cyclocopter Micro Air Vehicle in Hover," Proceedings of the 69th Annual National Forum of the American Helicopter Society, Phoenix, AZ, May 21–23, 2013.
58. Jarugumilli, T., Lind, A. H., **Benedict, M.**, Lakshminarayan, V. K., Jones, A. R., and Chopra, I., "Experimental and Computational Flow Field Studies of a MAV-scale Cycloidal Rotor in Forward Flight," Proceedings of the 69th Annual National Forum of the American Helicopter Society, Phoenix, AZ, May 21–23, 2013.

59. **Benedict, M.,** Lakshminarayan, V. K., Johnathan, P., and Chopra, I., "Fundamental Understanding of the Physics of a Small-Scale Vertical Axis Wind Turbine with Dynamic Blade Pitching: An Experimental and Computational Approach," Proceedings of the 54th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Boston, Massachusetts, April 8-11, 2013.
60. **Benedict, M.,** Coleman, D., Mayo, D., B., and Chopra, I., "Force and Flowfield Measurements on a Rigid Wing Undergoing Hover-Capable Flapping and Pitching Kinematics in Air at MAV-Scale Reynolds Numbers," Proceedings of the 54th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Boston, Massachusetts, April 8-11, 2013.
61. Shrestha, E., **Benedict, M.**, and Chopra, I., "Autonomous Hover Capability of Cycloidal-Rotor Micro Air Vehicle," Proceedings of the 51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Grapevine, TX, January 7–10, 2013.
62. Zachary, H., A., **Benedict, M.**, Hrishikeshavan, V., and Chopra, I., "Development of a Hover-Capable 500 gram Cyclogyro Utilizing a Novel Cam-Based Passive Blade Pitching Mechanism," Proceedings of the American Helicopter Society International Specialists' Meeting on Unmanned Rotorcraft, Scottsdale, AZ, January 22-24, 2013.
63. **Benedict, M.**, Mullins, J., Hrishikeshavan, V., and Chopra, I., "Development of an Optimized Quad Cycloidal-Rotor UAV Capable of Autonomous Stable Hover," Proceedings of the American Helicopter Society International Specialists' Meeting on Unmanned Rotorcraft, Scottsdale, AZ, January 22-24, 2013.
64. Jarugumilli, T., **Benedict, M.**, Lind, A. H., and Chopra, I., "Performance and Flow Visualization Studies to Examine the Role of Pitching Kinematics on MAV-scale Cycloidal Rotor Performance in Forward Flight," Proceedings of the American Helicopter Society International Specialists' Meeting on Unmanned Rotorcraft, Scottsdale, AZ, January 22-24, 2013.
65. Shrestha, E., **Benedict, M.**, Hrishikeshavan, V., and Chopra, I., "Development of a 100 gram Micro Cyclocopter Capable of Autonomous Hover," Proceedings of the 38th European Rotorcraft Forum, Amsterdam, Netherlands, September 4–7, 2012.
66. Jarugumilli, T., **Benedict, M.**, and Chopra, I., "Experimental Investigation of the Forward Flight Performance of a MAV-Scale Cycloidal Rotor," Proceedings of the 68th Annual National Forum of the American Helicopter Society, Fort Worth, TX, May 1–3, 2012.
67. **Benedict, M.**, Jarugumilli, T., Lakshminarayan, V., K., and Chopra, I., "Experimental and Computational Studies to Understand the Role of Flow Curvature Effects on the Aerodynamic Performance of a MAV-Scale Cycloidal Rotor in Forward Flight," Proceedings of the 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Honolulu, Hawaii, April 23-26, 2012.
68. Seshadri, P., **Benedict, M.**, and Chopra, I., "Towards a Fundamental Understanding of Low Reynolds Number Flapping Wing Aerodynamics," Proceedings of the 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Honolulu, Hawaii, April 23-26, 2012.
69. **Benedict, M.**, and Chopra, I., "Design and Development of an Unconventional VTOL Micro Air Vehicle: The Cyclocopter," Proceedings of the SPIE Micro-Nanotechnology Sensors, Systems, and Applications Conference, Baltimore, MD, April 23–27, 2012.

70. **Benedict, M.**, Shrestha, E., Hrishikeshavan, V., and Chopra, I., "Development of 200 gram Twin-Rotor Micro Cyclocopter Capable of Autonomous Hover," Proceedings of the American Helicopter Society Future Vertical Lift Aircraft Design Conference, San Francisco, CA, January 18–20, 2012.
71. **Benedict, M.**, Gupta, R., and Chopra, I., "Design, Development and Flight Testing of a Twin-Rotor Cyclocopter Micro Air Vehicle," Proceedings of the 67th Annual National Forum of the American Helicopter Society, Virginia Beach, VA, May 3–5, 2011.
(Best Paper Award Winner in the Advanced Vertical Flight Session)
72. Jarugumilli T., **Benedict, M.**, Chopra, I., "Experimental Optimization and Performance Analysis of a MAV Scale Cycloidal Rotor," Proceedings of the 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Orlando, FL, January 4-7, 2011.
73. **Benedict, M.**, Jarugumilli, T., and Chopra, I., "Experimental Investigation of the Effect of Rotor Geometry and Blade Kinematics on the Performance of a MAV-Scale Cycloidal Rotor," Proceedings of the American Helicopter Society International Specialists' Meeting on Unmanned Rotorcraft, Tempe, AZ, January 25-27, 2011.
74. Seshadri, P., **Benedict, M.**, and Chopra, I., "Control of a Biomimetic Insect-Based Flapping Mechanism for a Hovering Micro Air Vehicle," Proceedings of the American Helicopter Society International Specialists' Meeting on Unmanned Rotorcraft, Tempe, AZ, January 25-27, 2011.
75. **Benedict, M.**, Jarugumilli, T., and Chopra, I., "Experimental Performance Optimization of a MAV-Scale Cycloidal Rotor," Proceedings of the American Helicopter Society Specialists' Meeting on Aeromechanics, San Francisco, CA, Jan 20–22, 2010.
76. Seshadri, P., **Benedict, M.**, and Chopra, I., "Experimental Investigation of an Insect-based Flapping Wing Hovering Micro Air Vehicle," Proceedings of the American Helicopter Society Specialists' Meeting on Aeromechanics, San Francisco, CA, Jan 20–22, 2010.
77. **Benedict, M.**, Mattaboni, M., Chopra, I., and Masarati, P., "Aeroelastic Analysis of a MAV-Scale Cycloidal Rotor," Proceedings of the 51st AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Orlando, FL, April 12-15, 2010.
78. Mattaboni, M., **Benedict, M.**, Masarati, P., and Chopra, I., "MAV-Scale Cycloidal Rotor Multibody Aeroelastic Analysis," Proceedings of the 1st Joint International Conference on Multibody System Dynamics, Lappeenranta, Finland, May 25–27, 2010.
79. Malhan, R., **Benedict, M.**, and Chopra, I., "Experimental Investigation of an Avian-based Flapping Wing Concept for a Micro Air Vehicle," Proceedings of the 66th Annual National Forum of the American Helicopter Society, Phoenix, AZ, May 11–13, 2010.
80. **Benedict, M.**, Jarugumilli, T., and Chopra, I., "Design and Development of a Hover-Capable Cyclocopter MAV," Proceedings of the 65th Annual National Forum of the American Helicopter Society, Grapevine, TX, May 27–29, 2009.
81. **Benedict, M.**, Ramasamy, M., Chopra, I., and Leishman, J. G., "Experiments on the Optimization of the MAV-Scale Cycloidal Rotor Characteristics Towards Improving Their Aerodynamic Performance," Proceedings of the American Helicopter Society International Specialists' Meeting on Unmanned Rotorcraft, Scottsdale, AZ, January 20-22, 2009.
82. Seshadri, P., **Benedict, M.**, and Chopra, I., "Understanding Insect-Based Flapping Flight from a Micro Air Vehicle Perspective," Proceedings of the American Helicopter Society

International Specialists' Meeting on Unmanned Rotorcraft, Scottsdale, AZ, January 20-22, 2009.

83. **Benedict, M.**, Chopra, I., Ramasamy, M., and Leishman, J. G., "Experimental Investigation of the Cycloidal rotor for a Hovering Micro Air Vehicle," Proceedings of the 64th Annual National Forum of the American Helicopter Society, Montreal, Canada, April 28–30, 2008.
84. **Benedict, M.**, Sirohi, J., and Chopra, I., "Design and Testing of a Cycloidal-Rotor MAV", Proceedings of the American Helicopter Society International Specialists' Meeting on Unmanned Rotorcraft, Chandler, AZ, January 23-25, 2007.
85. **Benedict, M.**, Bhattacharya, A., and Pant, R., "Economic Benefit of Operating Turboprop Regional Aircraft on Three Short Haul Routes in India", Air Transport Research Society World Conference, Istanbul, Turkey, July 1-3, 2004.
86. **Benedict, M.**, Sudhakar, K., Mujumdar, P.M., and Issac, K.K., "Aeroelastic Design of an Ornithopter Wing", Proceedings of the International Seminar on Advances in Aerospace Sciences, Bangalore, India, December 17-18, 2003.
    (Best Paper Award winner)

STUDENT CONFERENCE PUBLICATIONS

1. *Harmon, M., and **Benedict, M.**, "Development of a Hybrid Aerial/Ground Transformer Platform," Proceedings of the 2019 Annual AIAA Region IV Student Conference, University of Texas, Austin, TX, March 29-31, 2019.
2. *McElreath, J., and **Benedict, M.**, "Force and Flowfield Measurements to Understand Unsteady Aerodynamics of Cycloidal Rotors in Hover," Proceedings of the 2018 Annual AIAA Region IV Student Conference, University of New Mexico, Albuquerque, NM, April 13-14, 2018.
3. *Walther, C., *Coleman, D., and **Benedict, M.**, "Understanding Unsteady Aerodynamics of Cycloidal Rotors in Hover at Ultra-low Reynolds Numbers," Proceedings of the 2017 Annual AIAA Region IV Student Conference, Houston, TX, April 28-30, 2017.
   (First place in the graduate category)
4. *Gakhar, K., and **Benedict, M.**, "Experimental Analysis of the Aeromechanics and Efficiency of a Robotic Hummingbird," Proceedings of the 2017 Annual AIAA Region IV Student Conference, University of Houston, Houston, TX, April 28-30, 2017.
   (Second place in the undergraduate category)
5. *Runco, C., and **Benedict, M.**, "Development and Flight Testing of a Meso-Scale Cyclocopter," Proceedings of the 2016 Annual AIAA Region IV Student Conference, University of Texas at Arlington, Arlington, TX, April 1-2, 2016.
   (First place in the graduate category)
6. *Himmelberg, B., and **Benedict, M.**, "Performance Measurements of Meso-Scale Cycloidal Rotors in Hover," Proceedings of the 2016 Annual AIAA Region IV Student Conference, University of Texas at Arlington, Arlington, TX, April 1-2, 2016.
   (First place in the undergraduate category)
7. *Kellen, A., and **Benedict, M.**, "Design, Development and Performance Measurements of a UAV-Scale Cycloidal Rotor," Proceedings of the 2016 Annual AIAA Region IV Student Conference, University of Texas at Arlington, Arlington, TX, April 1-2, 2016.
   (Second place in the undergraduate category)

8. *Coleman, D., and **Benedict, M**., "On the Development of a Robotic Hummingbird," Proceedings of the 2015 Annual AIAA Region IV Student Conference, University of Houston, Houston, TX, April 18-19, 2015.
   (First place in the graduate category)
9. Mills, A., **Benedict, M.**, and Chopra, I., "Investigation of the Effect of Blade Kinematics and Reynolds Number on the Aerodynamic Performance of a Small-Scale Vertical Axis Wind Turbine with Dynamic Blade Pitching," Proceedings of the 2015 Annual AIAA Region I Student Conference, Blacksburg, VA, March 27-28, 2015.
   (First place in the undergraduate category)
10. Muller, B., **Benedict, M.**, and Chopra, I., "Development of a 135 gram Cyclocopter at Micro Air Vehicle Scale," Presented at the AIAA, Region I-MA, Student Conference, Cornell University, NY, April 25-26, 2014.
    (Third place in the undergraduate category)
11. Mullins, J., **Benedict, M.**, and Chopra, I., "Design and Development of a Flying Cyclocopter," Presented at the American Institute of Aeronautics and Astronautics, Region I-MA, Student Conference, University of Maryland, MD, April 5-6, 2013.
    (Second place in the undergraduate category)
12. Shrestha, E., **Benedict, M.**, and Chopra, I., "Autonomous Hover Capability of Cycloidal-Rotor Micro Air Vehicle," Presented at the American Institute of Aeronautics and Astronautics, Region I-MA, Student Conference, Pennsylvania State University, PA, April 13-14, 2012.
    (First place in the undergraduate category)
13. Jarugumilli T., **Benedict, M.**, and Chopra, I., "Understanding the Effects of Number of Blades and Rotor Configuration on MAV-Scale Cycloidal Rotor Performance," Presented at the American Institute of Aeronautics and Astronautics, Region I-MA, Student Conference, Charlottesville, VA, April 8-9, 2011.
    (Second place in the undergraduate category)
14. Seshadri, P., **Benedict, M.**, and Chopra, I., "Aerodynamics and Control Towards A Biomimetic Hovering Flapping Wing Vehicle," Presented at the American Institute of Aeronautics and Astronautics, Region I-MA, Student Conference, Charlottesville, VA, April 8-9, 2011.
15. Shrestha, E., **Benedict, M.**, and Chopra, I., "Design and Control of a Cycloidal Rotor Aircraft," Presented at the American Institute of Aeronautics and Astronautics, Region I-MA, Student Conference, Charlottesville, VA, April 8-9, 2011.
16. Elliot, J.B., **Benedict, M.**, and Chopra, I., "Design and Control of a MAV Scale Quad Rotor Cyclocopter," Presented at the American Institute of Aeronautics and Astronautics, Region I-MA, Student Conference, Blacksburg, VA, April 9-11, 2010.
17. Jarugumilli T., **Benedict, M.**, and Chopra, I., "Experimental Optimization and Performance Analysis of a MAV Scale Cycloidal Rotor," Presented at the AIAA, Region I-MA, Student Conference, Blacksburg, VA, April 9-11, 2010.
    (First place in the undergraduate category)
18. Seshadri, P., **Benedict, M.**, and Chopra, I., "Design and development of an insect based flapping wing micro air vehicle," Presented at the American Institute of Aeronautics and Astronautics, Region I-MA, Student Conference, Norfolk, VA, April 3-4, 2009.

* *Students advised by Dr. Moble Benedict at Texas A&M University*

INVITED PRESENTATIONS

1. **Benedict, M.**, "Novel Vertical Flight Concepts", Invited seminar at Duke University, March 17, 2021.
2. **Benedict, M.**, "Novel VTOL Micro Air Vehicle Concepts", Invited seminar at Texas Systems Day, TAMU, College Station, March 31, 2017.
3. **Benedict, M.**, "Cycloidal Propulsion System: From UAVs to AUVs", Invited seminar at the Naval Surface Warfare Center, Carderock, MD, October 17, 2016.
4. **Benedict, M.**, "Novel Unmanned Aerial Vehicle Concepts", Invited seminar at M.A. College of Engineering, Kerala, India, December 11, 2014.
5. **Benedict, M.**, "Novel Hover-Capable MAV Concepts", Invited seminar at Bell Helicopters, Dallas, TX, October 24, 2014.
6. **Benedict, M.**, "Novel Hover-Capable MAV Concepts", Invited seminar at Aerospace Engineering Seminar Series, Texas A&M University, College Station, TX, February 26, 2014.
7. **Benedict, M.**, "Cyclogiros: A Myth to Reality", Invited seminar at the United States Air Force Academy, Colorado Springs, CO, April 22, 2013.
8. **Benedict, M.**, and Chopra, I., "Design and Development of an Unconventional VTOL Micro Air Vehicle: The Cyclocopter", Invited talk at the SPIE sponsored Micro- and Nanotechnology Sensors, Systems, and Applications Conference, Baltimore, MD, April 23 – 27, 2012.
9. **Benedict, M.**, "Design and Fabrication of an Aeroelastically Tailored Wing for a Flapping Wing Mini Air Vehicle", Invited talk at the National Seminar on Micro Aerial Vehicles organized by Institution of Engineers (India), Pune, India, February 28, 2004.

NEWS MEDIA REPORTS

1. "A Fresh Look at the Cyclocopter", **eVTOL Aviation**, December 2021. (link)

2. "Texas A&M team still competing in Boeing's GoFly", **The Eagle**, May 2020. (link)

3. "Ahead of the Jetsons: Texas A&M engineers to build flying motorcycle", **Houston Chronicle**, May 2019. (link)

4. "After More Than a Century, the Cyclocopter Is Making a Comeback", **Popular Mechanics**, April 2019. (link)

5. "Texas A&M Team wins second round of Boeing backed flight device competition", **Houston Innovation Map**, April 2019. (link)

6. "Aggie engineering group's design for flying vehicle taking off", **The Eagle**, April 2019. (link)

7. "Texas A&M's Harmony Team develops personal flying machine for Boeing's GoFly Prize Competition", **The Battalion**, April 2019. (link)

8. “Meet the 5 Winners Of GoFly Phase II”, **GoFly Prize**, March 2019. (link)

9. “GoFly Prize Picks eVTOL Personal Fliers, Heads Toward Flyoff”, **Aviation Week**, March 2019. (link)

10. “Would You Fly On These? Boeing-Funded Contest To Develop Personal Aircraft Picks 5 Finalists”, **Forbes**, March 2019. (link)

11. “Russian military is building a flying vehicle with rotating paddles”, **NewScientist**, March 2019. (link)

12. “Personal flying machine designs revealed in Boeing GoFly contest”, **CNN Travel**, June 2018. (link)

13. “Contest Aims to Lift Personal Flying Machines Off the Page”, **New York Times**, June 2018. (link)

14. “Military robots are getting smaller and more capable”, **The Economist**, December 2017. (link)

15. “Paddlewheel Propulsion is now Vertical and Multi-Modal”, **AHS Vertiflite Magazine**, July 2017. (link)

16. “Tiny drones, big questions”, **Aerospace America**, February 2017. (link)

17. “World's Smallest Cyclocopter Brings Unique Design to Microdrones”, **IEEE Spectrum**, Nov 10, 2016. (link)

18. “Robotic Hummingbird”, **IEEE Spectrum**, May 8, 2015. (link)

19. “Mutant Quadrotor MAV Lifts Off After a Century of Development”, **IEEE Spectrum**, July 22, 2011. (link)

INTELLECTUAL PROPERTY AND TECHNOLOGY COMMERCIALIZATION

PATENTS

1. **Title:** A Non-Contact, Gas-Driven Bearing Using a Continuous Gas Curtain and Supersonic Flow for Levitation at Millimetric Heights, U.S. Patent Application No. 62/394,626 *(patent granted, 2019)*
   Lead Inventor: Adonios Karpetis; *Co-inventors*: Dean Ellis, **Moble Benedict**, Yogesh Babbar

2. **Title:** Cycloidal Rotor Micro Air Vehicle, U.S. Patent Application No. 62/441,719 *(full patent filed, 2018)*
   Lead Inventor: **Moble Benedict**; *Co-inventors*: Carl Runco, David Coleman

3. **Title:** Hybrid Aerial/Ground Transformer Robot Capable of Multi-Modal Locomotion, U.S. Patent Application No. 62/508,640 *(full patent filed, 2018)*
   Lead Inventor: **Moble Benedict**; *Co-inventors*: Hunter Denton, Vikram Hrishikeshavan

4. **Title:** Hover-Capable Flapping-Wing Aircraft, U.S. Patent Application No. 62/608,528 *(full patent filed, 2018)*
   Lead Inventor: **Moble Benedict**; *Co-inventor*: David Coleman

5. **Title:** Hover-Capable Aircraft, U.S. Patent Application No. 62/685,323 *(full patent filed, 2019)*
   Lead Inventor: **Moble Benedict**; *Co-inventors*: David Coleman, Carl Runco, Atanu Halder, Bochan Lee, Andrew Riha, Farid Saemi, Vishaal Subramanian, Eric Greenwood, Vinod Lakshminarayan,

6. **Title:** Air Launched Hover-Capable Rotary-Wing Aircraft, U.S. Patent Application No. 62/852,906 *(provisional patent filed, 2019)*
   Lead Inventor: **Moble Benedict**; *Co-inventors*: Hunter Denton, Hao Kang, Vikram Hrishikeshavan

7. **Title:** Vertical Flight Aircraft Autonomous Landing Using a Visual Cue, U.S. Patent Application No. 62/978,458 *(provisional patent filed, 2020)*
   Lead Inventor: Bochan Lee; *Co-inventors*: **Moble Benedict**

8. **Title:** Cycloidal Propeller Underwater/Ground Vehicle, U.S. Patent Application No. 63/025,427 *(provisional patent filed, 2020)*
   Lead Inventor: **Moble Benedict**; *Co-inventors*: Sean McHugh, Ramsay Ramsey, Chase Wiley, Adam Kellen, Yin Lu Young.

9. **Title:** High Torque Density Electric Machine with Directly Cooled End Windings, U.S. Patent Application No. 63/024,652 *(provisional patent filed, 2020)*
   Lead Inventor: Hamid Toliyat; *Co-inventors*: Matthew Gardner, **Moble Benedict**, Prasad Enjeti, Dion Antao, Jonathan Felts, Jaimie Grunlan, Brian Rasmussen, Patrick Shamberger

START-UP COMPANIES

Dr. Benedict co-founded *Harmony Aeronautics LLC* (Harmony website) as a direct spin-off from the Boeing GoFly effort to develop and commercialize a personal flying vehicle. The ultimate goal is to foster the development of safe, quiet, ultra-compact, vertical take-off and landing-capable personal flying vehicles, which could be used for a wide range of applications in both commercial and military sectors. The company has raised $0.5 million in both dilutive and non-dilutive funding, including an STTR grant from the U.S. Air Force. With this funding, the company has already started developing early-stage prototypes based on the licensed technology.

SPONSORED RESEARCH PROJECTS

EXTERNAL GRANTS [Total Amount: $6.8M; Benedict's share: $4.4M]

1. Project Title: *Aeromechanics, Flight Dynamics and Control of Air Launched UAS*
   Source of Support: Army/Navy/NASA's Vertical Lift Research Center of Excellence.
   Period Covered: 11/19/2021 – 09/29/2026
   Technical monitor: Mahendra Bhagwat
   Award Amount: Total: $750,000; Benedict's (PI) share: $750,000

2. Project Title: *CHARIOT: Connector High-speed Aerial Resupply/Insertion Over-the-horizon Transport*
   Source of Support: Lynntech, Inc.; DARPA SBIR Phase-I
   Period Covered: 09/01/2021 - 06/28/2022
   Award Amount: Total: $225,000; Benedict's (Co-PI) share: $20,000

3. Project Title: *Development of a Revolutionary Amphibious Vehicle with Cycloidal Propellers*
   Source of Support: Office of Naval Research
   Period Covered: 03/19/2021 – 03/18/2023
   Technical monitor: Troy Hendricks
   Award Amount: Total: $332,428; Benedict's (PI) share: $332,428

4. Project Title: *Multi-Physical Co-Design of Next Generation Axial Motors for Aerospace Applications*
   Source of Support: DOE-ARPA-E
   Period Covered: 02/08/2021 - 06/30/2022
   Technical monitor: Peter de Bock
   Award Amount: Total: $1,430,000; Benedict's (Co-PI) share: $116,000

5. Project Title: *Revolutionary Coaxial Propulsors for Ultra-Quiet eVTOL*
   Source of Support: *Harmony Aeronautics LLC; Air Force AFWERX STTR Phase-I.
   Period Covered: 05/12/2020 - 04/06/2021
   Technical monitor: Jared Evans
   Award Amount: Total: $150,000; Benedict's (PI) share: $45,698

6. Project Title: *Model Based Analysis for Hybrid-Electric Vertical Flight Aircraft Design*
   Source of Support: U.S. Army Research Office
   Period Covered: 07/21/2020 - 07/23/2023
   Technical monitor: Constandinos Mitsingas
   Award Amount: Total: $554,077; Benedict's (PI) share: $554,077
7. Project Title: *Aeromechanics, Flight Dynamics and Control of a Revolutionary Tube –Launched Rotorcraft*
   Source of Support: U.S. Army Research Office.
   Technical monitor: Hao Kang
   Period Covered: 05/14/2019 – 05/13/2024
   Award Amount: Total: $386,516; Benedict's (PI) share: $386,516

8. Project Title: *A Novel Amphibious Platform with Stowable Cycloidal Propellers*
   Source of Support: Office of Naval Research
   Period Covered: 06/01/2018 – 05/30/2019
   Technical monitor: Troy Hendricks
   Award Amount: Total: $200,000; Benedict's (PI) share: $120,000

9. Project Title: *Dynamics and Control of Hummingbird Inspired Aerial Robots*
   Source of Support: National Science Foundation
   Period Covered: 07/01/2017 – 06/30/2020
   Technical monitor: Jordan Berg
   Award Amount: Total: $242,241; Benedict's (PI) share: $242,241

10. Project Title: *Scalable Novel Configurations for UAS Applications*
    Source of Support: Army/Navy/NASA's Vertical Lift Research Center of Excellence
    Period Covered: 11/25/2016 – 09/29/2021
    Technical monitor: Mahendra Bhagwat
    Award Amount: Total: $ 878,974; Benedict's (PI) share: $744,086

11. Project Title: *Phase II IUCR: Center for Unmanned Air Systems C-UAS*
    Source of Support: National Science Foundation
    Period Covered: 03/15/2020 – 02/28/2022
    Technical monitor: Behrooz Shirazi
    Award Amount: Total: $200,000; Benedict's (Co-PI) share: $60,000

12. Project Title: *Low Thrust Trajectory Optimization*
    Source of Support: Technology Service Corporation
    Period Covered: 08/01/2018 – 05/31/2019
    Technical monitor: Alok Das
    Award Amount: Total: $170,000; Benedict's (Co-PI) share: $33,000

13. Project Title: *Model-Based Engineering for Design Space Exploration of VTOL UASs*
    Source of Support: U.S. Army Research Office
    Period Covered: 08/01/2017 – 08/27/2019
    Technical monitor: Eric Spero
    Award Amount: Total: $142,000; Benedict's (PI) share: $142,000

14. Project Title: *Development of the RSQ Personal Drone Prototype*
    Source of Support: RSQ-Systems
    Period Covered: 10/01/2017 – 09/30/2018
    Technical monitor: Mathiew Buyse
    Award Amount: Total: $100,000; Benedict's (PI) share: $100,000

15. Project Title: *Conceptual Modeling of Novel Configurations for UAS Applications*
    Source of Support: Army/Navy/NASA's Vertical Lift Research Center of Excellence
    Period Covered: 10/01/2014 – 09/30/2017
    Technical monitor: Mahendra Bhagwat
    Award Amount: Total: $450,000; Benedict's (Co-PI) share: $225,000

16. Project Title: *Highly-Maneuverable, High-Speed, Optimized Next-Generation Micro Cyclocopter*
    Source of Support: U.S. Army Research Office
    Period Covered: 06/01/2018 – 05/30/2019
    Technical monitor: Chris Kroninger
    Award Amount: Total: $342,000; Benedict's (PI) share: $342,000

17. Project Title: *Control of Cyclocopter for Aggressive Maneuvers and in Gusty Environments*
    Source of Support: U.S. Army Research Office
    Period Covered: 08/15/2015 – 08/14/2016
    Technical monitor: Chris Kroninger
    Award Amount: Total: $100,000; Benedict's (Co-PI) share: $50,000

18. Project Title: *Instrumentation for Performance, Blade Loads and Flowfield Measurement of Novel Hover-Capable Meso-Scale Aerial Platforms (Defense University Research Instrumentation Program, DURIP)*
    Source of Support: U.S. Army Research Office
    Period Covered: 08/15/2015 – 08/14/2016
    Technical monitor: Matthew Munson
    Award Amount: Total: $107,630; Benedict's (PI) share: $107,630

INTERNAL GRANTS

19. Project Title: *2018 T3 Program*
    Source of Support: Texas A&M University

Period Covered: 04/01/2018 – 03/31/2020
Award Amount: Total: $32,000; Benedict's (PI) share: $10,000

* **Harmony Aeronautics** is a start-up company co-founded by Moble Benedict (CEO) and his graduate students focusing on electric vertical flight aircraft.

PROFESSIONAL SERVICE

Faculty Advisor: Vertical Flight Society TAMU Student Chapter

Member: Advanced Vertical Flight Technical Committee (Vertical Flight Society)

Chair: Advanced Vertical Flight Session, 2021 Vertical Flight Society Annual Forum
Deputy Chair: Advanced Vertical Flight Session, 2020 Vertical Flight Society Annual Forum

Society Membership:
AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS, Senior Member
VERTICAL FLIGHT SOCIETY, Member

Peer Reviews:
JOURNAL OF AIRCRAFT (2011 onwards)
JOURNAL OF THE AMERICAN HELICOPTER SOCIETY (2011 onwards)
AIAA JOURNAL (2013 onwards)
JOURNAL OF FLUIDS AND STRUCTURES (2013 onwards)
JOURNAL OF INTELLIGENT MATERIAL SYSTEMS AND STRUCTURES (2013 onwards)
THE AERONAUTICAL JOURNAL, ROYAL AERONAUTICAL SOCIETY (2014 onwards)
JOURNAL OF SHIP RESEARCH (2015 onwards)
JOURNAL OF GUIDANCE, CONTROL AND DYNAMICS (2015 onwards)
IEEE TRANSACTIONS ON ROBOTICS (2016 onwards)
NATURE ENERGY (2016 onwards)
BIOINSPIRATION & BIOMIMETICS (2017 onwards)
INTERNATIONAL JOURNAL OF MICRO AIR VEHICLES (2019 onwards)
AIAA AVIATION CONFERENCE (2016 onwards)
AIAA SCIENCE AND TECHNOLOGY FORUM (SCITECH) (2017 onwards)

DEPARTMENT AND UNIVERSITY SERVICE

- Led a multi-disciplinary team of 8 engineering graduate students from TAMU and researchers from NASA Langley, and NASA Ames, which was selected as *one of the 10 Phase-I winners* (out of 600+ global entries) as well as *one of the 5 Phase-II winners* of the **Boeing GoFly X-Prize**, a two-year, $2 million international competition to create a personal flying device (link).
- One of the two faculty advisors to the Aerospace Hyperloop team, which is the only A&M team that proceeded to the build/test stage of the SpaceX Hyperloop competition.
- Introduced a new helicopter track in Camp Soar 2015/16/17/18, which is a high school summer camp offered by the Aerospace Department.

- One of the few faculty members leading Aerospace Engineering in the Physics and Engineering Festival.
- Was a member of the Strategic Aerospace Research Committee.
- Represented Aerospace Department at Center for Infrastructure Renewal Building Committee.
- Delivered sophomore seminars to get the in-coming sophomores excited about aerospace and the opportunities it offers.
- Served on 2020 Goldwater scholarship selection committee.
- Served on Aerospace department head search committee.
- Served on laboratory space committee.
- Re-instated the American Helicopter Society (AHS) student chapter (faculty advisor).

MEMBERSHIP ON GRADUATE DEGREE CANDIDATES COMMITTEES

Student Name	**Degree**	**Student Name**	**Degree**
David Coleman	PhD	Carolyn Walther	MS
Carl Runco	PhD	Bochan Lee	MS
Xuan Yang	PhD	Adam Kellen	MS
Atanu Halder	PhD	Hunter Denton	MS
Bochan Lee	PhD	Sunsoo Kim	MS
Farid Saemi	PhD	Thomas Fowler	MS
Sunsoo Kim	PhD	Venkata Tadiparthi	MS
Alexandre Berger	PhD	Justin Barnes	MS
Benjamin Wilcox	PhD	Han-Hsun Lu	MS
Zachary Adams (Purdue University)	PhD	Cameron Rogers	MS
		Jaewon Kim	MS
		Krista Kratty	MS

RECORD OF STUDENT ADVISEES

GRADUATED STUDENTS

Doctoral Students	Thesis Title	Graduation Date
David Coleman	Fundamental Understanding of the Aeromechanics, Flight Dynamics, and Control of Hummingbird-like Flight	Dec 2021
Bochan Lee	Shipboard Vertical Take-off and Landing Unmanned Aerial Vehicle Autonomous Landing System	Aug 2021
Atanu Halder	Nonlinear Aeroelastic Coupled Trim Modeling of Cycloidal Rotor based Micro Air Vehicle	Aug 2019

Masters Students	Thesis Title	Graduation Date
Hunter Denton	Design, Development, and Flight Testing of a Tube-Launched, Rotary-Wing Micro Air Vehicle	May 2021
Keerat Singh	Non-thesis	May 2021

Farid Saemi	Sizing and Modeling of Electric Powertrains for Small Unmanned Aerial Systems	Dec 2020
Adam Kellen	Performance Measurements on a UAV-Scale Cycloidal Rotor in Hover	May 2019
Vishaal Subramanian	Non-thesis	May 2019
Bochan Lee	Helicopter Autonomous Ship Landing System	May 2018
Carolyn Walther	Fundamental Understanding of the Unsteady Aerodynamics of Cycloidal Rotors in Hover at Ultra-Low Reynolds Numbers	Aug 2017

CURRENT GRADUATE STUDENTS

Doctoral Students	Thesis Title	Expected Graduation
Carl Runco	Flight Dynamics and Control of Meso-Scale Cyclocopters	May 2022
Xuan Yang	CFD-CSD Based Aeromechanics and Flight Dynamics Modeling of Robotic Hummingbirds	May 2022
Farid Saemi	Development of Model-Based Design Framework for Hybrid-Electric Aircraft	Aug 2023
Hunter Denton	Aeromechanics, Flight Dynamics and Control of Tube-Launched Rotorcraft	Aug 2023

Masters Students	Thesis Title	Expected Graduation
Ramsay Ramsey	Design, Development and Flight Testing of a Class-2 UAV Scale Cyclocopter	Aug 2022
Chase Wiley	Optimization of Composite Structures for Aviation Grade Electric Motors	Dec 2022
John White	Development of a Cycloidal Propeller Based Amphibious Underwater Vehicle	Aug 2023

COURSES TAUGHT

AERO 310: Aerospace Dynamics (Spring 2015, 2016, 2017, 2018, 2019)
AERO 211: Aerospace Engineering Mechanics (Fall 2019, 2020, 2021)
AERO 455/655: Helicopter Aerodynamics (Fall 2015, 2016, 2017, 2018, 2019, 2020, 2021)
AERO 302/307: Aerospace Laboratory (co-taught with 2 other professors) (Fall 2016, Spring 2017, Fall 2017, Spring 2018, Fall 2018, Spring 2019)
AERO 689: Helicopter Design (Spring 2018)
AERO 689: Helicopter Design - II (Fall 2018)
AERO 689: Helicopter Design - III (Spring 2019)
AERO 489: Hyperloop Design (Fall 2015, Spring 2016)

SELECTED RESEARCH PROJECTS

(1) GoFly VTOL Personal Air vehicle

Dr. Moble Benedict led a team (Harmony) comprising of six graduate students from the Advanced Vertical Flight Lab (AVFL) to compete in the *Boeing GoFly Prize*, a 2-year, $2 million international competition to build a vertical take-off and landing (VTOL) capable personal air vehicle (PAV) that is safe, quiet, and ultra-compact. The team won both first (conceptual design) and second (sub-scale demonstration, **Fig. 1**) phases of this challenge (among *top 5*) competing with 800+ entries from 101 countries. Harmony is also the only US-university based team to be in the top 5. The 750-pound gross weight (with 200-pound payload) all-electric coaxial rotorcraft (**Fig. 2**) that the team designed and built has a rotor diameter of 8.2 feet (footprint area of a Smart car) and measured a noise level of 73 dBA at 50 feet during take-off, which is unprecedented for a VTOL aircraft of that size, limiting the noise to below typical suburban background noise (57 dBA) at distances greater than 350 ft. **Fig. 3** compares the measured noise spectra (50/3 ft. away) of the 1/3rd scale GoFly rotor and a high-speed quad-rotor producing the same thrust. Our unique coaxial-rotor design was 18 dB quieter than the quad-rotor. As far as we know, this is the quietest VTOL aircraft at this scale.

Fig 1. 1/3rd scale GoFly aircraft in flight. development video link

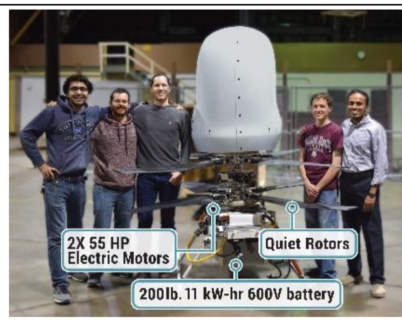


Fig 2. Full-scale PAV built at AVFL; Top 5 GoFly finalist from 800+ entries. flight test video link

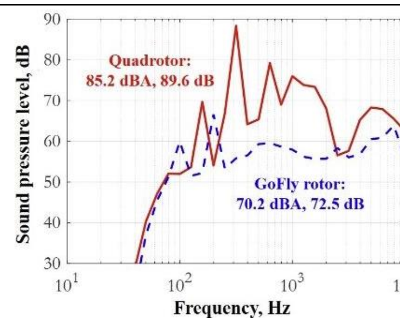


Fig 3. Measured noise: GoFly coaxial rotor 18 dB quieter than quadrotor while producing the same thrust. noise test video

The salient features of our design are:

1. Compact coaxial rotor system uniquely designed utilizing in-house rotary-wing aeroacoustic codes and 3D CFD analysis for low noise and hover/forward-flight efficiency.
2. Stiff lift-offset rotor design (no flap/lag hinges) with cyclic and collective pitch control for extreme agility, gust tolerance and high speed.
3. Robust "fly-by-wire" vehicle control through first ever electronically-coupled dual swash plate system.
4. A custom-designed 200-pound, 11 kW-hr, 600V air-cooled battery pack.
5. Ultralight, high strength-to-weight "*double-swept*" carbon fiber blades.
6. An efficient lightweight thermal management system for the 55 HP motors and invertors, via liquid cooling.

Dr. Benedict and his students founded *Harmony Aeronautics LLC* as a direct spin-off from the Boeing GoFly effort to develop and commercialize ultra-quiet and efficient propulsors for eVTOL aircraft. The company has raised around $0.5M in funds via private investments as well as a Phase-I STTR grant from Air Force (AFWERX Agility Prime).

(2) Cycloidal Rotor Aircraft -- Cyclocopter

Through five different grants from Army, Navy and NASA a revolutionary vertical flight concept called the "cycloidal rotor" was investigated as an alternative to conventional helicopter rotors. A cycloidal rotor is a horizontal axis rotating-wing system where the blade pitch angle is varied cyclically in a once-per-revolution fashion to produce net thrust. By changing the phase angle of the blade cyclic pitching, the direction of the thrust vector could be instantaneously altered, which could be utilized to improve agility. Through systematic experimental and computational studies spanning over a decade, we demonstrated that a cycloidal rotor could be more efficient, agile, gust tolerant, and quiet compared to conventional rotors and, therefore, has the potential to revolutionize the future VTOL aircraft. The experimental studies included measurements of time-averaged thrust and power in hover and wind tunnel, instantaneous blade forces in water tunnel, flowfield using particle image velocimetry (PIV) (**Fig. 4**), sound pressure levels, and flight dynamics model identification. The computational studies included the first ever aeroelastic modeling of a cycloidal rotor as well as CFD analysis (**Fig. 5**). Numerous cyclocopters over a range of scales from 30 grams (**Fig. 6**) all the way up to 55 pounds (**Fig. 7**) have been built and flight tested at AVFL.

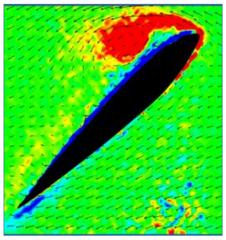


Fig 4. PIV measured flowfield & vorticity. video-1, video-2

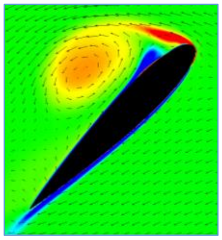


Fig 5. CFD predicted flowfield & vorticity.

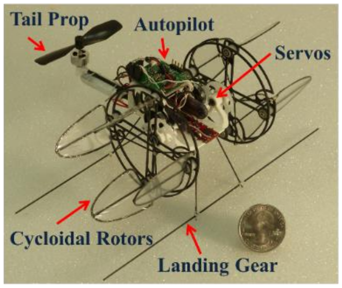


Fig 6. 30-gram cyclocopter MAV developed at AVFL. video-1, video-2

Fig 7. 55-lb cyclocopter UAV developed at AVFL.

(3) Robotic Hummingbird

Hummingbird flight is a marvel of the natural world of flight, filled with intricacies and nuances that enable some of the most impressive aerial performances, multi-modal flight capability, and exceptional maneuverability and agility. The objective of this NSF-funded project is to improve our understanding of the aeromechanics, flight dynamics, maneuverability, and wind-disturbance rejection capabilities of realistic hummingbird-like flapping-wing robots via simulations and flight experiments using a robotic hummingbird developed in-house. Towards this, a fully nonlinear 6-DOF flight dynamics model of a robotic hummingbird with flexible wings was developed by coupling rigid-body equations of motion with a CFD/CSD-based high fidelity wing aeroelastic model (CSD: Computational Structural Dynamics). Results from the aeroelastic simulations are shown in **Fig. 8**. A 62-gram biomimetic robotic

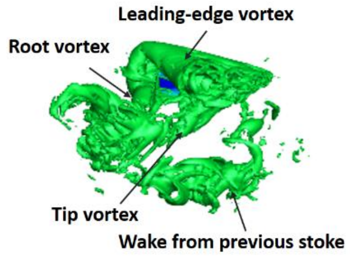


Fig 8. 3D flowfield around the hummingbird wing via CFD-CSD analysis. simulation video

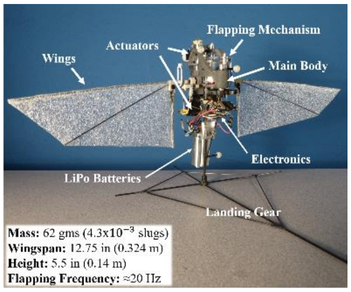


Fig 9. Robotic hummingbird developed at AVFL. flight test video

hummingbird (**Fig. 9**) that utilizes flexible, aeroelastically tailored wings flapping at 20 Hz during hover was also designed, built and flight tested. Wing structural deflections such as dynamic pitch, camber, and twist were quantified using digital image correlation (DIC) (deflection video).

Biologically inspired wing kinematic modulation strategies were implemented for attitude control. By tilting the flapping planes, varying the relative wing flapping amplitude, and shifting the mean position of the flapping stroke, the robotic hummingbird is able to modulate the magnitude, direction, and location of the lift vector of each of its wings in the same way that hummingbirds do to maneuver and stabilize themselves. This is the first ever study where the exact kinematic control strategies used by real hummingbirds are implemented on a robotic flyer and investigated through free-flight testing. Closed-loop control laws were also implemented on a custom-built 1.7-gram autopilot for active stability augmentation. The linear flight dynamics model of two-winged, hovering, hummingbird-like flight was derived from flight test data for the first time, which revealed unstable open-loop poles, and decoupled, but asymmetric, longitudinal and lateral modes. To compare these results against a familiar rotary-wing system, a physically similar (same mass and rotational inertias) quadrotor was developed, and flight tested. This helped answer the fundamental question of how the inherent flight dynamics, control authority and gust tolerance of a novel, biomimetic aerial system compare against a traditional UAV.

(4) Gun-Launched Micro Air Vehicle

The development of efficient, maneuverable, gust tolerant, and sustained hover-capable micro air vehicle (MAV) platforms with expanded flight envelope is the key to the success of many civilian and military missions. However, today's MAVs are heavily constrained in terms of hover endurance (< 20 minutes), operating altitude, and range primarily because of the low energy density of the batteries. Even though improving the endurance is still a significant barrier, the altitude and range of operation of the MAVs could be dramatically increased if the vehicle could be launched as a projectile and thereby not expending any of the stored energy in the vehicle to reach the operating location. This would also help the vehicle reach the operating point faster and quieter. Once the desired location and altitude is reached, the rotors could be deployed enabling sustained hover.

Fig 10. Gun-launched MAV developed at AVFL. flight test video

Fig 11. Next-generation gun-launched MAV design.

The objective of this Army–funded project is to conduct modeling and experimental studies to understand the aeromechanics, flight dynamics and control of a small-scale ultra-compact rotary-wing MAV that can be launched from a 40mm grenade launcher (**Figs. 10** and **11**). We have already developed a hover-capable, coaxial-rotor-based technology demonstrator prototype with foldable rotors and a novel thrust-vectoring based attitude control strategy which was successfully launched from a pneumatic cannon. The final deliverables will be (1) highly optimized gun-launched MAV design with principled understanding of the aeromechanics, flight dynamics and control and proof-of-concept prototypes with capabilities demonstrated through flight testing, and (2) data from flight dynamic simulations, performance measurements and flight testing.

(5) Amphibious Uncrewed Underwater Vehicle

This is a spinoff of our cycloidal rotor technology for underwater applications. The objective of this Navy-funded project is to develop a revolutionary amphibious (underwater/ground) uncrewed underwater vehicle (UUV) (**Figs. 12** and **13**) equipped with (1) four cycloidal propellers capable of 360° of instantaneous thrust vectoring using cyclic blade pitch control for superior station keeping and maneuvering across the spectrum of low to high speeds underwater, (2) the ability to easily retract the cycloidal propellers and stow them inside the rims of the specially designed wheels during ground locomotion, (3) single transmission to drive both the propeller and the wheel with a simple clutch to disengage wheel while under water, (4) an active ballast system for buoyancy control and longitudinal center of gravity adjustment, and (5) individual speed control for propellers/wheels for improved mobility in water and on the beach. The vehicle is designed to be symmetric about a horizontal mid-plane to enable operation even if the vehicle is upside down when washed-up on the beach. Extensive simulations were conducted using both CFD as well as our in-house cycloidal propeller unsteady fluid dynamics code to design a propeller optimized for a range of cruise speeds. The optimal propeller was built and systematically tested in a water tunnel facility at Texas A&M. A 350-pound UUV prototype was built and tested in a towing tank. We currently have a phase-II grant from the Navy to build and test an improved next-generation prototype.

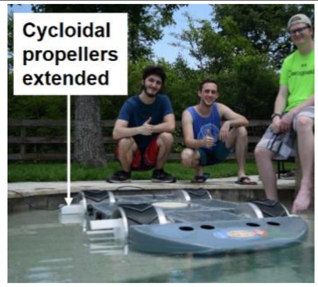


Fig 12. Amphibious UUV developed at AVFL in water mode.

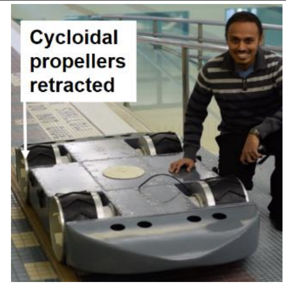


Fig 13. Amphibious UUV in ground mode (cyclo-props stowed).

(6) Cycloidal Wind Turbine

Another spinoff of the cycloidal rotor technology we have investigated is a cycloidal wind turbine (**Figs. 14** and **15**). Unlike large open windmill farms, extracting wind energy in an urban scenario is challenging because of the tight space constraints and the unsteady nature of the wind profile. Although small-scale Horizontal Axis Wind Turbines (HAWTs) appear to be the first choice, they suffer from certain drawbacks such as extreme sensitivity to magnitude and direction of wind and large spacing requirements. Foundational research was conducted towards developing a revolutionary vertical axis wind turbine (VAWT) with dynamic blade pitching (similar to cycloidal rotors), which has been experimentally proven to be more efficient than traditional fixed-pitch VAWTs, self-starting at extremely low speeds, self-adjusting to rapid fluctuations in wind speed/direction and achieves high efficiencies at low tip speed ratios (rotational speeds). We believe that the present turbine could revolutionize wind-power generation, especially in urban environment where energy needs are very high, space is constrained, and wind-conditions are extremely unpredictable. Note that this idea of cycloidal VAWT proposed by Dr. Benedict was the ***Grand Prize (25K) Winner of the Lockheed Martin 2012 Innovate the Future Global Challenge*** where the winning idea was selected out of 500 global entries.

Fig 14. 2kW cycloidal turbine.

Fig 15. Cycloidal wind turbine test setup.

(7) Texas A&M University Rotorcraft Analysis Code (TRAC)

A comprehensive helicopter flight dynamics code is developed and named Texas A&M University Rotorcraft Analysis Code (TRAC). This is a complete and modular software package, which could perform trim analysis to autonomous flight simulation and has the capability to model any helicopter configuration. Different components of the helicopter such as the main rotor, tail rotor, fuselage, vertical tail, and horizontal tail are modeled individually as different modules in the code and integrated to develop a complete helicopter model. Since the code is modular, it can be easily modified to include another component or configure any helicopter. TRAC can predict the dynamic responses of both the articulated rotor blades and the helicopter fuselage and yields the required pilot control inputs to achieve trim condition for different flight regimes such as hover, forward flight, coordinated turn, climb/descent, etc. (sample results shown in **Fig. 16**). These trim results are validated with the test data obtained from the UH-60 (Black Hawk) helicopter flight tests conducted by the US Army (**Fig. 17**).

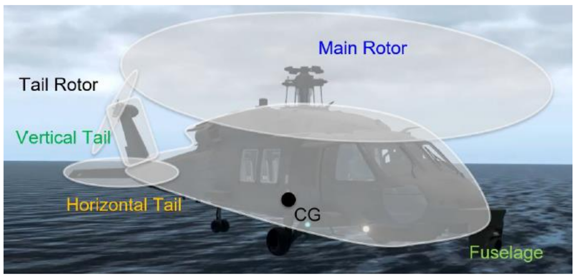


Fig 16. Different components of the UH-60 helicopter modeled in TRAC.

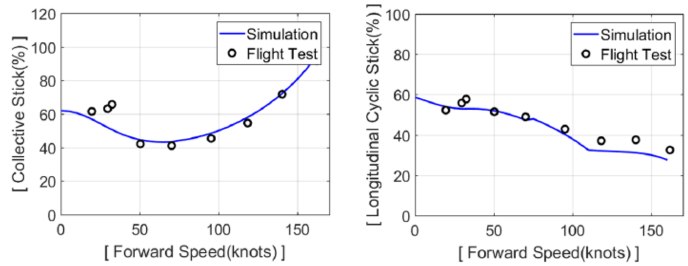


Fig 17. Trim control inputs vs. forward flight speed for UH-60 helicopter: TRAC simulation vs. US Army flight test results.

Beyond trim analysis, TRAC can also generate linearized models at various flight conditions based on a first-order Taylor series expansion. The extracted linear models show realistic helicopter dynamic behavior and were used to simulate a fully autonomous flight that involves a UH-60 helicopter approaching a ship and landing on the deck by implementing a Linear Quadratic Regulator (LQR) optimal controller. The simulations were conducted using TRAC, however, the visualization was performed using the X-plane software (ship landing simulation video). TRAC is currently being used for an Army-funded helicopter rotor morphing project in close collaboration with Boeing.

(8) Autonomous Vertical Flight UAV Ship Landing

The objective of this NSF project is to develop novel control algorithms by combining robust deep reinforcement learning (RL) with computer vision to enable precision autonomous approach and vertical landing of UAVs in challenging GPS-denied adversarial environments in the presence of wind gusts. Our approach is inspired by the procedure that Navy pilots follow for landing on space-constrained ship decks by utilizing the "*horizon reference bar*" (a standardized visual reference). A computer vision system using a single monocular camera is developed to detect the horizon bar (visual cue) and then accurately estimate the heading of the UAV and its relative distances in all three directions to the landing pad. The algorithm was able to estimate the distances in real-time within an accuracy of less than a centimeter and heading within a degree. A gain-scheduled nonlinear PID controller is then integrated with the vision system to achieve tracking and landing. The integrated system was able to perform successful autonomous landing with less than 5 centimeters of landing error.

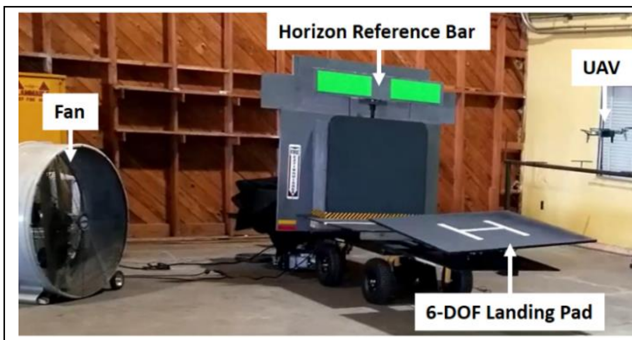


Fig 18. UAV ship landing test-rig developed at AVFL.
flight test video link

A deep RL-based control algorithm was also developed for autonomous landing, integrating it with the computer vison-based system for localization. The vision and RL-based control system was implemented on a UAV and flight tests were conducted where the UAV approached and landed on a sub-scale ship platform (**Fig. 18**) undergoing 6 degrees of freedom deck motions in the presence of wind gusts. Simulations and flight tests confirmed the superior disturbance rejection capability of the RL controller when subjected to sudden 5 m/s wind gusts in different directions. Specifically, it was observed during flight tests that the deep RL controller demonstrated a 50% reduction in lateral drift from the flight path and 3 times faster disturbance rejection in comparison to a nonlinear proportional-integral-derivative (PID) controller (wind rejection video link).

(9) Model-Based Design Tool for Electric UAS

We have obtained two different grants from the Army to develop and validate performance and sizing models of electric powertrains for group-1 (<20 lbs.) to group-3 (<1350 lbs.) UASs. Most electric powertrains utilize a brushless DC (BLDC) motor architecture along with a motor controller (or inverter), and lithium-polymer battery. The semi-empirical models we developed for the motor, power electronics, and battery use high-level component specifications to enable pre-conceptual design space exploration and mission-based design optimization of UAS without a library of test data. The models also enable tradeoff analyses between existing and/or conceptual designs without a series of flight tests.

To develop, tune, and validate the models for the group-1 UAS, a custom dynamometer test setup was designed and built to measure torque, speed, and electrical power data of small-scale motor drive systems (**Fig. 19**). The larger group-3 UAS motors were tested at an external dynamometer test facility (**Fig. 20**). The integrated motor and controller model was able to predict the powertrain performance within 5% of the experimental values. The validated models reveal that popular claims of "high efficiency" for electric powertrains are only valid in a narrow band of high-speed/low-torque operation. This is a critical finding for vehicle designers in the VTOL industry who are increasingly transitioning to electric powertrains in low-speed/high-torque applications which may decrease the overall system efficiency.

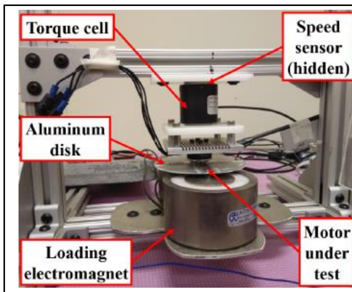


Fig 19. 100W group-1 UAS motor tested on a custom built dynamometer at AVFL.


Fig 20. 55HP group-3 motor tested at a dyno test facility.

Sizing models are currently being developed, which will be able to predict the size (length and diameter of motor) as well as weight of the motor, power electronics and battery given the torque and rpm profile for the mission, which will be obtained from our in-house aircraft performance models. An interesting insight gained from the sizing studies is that the weight of the motor scales with torque and not power. The models developed in this work can be immediately applied to design UAS given the torque and speed requirements of the rotors/propellers, the operating voltage of the vehicle system, and certain high-level component specifications for the motor, inverter, and battery. The models can also be used for BLDC powertrains for small terrestrial or aquatic electric vehicles.

(10) Next-Generation Axial Motor Design for Aerospace Applications

A group of Texas A&M engineering researchers including Dr. Moble Benedict have been awarded $1.4 million in funding from the U.S. Department of Energy ARPA-E's ASCEND (Aviation-class Synergistically Cooled Electric-motors with integrated Drives) program. The objective of this project is to develop an innovative lightweight and ultra-efficient electric motor with integrated inverter and thermal management systems (collectively referred to as the all-electric powertrain) that will help reduce net-zero carbon emissions and energy costs in single-aisle, 150-200 passenger commercial aircraft. The team will design, build and test a sub-scale all-electric powertrain (**Fig. 21**), which will have a power rating of 250 kW and an extremely high power-to-weight ratio (power density) of 12 kW/Kg and net efficiency > 90%.

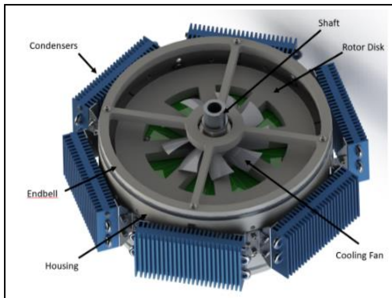


Fig 21. 250 kW electric motor design with 12 kW/Kg power-to-weight ratio & efficiency > 90%.

This unprecedented peak power density and efficiency will be achieved via (1) an axial flux motor with lightweight carbon fiber reinforced structural material, (2) a GaN multilevel inverter, (3) a thermally conductive nanocomposite electrical insulation and (4) a two-phase thermal management system with zeolite thermal energy storage to absorb the excess heat generated during takeoff. Each subsystem is designed for tight integration with the other subsystems to minimize weight. Benedict's role in this project is to design and fabricate the first ever carbon fiber structural components (rotor, stator, shaft, etc.) for an electric motor.

(11) Autonomous Deployment of Payload Packages to Spinning Rocket Bodies

This was an Air Force-funded Active Debris Removal (ADR) project conducted in collaboration between the Texas A&M Land, Air, Space Robotics lab (LASR) and AVFL. The topic of ADR has gained significant attention over the past few decades, and recent studies have indicated that at least five large Low Earth Orbit (LEO) debris objects must be removed each year (along with no further release) in order to stabilize LEO for the future. For large objects in an unknown flat-spin state, the challenge of carrying out rendezvous and proximity operations becomes compounded by the highly dynamic environment of relative motion. Even to track the large bodies, it is frequently useful to tag them using radio transponder packages. In the light of these important challenges involving large spinning bodies, our objective was to autonomously track a tumbling rigid body using vision-based sensors and deliver a payload at a specified location on the rigid body. The novelty of our approach is the integration of computer vision, a pneumatic payload delivery device, and the payload itself to provide a tethered connection between the mother craft and its target.

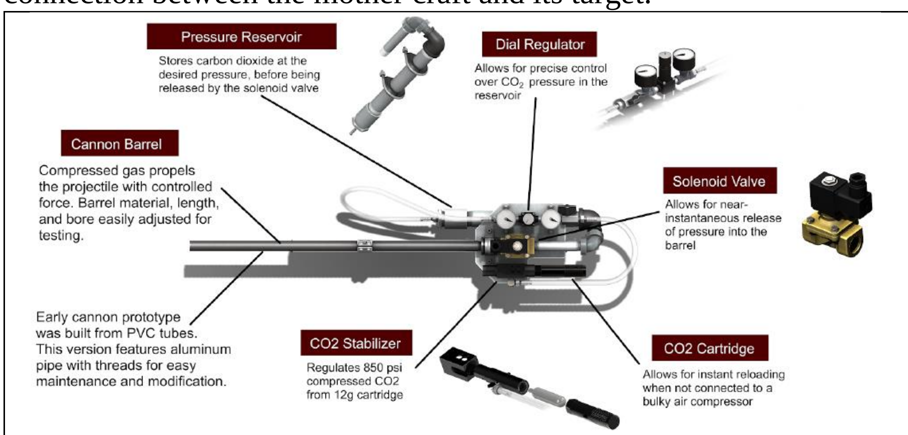


Fig 22. Automated Harpoon and Braking System (AHAB) prototype.

Fig 23. AHAB mounted on the ground robot.

The centerpiece of our mission operation is an Automated Harpoon and Braking System, also known as AHAB (schematic shown in **Fig. 22**). AHAB houses an on-board computer which receives camera data, performs the motion tracking algorithm and executes the payload delivery process. The payload delivery is performed using AHAB's pneumatic cannon. The cannon accepts gas via a small CO_2 cartridge and stores it in a pressure-regulated reservoir until a fire command is sent from the computer. The AHAB deploys a specially designed spring-loaded projectile, which could travel to, and through a rocket nozzle entrance to complete a tethered soft capture with the spacecraft. The target estimation performed by AHAB uses state-of-the-art computer vision algorithms paired with high refresh rate cameras to provide real-time, accurate estimates for the trajectory of the rotating target nozzle. AHAB was mounted on the omnidirectional motion emulator ground robot in LASR lab along with a height, azimuth and elevation manipulator (**Fig. 23**). Experiments were conducted where the AHAB system automatically detected and shot the projectile through the nozzle of a rotating sub-scale target nozzle with 90% success rate, demonstrating the repeatability of this concept.

(12) Mars Helicopter

In 2013, while working as a research scientist at University of Maryland, Dr. Benedict conducted pioneering work investigating the feasibility of a small helicopter on Mars. These studies were conducted for the Jet Propulsion Lab researchers, who had just initiated a Mars helicopter program at the time. The first step involved a design trade-off study to compare the performance of different rotorcraft configurations such as multi-copters, conventional helicopter, coaxial helicopter, etc., to achieve vertical flight in the thin Martian atmosphere. This study showed conclusively that a coaxial helicopter stands out from the standpoints of efficiency and compactness. The next step was to build and test a 1.5 ft. diameter optimized Martian rotor in a custom-built evacuation chamber at Martian atmospheric densities (**Figs. 24** and **25**). The rotor operated at an ultralow Reynolds number of 3300, but at a relatively high Mach number of 0.4. These conditions will never exist on a terrestrial rotorcraft. The evacuation chamber tests demonstrated that we could generate the required thrust at Martian air densities at a reasonable efficiency (figure of merit ~ 0.4), which proved the feasibility of the concept from an aerodynamics standpoint.

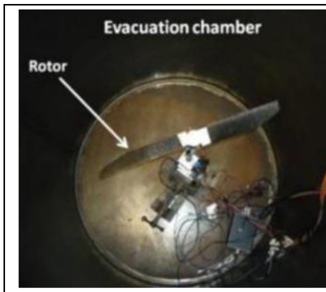


Fig 24. Martian rotor on the hover test stand inside the evacuation chamber.

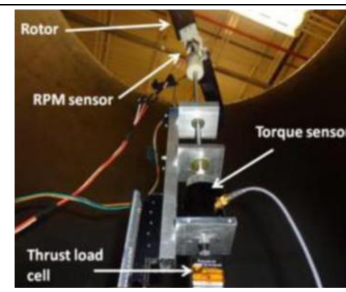
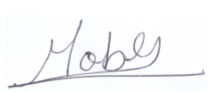


Fig 25. Close-up view of the sensors to measure thrust, torque, rpm, and temperature.

I certify that this curriculum vitae is a current and accurate statement of my professional record.

Signature: 

Date: 1/3/2022