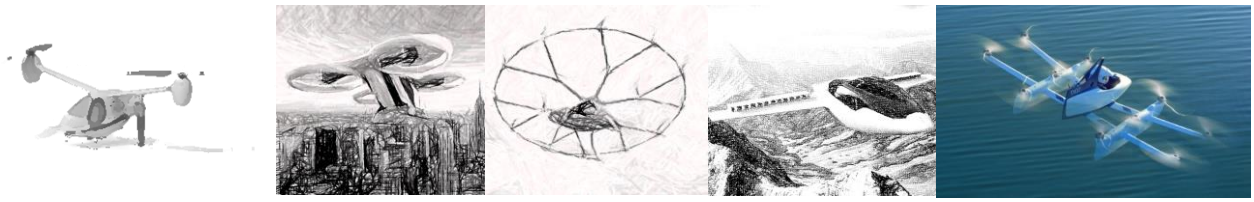
Short Course on Electric VTOL Technology



COURSE DESCRIPTION / OVERVIEW:

Electric Vertical Take Off and Landing aircraft – or eVTOL – are aircraft propelled by electric power and capable of carrying people. There has been a dramatic resurgence of interest in these aircraft, driven by advances in electric-propulsion, digital manufacturing, high-fidelity simulations, and drone technologies (mobile computing and deep-learning). However, man-rated aircraft are more complex than drones, and require more than a clever combination of scaled-up components from consumer electronics and automobiles. Maturation of eVTOL into a safe, sound, and sensible aircraft require a clear understanding of rotary-wing fundamentals, principles of enabling technologies and timely resolution of its major barriers. The objective of this course is to introduce these fundamentals, technologies and barriers.

Led by Anubhav Datta from the University of Maryland, this multi-presenter course will provide an overview of the unique challenges and opportunities of this new class of vehicles. Both electric and hybrid-electric passenger carrying vertical flight aircraft will be covered for a variety of missions ranging from personal/private use to urban air taxis to regional electric VTOL bizjets.

WHO SHOULD TAKE THE COURSE:

Aerospace engineers interested in electric power. Electrical / Mechanical engineers interested in VTOL aircraft. The content will be presented in a simplified and practical manner to allow innovators, entrepreneurs, and non-VTOL experts to be able to make useful calculations and build their own design / simulation tools. The content will be presented in a simplified and practical manner aimed to engage a wide audience of mixed aerospace and non-aerospace background. A simplified multi-rotor VTOL aircraft will be designed and analyzed in class, progressively, as a illustrative example.

Power point course notes will be emailed to all registered participants two weeks before the class.

INSTRUCTORS

Anubhav Datta, University of Maryland
Robert Hess, BAE Systems
Brad Paden, LaunchPoint Technologies & UC Santa Barbara
James Baeder, University of Maryland

COURSE CONTENTS

I. Fundamentals: Rotors, Aircraft, and Electric Power **2 hrs**
Anubhav Datta, Associate Professor, Alfred Gessow Rotorcraft Center

Introduction to eVTOL

Rotors

- Edgewise rotors vs propellers vs prop-rotors
- Fundamentals of rotor aerodynamics and dynamics
- Coaxial and shrouded (or ducted) rotors
- Blade structural loads (stresses/strains) and rotor hub loads
- Design example

eVTOL aircraft

- Trim solution; pitch vs rotor speed control
- eVTOL cruise performance; tip speed, torque and disk loading
- Rotor L/De vs aircraft L/D; hub drag
- Performance of example aircraft
- Sizing with piston, turbo-shaft and electric power plant
- Design example

Electric Power

- Li-ion batteries and PEM fuel cells for DC power
- Hydrogen storage
- Weights and overhead
- Design example
- Hybrid-electric engine-generators for AC power
- Fundamental characteristics of engines, generators and motors
- Component versus combined efficiencies
- Steady-state versus transient dynamics
- Weights and overhead
- Design example

II. Sizing Advanced Battery Systems for eVTOL Application **2 hrs**
Robert Hess, Systems Engineering Manager, BAE Systems

- Definitions
- Describe battery operations and management
- Fundamentals of safe management and control
- Detail elements of battery packaging
- Discuss battery modeling
- Relate electrical and thermal elements to basic first principles
- Detail how systems are sized
- Assess battery performance (example)
    - Power

    - Energy
    - Size
    - Weight
    - Life
    - Cost
- Review development standards and testing

III. Brushless Permanent Magnet Machines for Aircraft. **2 hrs**
Michael Ricci, LaunchPoint Technologies

- Basic PM motor physics for aeronautical engineering
- PM motor types and geometries (radial and axial flux)
- Motor performance metrics: size, weight, efficiency, torque, speed
- Characteristics and performance
- Designing a PM motor: sizing, weights and efficiencies
- Operating modes: motor vs generator
- Drives and gearboxes
- Electric Tail rotor example

IV. eVTOL and UAM noise **2 hrs**
James Baeder, Professor, Alfred Gessow Rotorcraft Center

- Definitions
- Fundamentals of rotor acoustics
- Types of noise: broadband, rotational, and impulsive noise
- Ffowcs Williams and Hawkings Model
- Method to calculate noise
- Lifting-line versus CFD inputs
- Single versus multiple rotors
- Hover and forward flight
- Active control of noise
- Fundamental limits
- How quiet is quiet enough ?

Anubhav Datta is a member of the Alfred Gessow Rotorcraft Center (AGRC) as an Associate Professor of Aerospace Engineering at the University of Maryland at College Park. He holds a M.S. and Ph.D. in Aerospace Engineering from Maryland. He joined AGRC in 2016 after nine years at the U. S. Army Aviation Development Directorate (ADD) at NASA Ames Research Center, where he worked on full-scale UH-60A Airloads Test, 3D solver development for rotor aeroelastic stress/strains, and initiated research on eVTOL in 2012. His current research in Maryland is focused on modeling and testing of new electric propulsion concepts for eVTOL and improving dynamic loads and stability of high-speed tilting prop-rotors through wind-tunnel testing and CFD/CSD simulations. He is the chair of the AHS Integrating Technical Team (ITT) on eVTOL, led NARI's inter-city eVTOL working-group in 2016-2018, Chair of the AIAA Structural Dynamics Conferences Sub-committee, member of AHS Dynamics Committee, and Associate Editor of the Journal of the American Helicopter Society. The research conducted by Datta and his colleagues and students have been recognized by AHS's Alfred Gessow Best Paper Award, Grover E. Bell Award, and Francois-Xavier Bagnoud Award, NASA's Technical Excellence in Publications Award, and Group Achievement Awards from the US Army and NASA.

Brad E. Paden, Ph.D., is Chairman of the Board and the Principal Engineer for LaunchPoint Technologies. As Co-Founder and former CEO, Dr. Paden led the magnetic bearing and control system consulting business, expanded the business to contract engineering in the mid-1990's, and in 2001, engaged the company in early-stage venture engineering activities. By involving the company with start-ups, intellectual property development, entity formation, and team building, Dr. Paden has focused LaunchPoint on value creation. He currently serves on the Board of Directors for LaunchPoint start-up partner, LaunchPoint Energy and Power, LLC (LEAP), and serves as an observer on the Boards of Magnetecs Corporation and LaunchPoint spin-off, Gravity Power, LLC.

Dr. Paden is also a Professor Emeritus of Mechanical Engineering at the University of California, Santa Barbara, with a joint appointment in the Department of Electrical and Computer Engineering. Dr. Paden is a Fellow of the IEEE and the American Institute of Medical

and Biological Engineering (AIMBE). He was the recipient of the ASME 2010 Charles. S. Draper Award for Dynamics and Control, the 2001 IEEE Control Systems Society Technology Award, and the 1993 Best Paper Award from the ASME Journal of Dynamic Systems, Measurement, and Control. Dr. Paden has authored over 80 publications and holds 17 patents in the field of engineering systems.

James Baeder is a member of the Alfred Gessow Rotorcraft Center as a Professor of Aerospace Engineering at the University of Maryland at College Park. He is currently the Associate Langley Professor Chair at the National Institute for Aerospace. He holds a M.S. and Ph.D. in Aeronautics and Astronautics from Stanford University. He joined the AGRC in 1993 after nine years at AFDD. His research interests are in developing and applying Computational Fluid Dynamic methods to better understand rotor aerodynamics, acoustics and dynamics. He is a pioneer in the development of high-fidelity CFD and aeroacoustic methods and tools for rotorcraft. Currently he is focused on the development of improved CFD algorithms on GPGPU technology, to: capture the details of laminar/turbulent transition; dynamic stall; as well as tip vortex formation, convection and interaction with other surfaces including fuselages, towers or the ground and including adjoint capabilities. Dr. Baeder's research has been funded by Excelon, NASA Ames and Langley, the Army Aeroflightdynamics Directorate, the Army Research Office, the National Rotorcraft Technology Center, NAVAIR and DARPA, with support from the various helicopter companies. Dr. Baeder is a Technical Fellow of the American Helicopter Society, member of the Acoustics Technical Committee (1996-present), member of the Aerodynamics and Propulsion Area Committee, and Chairs the Innovation and Commercialization Committee of the Business Network for Offshore Wind as well as the National Offshore Wind Innovation Center.

Robert Hess is a Systems Engineering Manager at BAE Systems. He has been working in the aerospace industry for over 35 years. He currently leads the development of high-power, high-voltage battery systems for vehicle propulsion at BAE Systems where he leverages a multidisciplinary design team to advance battery solutions. Over the last 10 years, Bob has been involved with the analysis and development of Li Ion, ultra-capacitor and LiS battery concepts for all-electric and hybrid-electric propulsion. He holds several patents in the area of battery systems. As he has many years' experience in vehicle avionics systems, Bob has is able to apply a broad systems approach to the design of battery systems, including design for

safe operations and sustainability. Prior to his work with battery systems, Bob was involved in the development of helicopter HUMS as well as aircraft aerodynamic analysis. He published a number of papers in the fields of battery systems, diagnostics, prognostics and aircraft aerodynamic modeling and simulation. He hold a B.S. degree in Mechanical Engineering from Western New England University as well as a M.S degree from the George Washington University. Bob is a member of VFS and SAE International.