CREATe

CENTER FOR RENEWABLE ENERGY AND AERODYNAMIC TECHNOLOGY

2016 ANNUAL HIGHLIGHTS

VirginiaTech
Invent the Future

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PREAMBLE

WILLIAM DEVENPORT
PROFESSOR AND
DIRECTOR OF THE
STABILITY WIND TUNNEL

Dear Friends of CREATe,

In review of the many activities and accomplishments of our center and the faculty involved in it, we thought it fitting to provide a brief report of it for our friends in the field. The 2016 annual report that follows covers some of the important contributions that have been made thanks in no small part to the collegial and technically invigorating atmosphere that the center has provided to the students, faculty, and staff involved in our operations.

For background about our organization, the vision of the Center for Renewable Energy and Aerodynamic Testing (CREATe) is to exploit the synergy between scientific advances in aerodynamics and acoustics, and engineering advances in renewable energy. The center was officially chartered by the university as a department level center in February 2014. It brings together 9 core faculty in the Crofton Department of Aerospace and Ocean Engineering and 10 affiliate faculty in a range of departments. The center's administrative home is in 660 McBryde Hall on the Blacksburg campus of Virginia Tech.

Members of the center are engaged in a diverse range of research projects that focus on the fundamentals of aerodynamics and aeroacoustics and on applied problems, with particular application to wind energy. Many of these efforts emphasize student-centered research and involve collaborations with other universities and industry, both domestic and international. Many of these efforts involve use of the Virginia Tech Stability Wind Tunnel. The wind tunnel is a major aeroacoustic research facility in the US for flow acoustics and a global leader for the aerodynamic and aero-acoustic testing of wind turbine blade designs. A key theme of the wind tunnel and the center is incorporating state of the art research tools and research problems into the undergraduate curriculum.

Much has happened in 2016. In June we initiated a new collaboration with Denmark Technical University who are building a large wind tunnel based on the Stability Tunnel Design through a workshop held at DTU. We discovered we have broad-ranging common interests, in diverse areas of research, in education, and in facilities. This looks likely to grow into a defining partnership for CREATe. Research and Scholarship have been, as always, an important focus. We have collectively published 40 refereed articles in 2016 in journals from Wind Energy to Combustion and Flame, from AIAA Journal to Measurement Science and Technology and been well represented at an equally diverse set of conferences. We welcomed Roger Simpson, Christine Ikeda and Stewart Glegg as CREATe affiliated faculty, and Tim Hight as our new financial support technician. Graduate student members have been particularly active through the year, organizing their own seminar series and much-loved Friday afternoon doughnuts, as well as activities such as the CREATe writing group.

We hope this report stimulates thoughts for future discussions or even substantial new collaborations in areas of mutual interest. We look forward to hearing your feedback.

Best regards,

Prof. William Devenport, CREATe Director

CREATe

Quick Facts

CREATe faculty published over 40 journal publications and 30 conference papers in 2016 alone.

Over $2 million dollars in Major Grants and Contracts have been awarded and received in FY16 with another $1.2 million pending approval.

CREATe includes 8 more core faculty members and 14 affiliate members in an interdisciplinary array of areas

The CREATe Stability Wind Tunnel can produce wind speeds up to 80m/s and features two interchangeable 1.8 m x 1.8 m test sections for aerodynamic and aeroacoutic applications respectively, making it one of the largest university-owned wind tunnels in the United States

5 Students and 3 Faculty visited the Technical University of Denmark Department of Wind Energy, establishing a new major collaboration

CREATe faculty members advise more than 60 graduate students and extensive undergraduate research efforts

The CREATe Stability Wind Tunnel clocked in 1,113 hours of fan time for research use in 2016

WIND ENERGY - Quick Facts

American wind and power supported a record 88,000 jobs at the start of 2016-an increase of 20 percent

Wind turbine technician is now the fastest-growing profession in the U.S.

As of May 2016, the United States is home to 48,500 operating wind turbines. These turbines are present across 40 states plus Puerto Rico.

Wind power was the top source for new electric capacity last year in the U.S., comprising 35% of all new U.S. electric capacity additions

Equivalent number of average American homes powered in a year by current installed wind capacity: 20 million

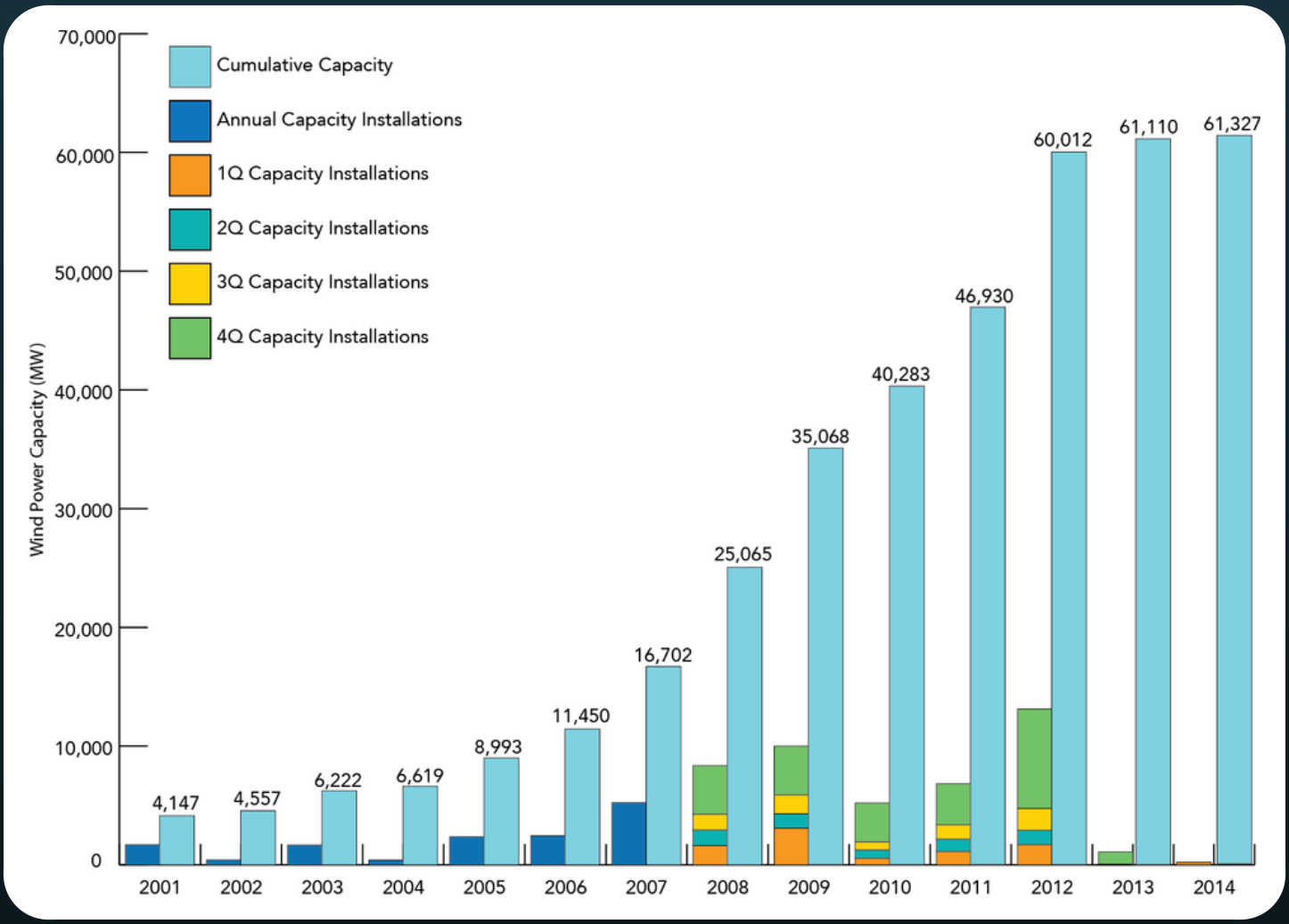
A single wind turbine can power 500 homes.

Quick Facts provided by the Wind Energy Foundation and the American Wind Association

Wind energy prices have dropped 66 percent since 2009. Lower wind turbine prices and installed project costs, along with improved capacity factors, are enabling aggressive wind power pricing

Wind power was the top source for new electric capacity last year in the U.S., comprising 35% of all new U.S. electric capacity additions

Installed wind energy capacity illustrating aggressive growth trend



Quick Facts provided by the Wind Energy Foundation and the American Wind Association

FACULTY AFFILIATED WITH THE CENTER

- **Core Faculty**

Nathan Alexander*	Assistant Professor
Aurelien Borgoltz*	Research Associate Professor
Seongim Choi	Assistant Professor
William Devenport*	Professor
Todd Lowe*	Associate Professor
Lin Ma*	Professor
Eric Paterson	Professor
Michael Philen	Associate Professor

- **Affiliate Faculty**

Ricardo Burdisso (Mechanical Engineering)	**Professor**
Dennis Grove (ICTAS)	**Program Manager**
Stewart Glegg (Florida Atlantic Univ.)	**Professor**
George Hagerman (Advanced Research Ins.)	**Research Associate**
Christine Ikeda (Aerospace & Ocean Eng.)	**Assistant Professor**
Nanyaporn Intaratep* (Aerospace & Ocean Eng.)	**Research Assistant Professor**
Sara Karpenty (Fish & Wildlife Conservation)	**Associate Professor**
Matthew Kuester* (Aerospace & Ocean Eng.)	**Postdoctoral Associate**
Tim Meyers* (Aerospace & Ocean Eng.)	**Research Engineer**
Wing Ng (Mechanincal Engineering)	**Chris Kraft End. Professor**
Joe Schetz (Aerospace & Ocean Eng.)	**Professor**
Roger Simpson (Aerospace & Ocean Eng.)	**Professor**
Nina Stark (Civil & Enviromental Eng.)	**Assistant Professor**
Heng Xiao (Aerospace & Ocean Eng.)	**Assistant Professor**
Lei Zou (Mechanical Engineering)	**Associate Professor**

*Resident Faculty (with offices in the center space in Mcbryde Hall).

GRADUATE RESEARCH STUDENTS

STUDENT NAME	DEPARTMENT AFFILIATION	FACULTY ADVISOR	DEGREE (AWARDED IN FY16*)
Abramson, Kyle	ME	Eric Paterson	MS
Antcliff, Kevin	AOE	Todd Lowe	PhD
Awasthi, Manuj	AOE	William Devenport	PhD*
Bailey, Matthew	AOE	William Devenport	PhD*
Battista, Tom	AOE	Eric Paterson	PhD
Bialy, Adrian	AOE	Michael Philen	BS
Brown, Julian	AOE	William Devenport	BS
Brown, Kenneth A.	AOE	William Devenport	PhD*
Cadel, Daniel R.	AOE	Todd Lowe	PhD*
Capil, Tyler	AOE	Lin Ma	MS*
Chaurasia, Adarsh	AOE	Michael Philen	PhD
Chung, Howard	AOE	Michael Philen	MS*
Clark, Ian A.	AOE	William Devenport	PhD
Crosser, Kara	AOE	Todd Lowe	MS*
Doepke, Edward B.	AOE	Michael Philen	PhD
Gillespie, John	AOE	Todd Lowe	MS*
Grohol, Daniel	AOE	Aurelien Borgoltz	BS*
Groo, Lori	AOE	Michael Philen	BS
Guimaraes, Tamara	ME	Todd Lowe	PhD
He, Frank	AOE	Lin Ma	PhD*
Hickling, Christopher	AOE	Nathan Alexander	MS
Hyunsoon, Kim	AOE	Seongim Choi	PhD
Jaeyoung, Choi	AOE	Seongim Choi	PhD
Jones, Matt	AOE	Eric Paterson	PhD
Joseph, Liselle A.	AOE	William Devenport	PhD
Jung, Se Young	AOE	Eric Paterson	PhD
Kancharala, Ashok	AOE	Michael Philen	PhD*
Kim, Chu-Young	AOE	Todd Lowe	MS
Kirk, Hannah	AOE	Todd Lowe	MS
Lee, Hoogyoung	AOE	Seongim Choi	MS*
Lei, Qingchun	ME	Lin Ma	PhD*
Liu, Ning	AOE	Lin Ma	PhD
Lieu, Chris	AOE	Aurelien Borgoltz	BS
Martin, Christian	AOE	Eric Paterson	PhD
Millican, Anthony	AOE	William Devenport	PhD
Molinaro, Nicholas	AOE	William Devenport	MS
Murray, Henry	AOE	William Devenport	MS*
O'Donnell, Jeremy	AOE	Aurelien Borgoltz	BS
Offenberger, Sean	AOE	Michael Philen	MS*
Otero, Raul	ME	Todd Lowe	PhD
Page, Matt	AOE	Aurelien Borgoltz	BS*
Park, Jangho	AOE	Seongim Choi	PhD
Park, Suhyeon	ME	Lin Ma	PhD
Pera, Nicholas	ME	Todd Lowe	MS

GRADUATE RESEARCH STUDENTS

STUDENT NAME	DEPARTMENT AFFILIATION	FACULTY ADVISOR	DEGREE (AWARDED IN FY16*)
Reardon, Jonathan	AOE	Todd Lowe	MS*
Rude, Matthew	AOE	Seongim Choi	MS*
Rolfe, Eric	AOE	Todd Lowe	MS
Shea, Sean	AOE	Todd Lowe	PhD
Segee, Molly	AOE	Todd Lowe	PhD
Sobien, Daniel	AOE	Eric Paterson	MS*
Somero, Ryan	AOE	Eric Paterson	MS
Spidi, John	AOE	Aurelien Borgoltz	BS
Suiqb, Carson	AOE	Michael Philen	BS*
Stuber, Marcie	AOE	Todd Lowe	MS
Turner, Aaron	AOE	Seongim, Choi	MS
Vincent, Tyler	AOE	Todd Lowe	MS
Wall, Dylan	AOE	Eric Paterson	PhD
Wang, Haoting	AOE	Lin Ma	PhD
Witcher, Bennett	AOE	Nathan Alexander	PhD
Wisda, David M.	AOE	William Devenport	MS*
Wu, Yue	AOE	Lin Ma	PhD*
Xu, Wenjiang	AOE	Lin Ma	PhD
Zhang, Di	AOE	Eric Paterson	PhD

NEWS

The CREATe faculty significantly contributed to the research, education, and teaching mission of the department, college, and university through a broad and diverse range of activities. Below we highlight activities and some representative accomplishments.

JUNE 2016 - COLLABORATIVE WORKSHOP AT DENMARK TECHNICAL UNIVERSITY

From June 6-9 2016 CREATe faculty and students participated in a workshop at Denmark Technical University. The workshop was the culmination of many months of preparation and organization, and was sponsored by the NSF as well as the College of Engineering and Department of Aerospace and Ocean Engineering. Participants included Profs. Todd Lowe and William Devenport (who spearheaded this effort), Professor Nathan Alexander, as well as remote participants, Profs. Eric Paterson and Michael Philen. Student participants were Liselle Joseph, Brady Doepke, Ken Brown, Ian Clark and Dan Cadel. The purpose of the effort was to a broad new collaboration with the Wind Energy Department at Denmark Technical University, which is a recognized world leader in this field. It was hoped that the meeting would find common ground in research, in working with industrial customers, wind tunnel technology (DTU is building a wind tunnel modeled on VTs Stability Tunnel), and education, and thus spawn collaborative efforts for the future. The four days of the meeting, spent at DTUs campuses in Roskilde and Lyngby, as well as at the Middlegrunden offshore wind farm, turned out to be productive well beyond our already high expectations. DTU were extremely welcoming hosts, having organized meeting sites, working meals, facility tours and field trips. Some 19 DTU faculty were active participants. Technical activities included presentations (from both groups), discussion groups and wrap up sessions. The final report on this effort (K T Lowe and W J Devenport, “VT/DTU Wind Energy Workshop: Summary and Outcomes”) details numerous action items going forward. Far more areas of synergy were identified than either team had anticipated, and activity has begun since in several of the collaborative areas identified as realizable in the short term.

Delegation members during a boat tour of the Middelgrunden offshore wind farm outside Copenhagen on June 8th 2016. Left to right: William Devenport, Christopher Hickling, Nathan Alexander, Daniel Cadel, Andreas Fischer, Liselle Joseph, Brady Doepke, Todd Lowe, Kneeling: Ken Brown.

NEWS

RETREAT AT PEAKS OF OTTER LODGE

Later in June, the CREATe core faculty met in retreat at Peaks of Otter Lodge to engage in discussions regarding the Center. The agenda included presentations and discussions on the state of the center, the outcomes from the VT/DTU workshop, a report on the workforce development activities in wind energy going on in the state, a discussion of CREATe's role in the development of the new AOE curricula in aerospace and ocean engineering and in the Destination Areas being developed by the University, as well as discussions concerning attracting funding for research in unmanned vehicles as well as how to make our center activities and capabilities more visible within the university and to state politicians. As part of the proceedings, two new affiliate faculty members were elected to the center: Prof. Roger Simpson of the Aerospace and Ocean Engineering Dept. and Prof. Stewart Glegg of the Department of Ocean and Mechanical Engineering at Florida Atlantic University. Prof. Glegg has been a research collaborator with core faculty of the center for some 25 years.

CONFERENCES

Other significant events include conferences organized by CREATe core faculty this year (as chair or co-chair), specifically:

- 32nd AIAA Aerodynamic Measurement, Technology and Ground Testing Conference, Aviation 16, Washington DC, June 13-16, 2016 (Todd Lowe)
- ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems, Colorado Springs, September 21-23, 2015 (Michael Philen)
- AIAA/CEAS 22nd Aeroacoustics Conference, Lyon, May 30 – June 1, 2016 (William Devenport)

NEW COURSES DEVELOPED BY CENTER FACULTY

Technical Elective Course: Avionics – Michael Philen

Data Analysis for Fluid Dynamics Research 3 credit hours– Kevin T. Lowe

AOE/ME 4234 Aerospace Propulsion Systems, 3 credit hours – Kevin T. Lowe

NATHAN ALEXANDER

ASSISTANT PROFESSOR

STAFF:

CHRISTOPHER HICKLING

PROJECT PERIOD:

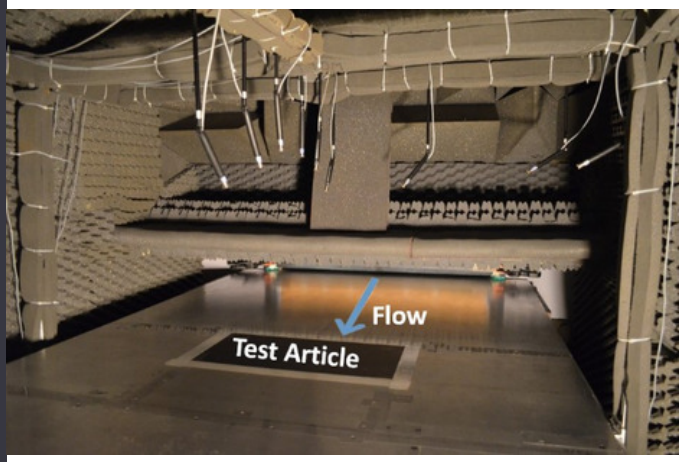
JUNE, 2016 - MAY, 2018

SPONSOR:

HX5 SIERRA, LLC

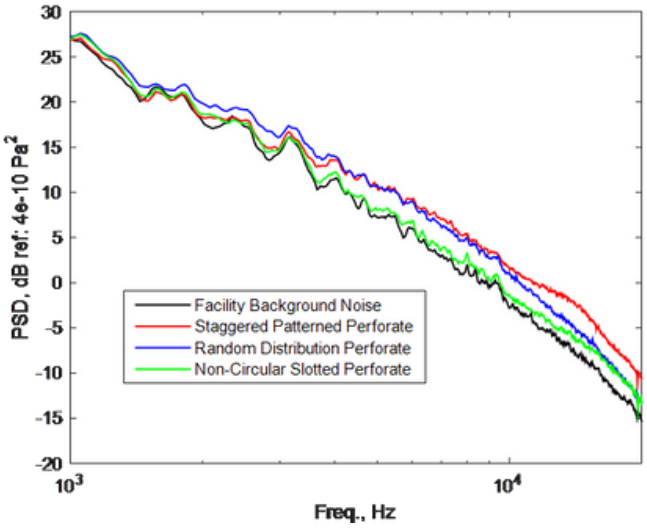
CREATe
Virginia Tech Center for Renewable Energy and Aerodynamic Technology

ACOUSTIC MEASUREMENTS OF FABRIC-COVERED PERFORATE LINERS



Wall-jet facility used for measurements.

Comparison of the self-noise produced by panels with varying perforate geometry. (right)



The perforated walls of the 9'x15' LSWT at the NASA Glenn Research Center are speculated to contribute significantly to the total background noise of the facility. As part of planned facility upgrades, various surface configurations are being considered to reduce the surface noise produced by the walls of the tunnel. The planned modifications include altering the face sheet of the acoustic absorbers lining the test section by adding a metal cloth or fabric surface layer to shield the pores of the open perforate. A series of surface configurations are being examined in the Virginia Tech anechoic wall-jet facility in order to assess their acoustic performance. Experiments show that self-noise produced by the liners is a function of the boundary layer, the perforate geometry, and the surface cloth characteristics. In this project, acoustic measurements are being conducted on a series of panels considered for the final design to investigate the impact of differing cloth materials and perforate geometries as well as manufacturing techniques on the self-noise. The self-noise is being analyzed with respect to measurements of the near-wall boundary layer profile.

Alexander, W. N., and Devenport, W., 2015, "Noise Produced by Fabric and Wire Mesh Covered Panels in Low-Speed Anechoic Wind Tunnels", 21st AIAA/CEAS Aeroacoustics Conference, Dallas, TX, AIAA 2015-3261.
Alexander, W. N., and Devenport, W., 2014, "Noise from Boundary Layer Flow over Fabric Covered Perforate Panels", 20th AIAA/CEAS Aeroacoustics Conference, Atlanta, GA, AIAA 2014-2908.

WILLIAM DEVENPORT

PROFESSOR AND DIRECTOR OF THE STABILITY WIND TUNNEL

STAFF:

TIM MEYERS
LISELLE JOSEPH
NICHOLAS MOLINARO

PROJECT PERIOD:

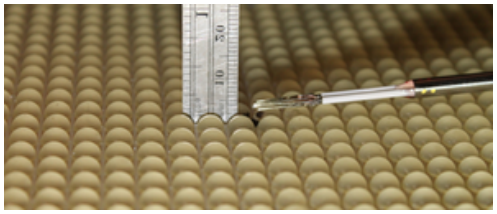
SEPTEMBER, 2014 - AUGUST, 2017

SPONSOR:

OFFICE OF NAVAL RESEARCH
NATIONAL SCIENCE FOUNDATION

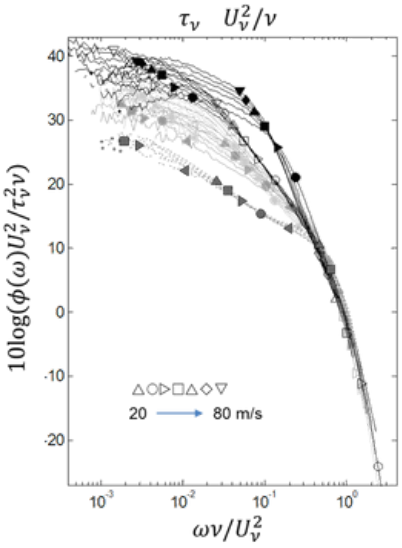
CREATe
Virginia Tech Center for Renewable Energy and Aerodynamic Technology

ESTABLISHING UNIVERSAL SCALING LAWS FOR PRESSURE FLUCTUATIONS IN HIGH RE ROUGH WALL TURBULENT BOUNDARY LAYERS



Rough surface installed in the Stability Wind Tunnel (Above).

Normalization of pressure spectra on the substrate friction velocity (Right).



The overarching objective of this work is to establish the scaling of wall pressure fluctuations in high Reynolds number rough wall boundary layers. Recent work, involving large scale experiments on fully rough surfaces formed from small hemispherical elements, has begun to shed light on this previously neglected regime. These measurements suggest that wall-pressure spectrum at these conditions has three scaling regions, controlled at mid-frequency by the Strouhal number of the roughness elements, and anchored at high frequency by a new viscous scaling that depends on the substrate friction velocity U_ν – the friction velocity adjusted to exclude the pressure drag on the roughness elements. The work we are performing here addresses fundamental issues raised by this new insight. We outline an experimental program that will directly establish the persistence of these scalings, and thus of the physical processes they imply, as the geometry of the roughness is varied and as the roughness density is increased to the point where the substrate ceases to be dynamically significant. Also proposed are experiments on a two-scale surface, to test the physical picture behind the triple scaling hypothesis, and the development of an interpolation function for rough-wall boundary layer pressure spectra.

T. Meyers, J. B. Forest and W. J. Devenport, 2015, “The Wall Pressure Spectrum of High Reynolds Number Turbulent Boundary Layer Flows over Rough Surfaces”, Journal of Fluid Mechanics, vol. 768, pp. 261-293, doi: http://dx.doi.org/10.1017/jfm.2014.743

L. Joseph, T. Meyers, N. Molinaro, W. Devenport, 2016, “Pressure Fluctuations in a High-Reynolds-Number Turbulent Boundary Layer Flow over Rough Surfaces”, 22nd AIAA/CEAS Aeroacoustics Conference, Lyon, France, May 30 – June 1.

T Meyers, N. Alexander, W Devenport, S Glegg, 2013, High Reynolds Number Turbulent Boundary Layer Flow over Rough Walls: Wall Pressure Spectrum and Noise, Paper AIAA 2013-2249, AIAA 19th AIAA/CEAS Aeroacoustics Conference, May 27-29, Berlin, Germany

T Meyers, N Alexander, W Devenport, 2012, “The Effect of Roughness Distribution on the Wall Pressure Spectrum of High Reynolds Number Turbulent Boundary Layers” (abstract only), European Fluid Mechanics Conference 9, 9-13 September 2012, University of Rome “Tor Vergata”, Italy.

J. B. Forest and W. Devenport, 2011, “The Wall Pressure Spectrum of High Reynolds Number Rough-Wall Turbulent Boundary Layers”, 17th AIAA/CEAS Aeroacoustics Conference, June 6th-8th, Portland OR, AIAA-2011-2741

CHRISTINE IKEDA

ASSISTANT PROFESSOR

STAFF:

ZHONGSHU REN
YUCHEN ZHOU

PROJECT PERIOD:

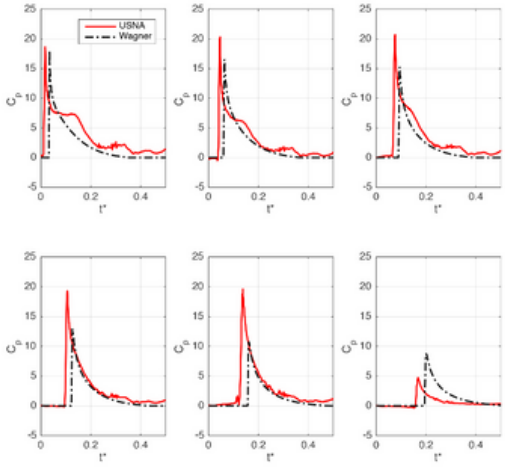
JUNE, 2015 - FEBRUARY, 2019

SPONSOR:

OFFICE OF NAVAL RESEARCH
(YOUNG INVESTIGATORS PROGRAM)

CREATe
Virginia Tech Center for Renewable Energy and Aerodynamic Technology

HULL DEFLECTIONS DUE TO HYDRODYNAMIC LOADING ON HIGH-SPEED PLANING CRAFT

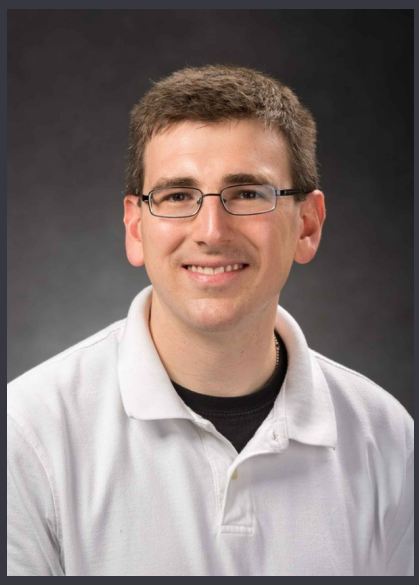


Nondimensional pressure versus nondimensional time on the USNA Rigid Wedge measured at six locations with increasing distance from the keel.

High-speed planing craft are subjected to repeated slamming events in waves that can be very extreme depending on the wave topography, impact angle of the ship, forward speed of the ship, encounter angle, and height out of the water. The current work examines this fluid-structure interaction problem through the use of wedge drop experiments and theoretical prediction. The experimental program consisted of two prismatic wedges, one rigid (“USNA”) and one flexible (“UNO”), dropped from a range of heights, while pressure and acceleration of the single, vertical slam were measured. The resulting pressure measurements from both models were compared with a non-linear boundary value flat cylinder theory (“Wagner”) in order to determine the effects of flexibility on the hydrodynamic pressure. The theory assumes a rigid structure, therefore, the results between the code and the first experiment are in better agreement than the flexible experiment. However, in both cases, due to the linear hydrodynamic simplification in the theoretical prediction, the pressure pulse is under-predicted. In the flexible structure experiment, the pressure pulse is under-predicted more, and the prediction of the time for the pulse to reach each sensor lags the experiment. Future experiments will include measurements of the strain field on the bottom of the flexible wedge model.

Ikeda, C. and Taravella, B., Analytical Predictions of the Structural Response of High-Speed Planing Craft, SNAME Maritime Convention 2016, Bellevue, WA, USA, 1–4 November 2016.
Ikeda, C., Deflections on the Bottom of a Wedge-Shaped Hull due to Slamming Loads, 5th World Maritime Tech- nology Conference, Providence, RI, USA, 4–6 November 2015.
Ikeda, C., Ghandehari, P., Castro, F., Aucoin, C., and Bye, B., Slamming Load Effects on the Bottom of High-Speed Aluminum Planing Craft, 13th International Conference on Fast Sea Transportation, Washington, DC, USA, 2–4 September 2015.
Ikeda, C., Ren, Z., Taravella, B., and Judge, C., On the Effect of Structural Response on the Hydrodynamic Loading of a Free-Falling Wedge (abstract only), 69th Annual Meeting of the APS Division of Fluid Dynamics, Portland, OR, (November 20-22, 2016).
Ikeda, C., Taravella, B., and Eastridge, J., Hydroelasticity of High-Speed Planing Craft Subjected to Slamming Events (abstract only), 2016 University of New Orleans Engineering Forum, New Orleans, LA, (September 16, 2016).
Ikeda, C., Taravella, B., and Judge, C., Structural Effects due to the Slamming Pressures of High-Speed Planing Craft (abstract only), 68th Annual Meeting of the APS Division of Fluid Dynamics, Boston, MA, (November 22–24, 2015).
Ikeda, C., An Experimental Investigation of the Fluid-Structure Interaction of High-Speed Planing Craft in Waves (abstract only), Southeast Symposium on Contemporary Engineering Topics and University of New Orleans Engineering Forum, New Orleans, LA, (September 11, 2015).

DEVELOPMENT OF UNSTEADY AIRFOIL TESTING CAPABILITY IN THE STABILITY WIND TUNNEL



MATTHEW KUESTER

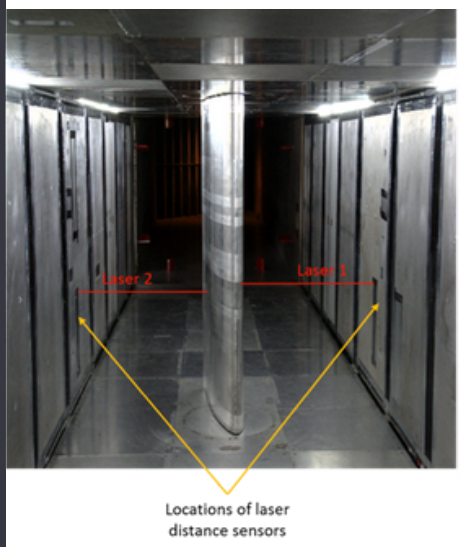
POSTDOCTORAL RESEARCH ASSOCIATE

STAFF:

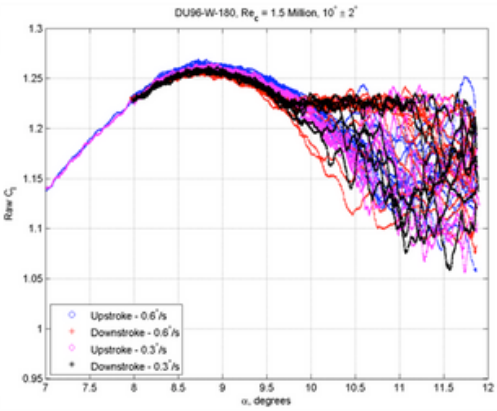
AURELIEN BORGOLTZ
WILLIAM DEVENPORT

PROJECT PERIOD:

JANUARY, 2016 - DECEMBER, 2018



0.8m chord DU96-W-180 installed in the Stability Wind Tunnel.



Unsteady lift coefficient near stall separated into upstrokes and down-strokes for two rotation rates.

The goal of this work is to study dynamic airfoil force and moment coefficients in the Stability Wind Tunnel at Virginia Tech. Most of the existing literature on unsteady airfoil aerodynamics and dynamic stall focuses on low-Re/high Mach number regimes (appropriate for helicopter aerodynamics). There is considerably less experimental data for Re/Mach number combinations associated with wind turbine blades, which is significant, as experimental results are used to inform unsteady aerodynamic models. In this project, the Stability Wind Tunnel team upgraded the airfoil testing infrastructure to make unsteady pressure measurements on airfoil models undergoing pitch motions. Pressure scanners were placed inside of an airfoil to enable unsteady pressure measurements up to 600 Hz, and laser distance sensors (installed in the walls) were used to track the angle of attack as the model rotates. Unsteady measurements using a DU96-W-180 airfoil showed differences in the post-stall separation between the upstroke (when the angle of attack is increasing) and the downstroke (where the angle of attack is decreasing). Future effort will focus on increasing the pitching rates to move from quasi-steady measurements towards more unsteady flows, such as dynamic stall.

CREATe
Virginia Tech Center for Renewable Energy and Aerodynamic Technology

TODD LOWE

ASSOCIATE PROFESSOR

STAFF:

KYLE DANIEL
DAVID MAYO
SEAN SHEA
MARCIE STUBER
WING NG

PROJECT PERIOD:

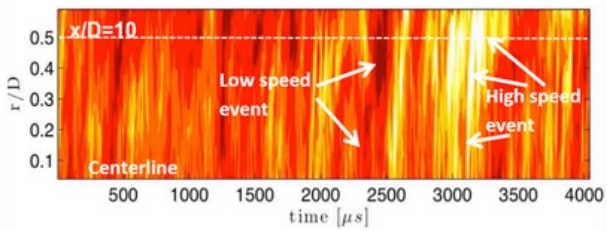
JUNE, 2016 - MAY, 2018

SPONSOR:

OFFICE OF NAVAL RESEARCH

CREATe
Virginia Tech Center for Renewable Energy and Aerodynamic Technology

TURBULENCE DEVLOPMENT IN NON-UNIFORM HEATED SUPERSONIC JETS FOR NOISE REDUCTION



Flow velocity time/space "heat map" showing evidence of convecting large scale structures in a heated supersonic jet.

Image of Doppler velocimetry lasers in multi-stream jet test.

Modern tactical aircraft engines and future propulsion concepts for supersonic transport aircraft produce intense noise familiar to anyone who has attended an airshow. Well beyond the annoyance to the general public, crew-persons on aircraft carriers must work for extended periods in the region of most intense noise emissions of these aircraft. Sadly, these crew-persons can incur lifelong hearing damage from their service. In our program, we seek to obtain new information on the fundamental behaviors of high speed jets, supporting strategies to reduce noise via operational and design changes. Using a new flow diagnostics approach, information about the speed and intensity intermittent turbulent waves is obtained and interpreted based upon nozzle conditions and theory for jet noise radiation. If successful, the research will lead to explanations for the differences observed between laboratory-scale and full-scale supersonic jet noise results from past work.

Ecker TE, Lowe KT and Ng WF 2016 “On the distribution and scaling of convective wavespeeds in the shear layers of heated supersonic jets,” Flow, Turbulence and Combustion,doi:10.1007/s10494-016-9752-3.

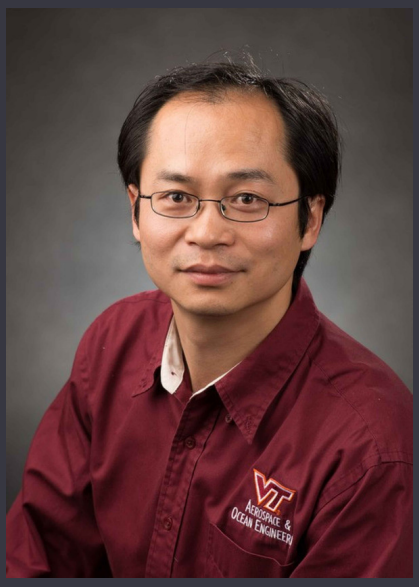
Ecker T, Lowe KT, and Ng W 2016 “Scale-up of the time-resolved Doppler global velocimetry technique,” AIAA SciTech 2016, San Diego, CA, 4-8 January, paper AIAA-2016-0029.

Ecker T, Lowe KT, Ng W, Henderson BS, and Lieb SJ 2016 “Velocity statistics and spectra in three-stream jets,” AIAA SciTech 2016, San Diego, CA, 4-8 January, paper AIAA-2016-1633.

Lowe KT and Nelson CC 2016 “Fluctuating pressure gradients in heated supersonic jets,” AIAA SciTech 2016, San Diego, CA, 4-8 January, paper AIAA-2016-0003.

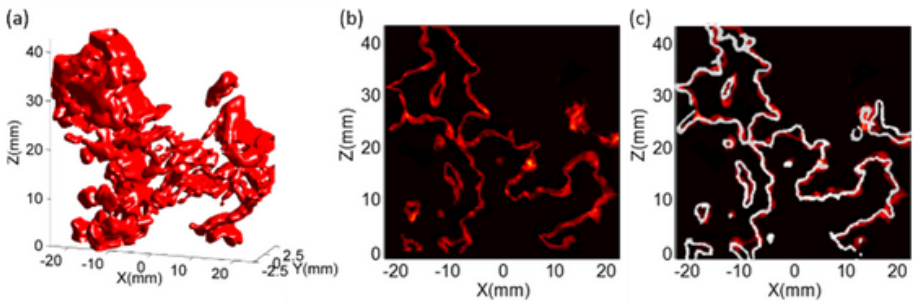
Ecker TE, Lowe KT and Ng WF 2016 “Development of Doppler global velocimetry for the measurement of eddy convective velocities,” 18th Intl. Symposium Appl. Laser Techniques and Imaging to Fluid Mech., Lisbon, Portugal, 4-7 July, paper 2.2.3.

VOLUMETRIC COMBUSTION DIAGNOSTICS



LIN MA

PROFESSOR



Panel (a): 3D VLIF measurement. Panels (b): the cross-section of the VLIF measurement. Panel (c): comparison of VLIF and PLIF.

PROJECT PERIOD:

SEPTEMBER, 2014 - SEPTEMBER, 2016

SPONSOR:

WRIGHT PATTERSON AIR FORCE BASE

This two-year project is aimed at establishing advanced diagnostics techniques for obtaining volumetric measurement of key combustion properties. The proposed techniques are designed to generate instantaneous volumetric (i.e., three-dimensional, 3D) data without scanning or raster, and thusly to enable measurement rate in the multi-kilohertz range, directly addressing a key experimental need in the study of turbulent flows. Six specific topics have been investigated during this project: 1) the establishment of a unified framework for volumetric tomography, 2) the investigation and validation of Volumetric Chemiluminescence imaging (VCHEM), 3) the investigation and validation of Volumetric Laser Induced Fluorescence (VLIF), 4) the investigation and validation of Volumetric Particle Image Velocimetry (VPIV), 5) the use of fiber bundles in volumetric tomography, and 6) algorithms for data Analysis and post processing.

Ma, L., Lei, Q., Capil, T., Hammack, S.D., Cater, C.D., Direct comparison of 2D and 3D LIF measurements on highly turbulent flames, Optics Letters, Accepted, Dec 2016.

Lei, Q., Xu, W., Wu, Y. and Ma, L., "Development and validation of a reconstruction algorithm for three-dimensional nonlinear tomography problems". Optics Express, 24(14), p15912-15926, July 2016.

Ma, L., Wu, Y., Xu, W., Hammack, S., Lee, T., Carter, C.D., Comparison of 2D and 3D flame topography measured by PLIF and tomographic chemiluminescence, Applied Optics,55(20), p5310-5315, 2016.

Ma, L., Non-intrusive and Multidimensional Optical Diagnostics and Their Applications in the Study of Thermal-Fluid Systems, Heat Transfer Engineering, 37(3-4), 359-368, (2016)

Y.W. Lin Ma, Qingchun Lei, Wenjiang Xu, Campbell D. Carter, 3D Flame Topography and Curvature Measurements at 5 kHz on a Premixed Turbulent Bunsen Flame, Combustion and Flame, 166, p66-75, (2016).

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Virginia Tech Center for Renewable Energy and Aerodynamic Technology

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PROJECT PERIOD:

August, 2012 - September 2018

SPONSOR:

U.S. NAVY, ROLLS-ROYCE, NEWPORT -NEWS SHIPBUILDING

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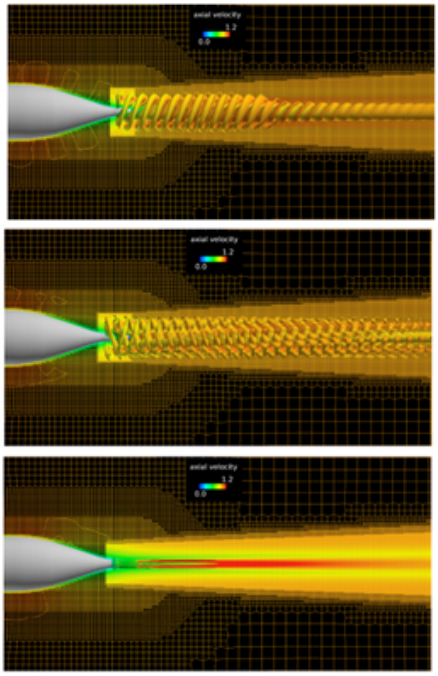
WAKES DYNAMICS IN ATMOSPHERIC AND OCEANIC ENVIRONMENTS



***A**. Single Propeller*

***B**. Contra-rotating propellers*

***C**. Jet*

Figure 3: Flow visualization from $1.0 \leq x/L \leq 1.5$ using Q-criterion visualization non-dimensionalized as $(L/U_0)^2 Q = 1.7$ colored by U_x/U_0.

The objective of this work is to understand system-environment interaction with focus on remote and in-situ sensing. Our approach is based upon computational fluid dynamics and electromagnetics, high-performance computing, field experiments, and theoretical model development. Recent work (Somero et al., 2017) has focused on explication of surface-ship wakes and the role of wake-wave interaction on the generation of Langmuir-type circulations. We have demonstrated the critical role this phenomenon has on the structure and persistence of wakes, and are continuing work in the areas of bubbly wakes, surfactant distribution, surface-roughness modification, and scattering of electromagnetic energy from the ocean surface. In a separate study, Jones and Paterson (2015) implemented a generalized Stokes-Ekman model to account for Coriolis forcing and wind-driven vertical shear in stratified wakes. More recently, Jones and Paterson (2016, 2017) have focused on study of vehicle propulsion and the generation and transport of potential and kinetic energy in the near wake of self-propelled vehicles. Their work has shown that selection of the propulsion type, e.g., single-open-wheel vs. contra-rotating propellers vs. waterjet, can have a significant impact on the perturbation of the ocean medium. Work is now underway on eddy-resolving turbulence simulation so that role of turbulence on vertical and horizontal fluxes and correlations of temperature and salinity can be better understood and incorporated in large-scale simulations.

R. Somero, A. Basovich, and E. Paterson, “Wake-Wave Interaction and Generation of Langmuir-Type Circulations in Ship Wakes: Explanation for Structure and Persistence,” Journal of Fluid Mechanics, under review, 2017.

M. Jones and E. Paterson, “Influence of Propulsion Type on the Near-Wake Evolution of Kinetic and Potential Energy,” Fifth International Symposium on Marine Propulsors, 12th - 15th June 2017, Helsinki - Finland.

M. Jones and E. Paterson, "Evolution of the Propeller Near-Wake and Potential Energy in a Thermally-Stratified Environment,” OCEANS 16, Monterey California, USA, September 19-23 2016.

M. Jones and E. Paterson, "Evolution of Stratified Boundary-Free Shear Flows under Stokes-Ekman Forcing," In AIAA Aviation, AIAA Fluid Dynamics Conference, Dallas, June 22-26 2015.

MICHAEL PHILEN

ASSOCIATE PROFESSOR AND ASSISTANT DEPARTMENT HEAD FOR LABORATORY FACILITIES

STAFF:

HENG XIAO
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PROJECT PERIOD:

JUNE, 2015 - FEBRUARY 2016

SPONSOR:

DEPARTMENT OF ENERGY

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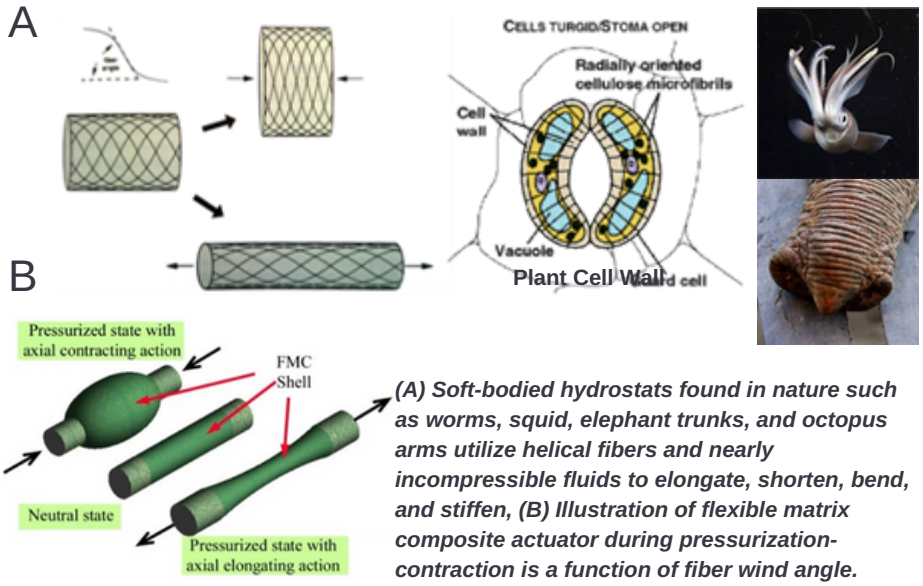
BIOLOGICALLY INSPIRED FLUIDIC FLEXIBLE MATRIX COMPOSITE PUMPS FOR WAVE ENERGY CONVERSION

There is increasing interest in renewal energy technologies to convert wave energy into usable electricity. Technologies that are simple and robust are highly prized for the harsh ocean environment. Inspired by the fibrillar network in plant cell walls and the helical fibers found in soft bodied hydrostats (e.g. worms, squid, elephant trunks, and octopus arms), fluidic flexible matrix composites (F2MCs) are composite tubes that consist of multiple layers of oriented, high performance fibers, such as carbon, precisely placed in a flexible matrix resin to form high-mechanical advantage actuators and variable stiffness materials. Unique to the F2MC tube is its ability to generate high pressures and volume change with a small external load as a result of the stiff reinforcement fiber orientation in the wall of the tube and the soft supporting elastomer. When a load is applied to the tubes, the volume of the composite pump is reduced and fluid is forced out of the tube by the reinforcing fibers. A few advantages of the F2MCs over other types of pumps (e.g. piston) include no moving parts, flexible, and simple. The F2MC pumps provide a simple means for converting wave energy into hydraulic energy, which can be later converted to electricity. As illustrated below, during the passage of a wave crest, the F2MC tether is stretched, forcing fluid out of the pump. After passage, the pump returns to its original length, drawing in fluid for the next wave. As the first F2MC tether is refilling, the second tether is pumping.

The goal of this research was to design, fabricate and characterize F2MCs for use in wave energy conversion where ocean waves provide the axial load to drive fluid through the pumps. F2MCs pumps were evaluated in a tow tank at Stevens Institute for different wave heights and periods. The RMS power output and efficiency are both shown to increase with increasing wave frequency. The experiments demonstrate that F2MC pumps can be used to convert wave energy into hydraulic energy with efficiencies as large as 40%. Theoretical efficiencies as large as 85% are expected with design iterations.



(A) Soft-bodied hydrostats found in nature such as worms, squid, elephant trunks, and octopus arms utilize helical fibers and nearly incompressible fluids to elongate, shorten, bend, and stiffen, (B) Illustration of flexible matrix composite actuator during pressurization-contraction is a function of fiber wind angle.

JOURNAL PUBLICATIONS

AUTHORS	TITLE	JOURNAL
Kuester, M. S., Brown, K., **Meyers, T., Intaratep, N., Borgoltz, A., & Devenport, W. J.**	Wind Tunnel Testing of Airfoils for Wind Turbine Applications	Wind Engineering
Im, D., **Choi, S,** and McClure, J.	A Mapped Chebyshev Pseudospectral Method for Unsteady Flow Analysis	AIAA Journal
Kwon, H., Yi, S., and **Choi, S.**	Aerodynamic Design of EAV Propeller Using a Multi-Level Optimization Method	AIAA Journal of Propulsion and Power
S. Glegg, **W. Devenport, W. Alexander**	Broadband rotor noise predictions using a time domain approach	Journal of Sound and Vibration
M. Kuester, K. A. Brown, **T. W. Meyers, N. Intaratep, A. Borgoltz and W. J. Devenport**	Wind Tunnel Testing of Airfoils for Wind Turbine Applications	Wind Engineering
Kuester, M. S. and White, E. B	Roughness Receptivity and Shielding in a Flat Plate Boundary Layer	Journal of Fluid Mechanics
Ecker T*, **Lowe KT** and Ng WF 2015	Eddy Convection in Developing Heated Supersonic Jets	AIAA Journal
Guillot S., Ng, W., Hamm H.D. Stang U., **Lowe K.T.**	The experimental studies of improving the aerodynamic performance of a turbine exhaust system	ASME J. Eng. Gas Turbines Power
Cadel DR* and **Lowe KT**	Cross-correlation Doppler global velocimetry (CC-DGV)	Optics and Lasers in Engineering
Wohl CJ, Kiefer JM, Petrosky BJ*, Tiemsin PI, **Lowe KT**, Maisto PM* and Danehy PM	Synthesis of Fluorophore-Doped Polystyrene Microspheres: Seed Material for Airflow Sensing	ACS Applied Materials & Interfaces

Journal publications authored by center core and resident faculty in FY 2016
(CREATe members in bold)

JOURNAL PUBLICATIONS

AUTHORS	TITLE	JOURNAL
Petrosky BJ*, **Lowe KT**, Danehy PM, Wohl CJ and Tiemsin PI	Improvements in laser flare removal for particle image velocimetry using fluorescent dye-doped particles	Measuremnt Science and Technology
Ma, Lin	Non-intrusive and Multidimensional Optical Diagnostics and Their Applications in the Study of Thermal-Fluid Systems	Heat Transfer Engineering
He, F., **Ma, Lin**	3D Flame Topography and Curvature Measurements at 5 kHz on a Premixed Turbulent Bunsen Flame	Combustion and Flame
Wu, Y., Xu, W., **Ma, Lin**	Single-shot Volumetric Laser Induced Fluorescence (VLIF) Measurements in Turbulent Flows Seeded with Iodine	Optics Express
Ma, Lin, Wickersham, A. J., Xu, W., Peltier, S., Ombrello, T., Carter, C.D	Multi-angular Flame Measurements and Analysis in a Supersonic Wind Tunnel Using Fiber-Based Endoscopes	Gas Turbines Power
Ma, Lin, Lei, Q., Wu, Y., Xu, W., Ombrello, T.M., and Carter, C.D.	From ignition to stable combustion in a cavity flameholder studied via 3D tomographic chemiluminescence at 20 kHz	Combustion and Flame
He, F., **Ma, Lin**	Thermal management of batteries employing active temperature control and reciprocating cooling flow	International Journal Of Heat And Mass Transfer
Ma, Lin, Lei, Q., Wu, Y., Ombrello, T.M., and Carter, C.D.	3D measurements of ignition processes at 20 kHz in a supersonic combustor	Applied Physics B

JOURNAL PUBLICATIONS

AUTHORS	TITLE	JOURNAL
Xu, W., Wickersham, A.J., He, F., **Ma, Lin**	3D flame topography obtained by tomographic chemiluminescence with direct comparison to planar mie scattering measurements	Applied Optics
Li, X., **Ma, Lin**	Capabilities and limitations of 3D flame measurements based on computed tomography of chemiluminescence	Combustion and Flame
Kang, M., Li, X., **Ma, Lin**	Three-dimensional flame measurements using fiber-based endoscopes	Proceedings of the Combustion Symposium
Zhang, M., Wang, J., Jin, W., Huang, Z., Kobayashi, H., and **Ma, Lin**	Estimation of 3D flame surface density and global fuel consumption rate from 2D PLIF images of turbulent premixed flame	Combustion and Flame
Freeman, E., Farimani, A., Aluru, N., **Philen, M.**	Multiscale modeling of droplet interface bilayer membrane networks	Biomicrofluidics
Allen, D., Jones, M., McCue, L., Moore, W., **Philen, M.**, and **Woolsey, C.**	Exploring the Oceans of Europa with Biologically-Inspired Underwater Vehicles	Journal of the British Interplanetary Society
Bilel, A., **Philen, M**., and Case, S.	Progressive damage assessment of centrally notched composite specimens in fatigue	Composites Part A: Applied Science and Manufacturing
Masghouni, N., Burton, J., **Philen, M**., and Al-Haik, M.	Investigating the energy harvesting capabilities of a hybrid ZnO nanowires/ carbon fiber polymer composite beam	Nanotechnology

JOURNAL PUBLICATIONS

AUTHORS	TITLE	JOURNAL
D. Moreau, C. Doolan, **N. Alexander, T. Meyers and W. Devenport**	Wall-Mounted Finite Airfoil-Noise Production and Prediction	AIAA Journal
L. A. Joseph, A. Borgoltz, W. Devenport	Infrared Thermography for Detection of Laminar-Turbulent Transition in Low Speed Wind Tunnel Testing	Experiments in Fluids
I A Clark, C A Daly, **W J Devenport, W N Alexander**, N Peake, J Jaworski and S Glegg	Bio-Inspired Canopies for the Reduction of Roughness Noise	Journal of Sound and Vibration
I A Clark, **W J Devenport, W N Alexander,** S Glegg, J Jaworski, C A Daly and N Peake	Bio-Inspired Trailing Edge Noise Control	AIAA Journal
K. Brown, N. Molinaro, **T. Meyers, A. Borgoltz, W. Devenport,** J. Luedke, D. Pesetsky	Sensitivity of wind turbine airfoil sections to geometry variations inherent in modular blades	AIAA Journal
Ma Lin	Flow visualization	McGraw-Hill Encyclopedia of Science and Technology, ed. John Rennie et al, McGraw-Hill
Ma, Lin, Wu, Y., Xu, W., Hammack, S., Lee, T., Carter, C.D.	Comparison of 2D and 3D flame topography measured by PLIF and tomographic chemiluminescence	Applied Optics
Fan Genga, Gang Luo, **Ma, Lin**, Hongli Chai, Yimin Li, Zhulin Yuan	Study on dynamic transport of flexible ribbon particles in a rotary dryer	Powder Technology

JOURNAL PUBLICATIONS

AUTHORS	TITLE	JOURNAL
Ma, Lin	Non-intrusive and Multidimensional Optical Diagnostics and Their Applications in the Study of Thermal-Fluid Systems	Heat Transfer Engineering
He, F., **Ma, Lin**	Thermal Management in Hybrid Power Systems Using Cylindrical and Prismatic Battery Cells	Heat Transfer Engineering
Ma, L., Lei, Q., Ikeda, J., Xu, W. , Carter, C.D.	Single Shot 3D Flame Diagnostic Based on Volumetric Laser Induced Fluorescence (VLIF)	36th International Combustion Symposium
Ma, L., Wu., Y., Lei, Q., Xu, W., Carter, C.D.	3D Flame Topography and Curvature Measurements at 5 kHz on a Premixed Turbulent Bunsen Flame	Combustion and Flame
Freeman, E., Najem, J., Sukharev, S., **Philen, M.**, Leo, D.	The Mechanoelectrical Response of Droplet Interface Bilayer Membranes	Soft Matter
Cadel, D.R. and **Lowe, K.T.**	Investigation of measurement sensitivities in cross-correlation Doppler global velocimetry	Optics and Lasers in Engineering

CONFERENCE PAPERS

AUTHORS	TITLE	CONFERENCE
S. Glegg, J. Grant, D. Wisda, H. Murray, **N. Alexander and W. Devenport**	Broadband Noise from a Rotor at an Angle to the Mean Flow	AIAA Scitech 2016
L. Joseph, T. Meyers, N. Molinaro, **W. Devenport**	Pressure Fluctuations in a High-Reynolds-Number Turbulent Boundary Layer Flow over Rough Surfaces	22nd AIAA/CEAS Aeroacoustics Conference
N. Intaratep,. **W. N. Alexander, W. Devenport,** S. Grace, A. Dropkin	Experimental Study of Quadcopter Acoustics and Performance at Static Thrust Conditions	22nd AIAA/CEAS Aeroacoustics Conference
William N. Alexander; Nicholas J. Molinaro; Henry Murray; **William J. Devenport**; Stewart A. Glegg	Phased Array Measurements of a Rotor Ingesting a Turbulent Shear Flow	22nd AIAA/CEAS Aeroacoustics Conference
Stewart A. Glegg; Justin Grant; **William J. Devenport; William N. Alexander**	Sound Radiation from a Rotor Operating at High Thrust Near a Wall	22nd AIAA/CEAS Aeroacoustics Conference
A. Clark, D. Baker, **N. Alexander, W. Devenport,** N. Peake, S. Glegg and J. W. Jaworski	Experimental and Theoretical Analysis of Bio-Inspired Trailing Edge Noise Control Devices	22nd AIAA/CEAS Aeroacoustics Conference
Lowe, K.T. and Nelson, C.C.	Fluctuating Pressure Gradients in Heated Supersonic Jets	54th AIAA Aerospace Sciences Meeting
Lowe, K.T. and Nelson, C.C.	Volumetric Vector Velocity Measurements In A Hot Supersonic Jet	17th Intl. Symposium Appl. Laser Techniques to Fluid Mech.

CONFERENCE PAPERS

AUTHORS	TITLE	CONFERENCE
Guimarães, T., **Lowe, K.T.** and O'Brien, W.	An overview of recent results using the StreamVaneTM method for generating tailored swirl distortion in jet engine research	54th AIAA Aerospace Sciences Meeting
Ecker, T., **Lowe, K.T.**, Ng, W.F., Henderson, B.S. and Leib, S.J.	Velocity Statistics and Spectra in Three-Stream Jets	54th AIAA Aerospace Sciences Meeting
Cadel, D.R., Shin, D. and **Lowe, K.T.**	A Hybrid Technique for Laser Flare Reduction	54th AIAA Aerospace Sciences Meeting
Frohnapfel, D.J., Ferrar, A.M., Bailey, J., O'Brien, W.F. and **Lowe, K.T.**	Measurements of Fan Response to Inlet Total Pressure and Swirl Distortions Produced by Boundary Layer Ingesting Aircraft Configurations	54th AIAA Aerospace Sciences Meeting
Ecker, T., **Lowe, K.T**. and Ng, W.	Scale-up of the Time-Resolved Doppler Global Velocimetry Technique	54th AIAA Aerospace Sciences Meeting
Raul Otero; Kevin Lowe; Wing Ng; **Lin Ma**; Chuyoung Kim	Non-Intrusive Measurement of Gas Turbine Engine Exhaust Characteristics using Acoustic Measurements	Aerodynamic Measurement, Technology and Ground Testing Conference
Wu, Y., Lei, Q., Xu, W., **Ma, L**.	High Speed Volumetric Laser Induced Fluoresence Measurement in Turbulent Flows Seeded with Iodine	Aerodynamic Measurement Technology and Ground Testing Conference
Lei, Q., Wu, Y., Xu, W., **Ma, L.,** Ombrello, T.M., Carter, C.D.	3D measurement in a Mach 2combustor based on tomographic chemiluminescence	Aerodynamic Measurement Technology and Ground Testing Conference

CONFERENCE PAPERS

AUTHORS	TITLE	CONFERENCE
Xu, W., Lei, Q., Ikeda, J., Wu, Y., **Ma, L.**, Carter, C.D	2016 Single-Shot 3D Flame Imaging Based on VLIF (Volumetric Laser Induced Fluorescence)	Aerodynamic Measurement Technology and Ground Testing Conference
Haoting Wang, Tyler Capil, **Lin Ma**	Actively controlled thermal management of prismatic cell under elevated/varying thermal environment	2016 Automotive Research Center conference
Tyler Capil, **Lin Ma**	Active control cooling and thermal optimization for large scale battery pack	2016 Automotive Research Center conference
Offenberger, S. Boroujeni, A., Emami, A., Al-Haik, M., and **Philen, M**	Fiber Reinforced Composites with Zinc Oxide Piezoelectric Nanowires for Structural Health Monitoring and Enhanced Interlaminar Strength	20th International Conference on Composite Materials
Beaty, N., Burns, M., MacNeal, C., Mohan, G., Pyne, K., Weit, C., Bialy, A., Heim, M., Woolsey, C. A., and **Philen, M.**	Implementation of Flexible Matrix Composite Actuators into the eSPAARO Unmanned Air Vehicle	54th AIAA Aerospace Sciences Meeting

SEMINAR PROGRAMS

Center faculty organized professional and student seminars in FY2016. The professional seminar series was temporarily reduced in scope because of the need for the AOE Department to accommodate seminars from candidates for 5 new faculty positions, and thus formal CREATe seminars were restricted to a single event. This seminar was given by Dr. J. V. Larssen, Community Noise Lead Engineer, Boeing Commercial Airplanes, at the invitation of Profs. Devenport and Borgoltz. The CREATe student seminar series continued a vigorous program throughout the year with the following speakers and topics.

Haoting Wang, Liselle Joseph, 2/26/16, Aeroacoustic and c cooling batteries and modeling flames

Tamara Guimaraes, Raul Otero, and Tyler Vincent, 3/4/16, aeroacoustics

Nick Molinaro, John Gillespie, Molly Segee, 3/18/16, jet propulsion and the second aeroacoustics

Daniel Cadel, 3/25/16, Pre-Defense

Wenjiang Xu, Will George, Brady Doepke, 4/1/16, cooling batteries and modeling flames, jet propulsion aerodynamics inside engine cells and jet noise

Ian Clark, Marcie Stuber, Manuj, 4/8/16, jet propulsion aerodynamics inside engine cells and jet noise

Kara Crosser, Di Zhang, Eric Rolfe, 4/15/16, jet propulsion aerodynamics inside engine cells and jet noise

Sean Shea, Kenneth Brown, Anthony Millican, 4/22/16, boundary layer flows, turbulence ingestion and wind turbine noise

Henry Murray, 4/29/16, Defense

Tamara Guimaraes, Anthony Millican, Liselle Joseph, 9/30/16, turbulence ingestion for jet engine noise, bio-inspired trailing edge noise treatments, rough wall boundary layer scaling

Eric Rolfe, Ian Clark, 10/7/16, heat transfer instrumentation, bio-inspired trailing edge noise control

Neehar Balantrapu, Brady Doepke, 10/14/16, wind energy, morphing structures and applications to energy harvesting

Will George, Mark Pastor Hurtado, Sterling McBride, 10/21/16, jet engine aerodynamics, aeroacoustics of fan design, computational aeroacoustics for wind farms

Tyler Vincent, Nick Molinaro, 10/28/16, heat transfer instrumentation, applications of hot-wire anemometry, velocimetry development

David Mayo, 11/11/16 Turbulence Development in Non-Uniform, Heated Supersonic Jets for Noise Reduction

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