ANNUAL REPORT
BENTLY CENTER FOR ENGINEERING INNOVATION AWARDS

FOR 2017-2018

Compiled by Charles Birdsong
Bently Center Director 2018-2020

October 2018

Introduction

The Donald E. Bently Center for Engineering Innovation was established in spring 2003 through a substantial donation by Donald E. Bently. The Center is contained within the Mechanical Engineering Department. The purpose of the endowment is to promote innovation within the discipline, support applied research, expand the curriculum and bring vision and breadth to engineering instruction. The mission of the Center is advancement of research, education, and the practice of mechanical engineering with innovation as a guiding principle. Rotor dynamics is the primary focus of the center; however, the center supports a broad range of secondary focus areas.

Every year the Center issues a request for proposals to the Cal Poly M.E. faculty to sponsor faculty release time. The proposals are reviewed by a committee consisting of the Bently Center Director, ME Department Chair, and a third reviewer, typically the CENG Associate/Assistant Dean of Research. Awards are made based on criteria that includes meeting the mission of the Center, leveraging the award, deliverables, past performance, need and the proposal quality. The Bently Director is awarded 24 WTUs per year and expected to further the mission of the Center and administer the endowment, RFP process and documentation.

Awardees that are granted 12 – 18 WTUs are given the title of "*Bently Professors*" In addition to the *Bently Professor* awards, smaller awards are granted as well. A short bio of the 2017 *Bently Professors* is given below.

Steve Klisch, Professor of Mechanical Engineering

Dr. Klisch served as the Bently Center Director from 2014-2017. His research is focused on developing experimental and analysis protocols and conducting motion analysis studies of gait, cycling, elliptical training, and baseball pitching for our funded research projects. Dr. Klisch teaches courses in solid mechanics and biomechanics.

Russ Westphal, Professor of Mechanical Engineering

Professor Westphal's research focused on development of an alternative, modular version of the Cal Poly Boundary Layer Data System (BLDS), that employs the BLDS-M strategy, closely aligned with the latest "internet of things" (IoT) concepts. Professor Westphal teaches lecture and lab courses in Fluid Dynamics, Heat Transfer, Measurement, and Thermodynamics at the undergraduate and graduate levels.

John Chen, Professor of Mechanical Engineering

Dr. Chen's research focused on (i) grit and how it is affected through students' learning experiences, (ii) the collection of non-cognitive (NCA) factors related to student success, and (iii) metacognition, or awareness and control of one's learning. Professor Chen regularly teaches statics, introductory and advanced thermodynamics, and heat transfer. He enjoys the varied mix of students from different majors across the College of Engineering in the introductory courses, as well as working with students that are learning deeper disciplinary content within Mechanical Engineering.

Patrick Lemieux, Professor of Mechanical Engineering

Dr. Lemieux's research interests focus on internal combustion engines and alternative energy. He is currently primarily involved in the development of alternative thermodynamic cycles for the gas turbine and reciprocating internal combustion engine, as well as their mechanical design analysis near their failure points. Along with faculty colleagues, he has also founded the Cal Poly Wind Power Research Center on a remote ranch outside of the main campus, where the design and operation issues most relevant to the wind industry are investigated in a controlled way. Dozens of students have been involved in its various projects; the Center is most recently involved in the development of prognostic health monitoring systems for the distributed wind industry. Dr Lemieux has also been involved in the study of hybrid rocket motors and sits of the Hybrid Rockets Technical Committee of the AIAA. Professor Lemieux teaches courses in thermodynamics, fluid mechanics, heat transfer, control systems, internal combustion engines, refrigeration, wind energy and compressible flow gas dynamics.

Final project reports are due a month after the end of the Bently support period. The reports should include a the awardee's name, the number of weighted teaching units (WTSs) granted in the award, a summary of accomplishments, publications and other deliverables, student impacts, proposals and other leverage.

Below is a list of all the 2017-2018 awardee names, proposal titles, and number of WTUs awarded. A report from each awardee is included in the following pages.

List of Awardees

Awardee, Proposal Title, Number of WTWs awarded Page

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John Chen, "The role of grit in student achievement", 12 WTUs. 10

Patrick Lemieux, "Prognostic condition monitoring of distributed wind turbines & improving the gas turbine cycle with compressed air energy storage", 12 WTUs. 14

Eltahry Elghandour, "Incorporation of bio-composite materials in structural applications", 10 WTUs. 18

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Sthanu Mahadev, "Incorporation of bio-composite materials in structural applications", 6 WTUs. 22

Julia Wu, "Build a data acquisition system to replace ADRE208 using MATLAB/Simulink", 7 WTUs. 24

Andrew Davol, "Enhancing the exchange program at the Munich University of Applied Sciences", 6 WTUs. 28

Stephen M. Klisch, "Establishing Cal Poly's Human Motion Biomechanics (HMB) Lab and serve as Bently Center Director", 24 WTUs

Awardee
Stephen M. Klisch, Professor, Mechanical Engineering, sklisch@calpoly.edu

Award
24 units (6 in 2017 Summer quarter, 8 in 2016 Fall quarter, 5 in 2018 Winter quarter, 5 in 2018 Spring quarter)

Summary of Accomplishments
As stated in the original proposal, the **primary objectives** of the assigned time were: *"to maintain momentum in establishing Cal Poly's Human Motion Biomechanics (HMB) Lab and … to serve as an effective and conscientious steward of the Bently endowment*" Most of my supported time was spent in three areas: 1) working with 18 Cal Poly students, 2 visiting scholars, and 3 high school students conducting research on funded proposals; 2) launching the HMB Lab Diversity Program; and 3) serving as Director of the Bently Center.

During the period of support, my primary activities included 1) mentoring students as they submitted or presented 14 conference and 1 journal papers, 2) mentoring students as they further developed experimental and analysis protocols and conducted motion analysis studies of gait, cycling, elliptical training, and baseball pitching for our funded research projects, 3) preparing IRB protocols for several research projects, 4) co-authoring 2 published peer-reviewed journal papers, and 5) performing administrative tasks related to my positions as HMB Lab and Bently Center Directors.

Publications and other Deliverables (Cal Poly students in bold)
Peer-reviewed conference papers (presented or submitted & accepted)
1. **Rumery MG**, **Lane GT**, Klisch SM, Hazelwood SJ. Gait and cycling finite element predictions of knee cartilage pressure for linear and porous elastic materials. *Annual Meeting of the Biomedical Engineering Society,* Oct 2018.
2. **Tucker S**, Profiti V, Hazelwood SJ, Klisch SM. Knee angles with soft tissue artifact correction for normal weight, overweight and obese subjects in gait and cycling. *American Society of Biomechanics Annual Meeting*, Aug 2018.
3. **Sterner J**, **Sanchez Porush SR**, Reaves SK, Hazelwood SJ, Klisch SM. DXA-driven inverse dynamics of pitching arm kinetics in youth baseball players. *American Society of Biomechanics Annual Meeting*, Aug 2018.
4. **Heyde EA**, **Orekhov G**, Robinson AM, Hazelwood SJ, Klisch SM. Hip and knee forces for transtibial amputees in gait and cycling. *American Society of Biomechanics Annual Meeting*, Aug 2018.
5. **Pottinger MV**, Schueckler OJ, Hazelwood SJ, Klisch SM. Internal knee joint abduction moments of ACL reconstruction patients during gait and cycling using Opensim. *American Society of Biomechanics Annual Meeting*, Aug 2018.
6. **Skaro JM**, Hazelwood SJ, Klisch SM. Knee angle and axes crosstalk corrections in gait, bicycling and elliptical exercises using principal component analysis. *American Society of Biomechanics Annual Meeting*, Aug 2018.

7. Marino C, **Pottinger MV**, Hazelwood SJ, Klisch SM. EMG-driven Opensim analysis of knee forces in normal weight, overweight, and obese subjects during gait, cycling and elliptical exercises. *American Society of Biomechanics Annual Meeting*, Aug 2018.
8. **Tucker S**, Profiti V, Hazelwood SJ, Klisch SM. Knee angles with soft tissue artifact correction for normal weight and overweight subjects in gait and cycling. *World Congress of Biomechanics*, Jul 2018.
9. **Orekhov G**, **Heyde EA**, Robinson AM, Hazelwood SJ, Klisch SM. Asymmetry in peak ground/pedal reaction forces for transtibial amputees in gait, cycling, and elliptical training. *World Congress of Biomechanics*, Jul 2018.
10. **Lane GT**, **Rumery MG**, Klisch SM, Hazelwood SJ. Human knee FEA model for transtibial amputee tibial cartilage pressure in gait and cycling. *World Congress of Biomechanics*, Jul 2018.
11. **Rumery MG**, **Lane GT**, Klisch SM, Hazelwood SJ. Finite element analysis predictions of knee cartilage contact pressure in gait and dependence on material model choice. *World Congress of Biomechanics*, Jul 2018.
12. **Tucker S**, **Yadlowsky N**, Profiti V, Hazelwood SJ, Klisch SM. A pseudo-rigid body method for soft tissue artifact (STA): results for STA simulation and standard gait experiments. *Annual Meeting of the Biomedical Engineering Society,* Oct 2017.
13. **Orekhov G**, **Heyde EA**, Robinson AM, Hazelwood SJ, Klisch SM. Ground/pedal reaction forces and knee flexion angles for transtibial amputees in gait and cycling. *Annual Meeting of the Biomedical Engineering Society,* Oct 2017.
14. **Mavrommati K**, **Pottinger MV**, Schueckler OJ, Hazelwood SJ, Klisch SM. Inverse dynamic analysis of knee contact loads for ACL reconstruction patients during gait and cycling. *Annual Meeting of the Biomedical Engineering Society,* Oct 2017.

Peer-reviewed journal papers

1. **Darke JD**, **Dandekar EM**, Aguinaldo AL, Hazelwood SJ, Klisch SM. Effects of game pitch count and body mass index on pitching biomechanics in 9-10 year old baseball athletes. *Orthopaedic Journal of Sports Medicine*, 6(4), April 2018.
2. Chan EF, Farnsworth CL, Klisch SM, Hosalkar S, Sah RL. 3-dimensional metrics of proximal femoral shape deformities in Legg-Calvé-Perthes disease and slipped capital femoral epiphysis. *Journal of Orthopaedic Research*, 36(5):1526-1535, 2018.

Miscellaneous presentations / activities

1. Klisch SM. Effects of overweight/obesity on injury-correlated biomechanical loads in sports & exercise. *Cal Poly's Center for Health Research Symposium*, May, 2018.
2. Klisch SM. Executive Board Member. *Cal Poly's Center for Health Research (formerly STRIDE)*, Sep 2016 - present.
3. Klisch SM. Scientific Board Member, *Proposal for hosting the European Society of Biomechanics 2020 Meeting*, Politecnico di Milano, Milan, Italy.
4. Klisch SM. Four IRB protocols submitted to, and approved by, *Cal Poly's Human Subjects Committee* and the *Army Human Research Protections Office*, Jun 2017-May 2018.

Student Impact

Supervision of Cal Poly M.S. students

1. Lane, GT. Human knee FEA model for transtibial amputee cartilage pressure in gait and cycling. *M.S. Thesis, California Polytechnic State University, San Luis Obispo, CA,* 2018 (Hazelwood lead advisor).

2. Skaro, J. Knee angles and axes crosstalk correction in gait, bicycling, and elliptical exercises. *M.S. Thesis, California Polytechnic State University, San Luis Obispo, CA,* 2018.
3. Megan Pottinger (MS thesis research, expected graduation in Summer 2018).
4. Greg Orekhov (MS thesis research, expected graduation in Summer 2018).
5. Michael Rumery (MS thesis research, expected graduation in Summer 2018, Hazelwood lead advisor).
6. Brad Wash (MS thesis research, expected graduation in Summer 2018, Self lead advisor).
7. Sam Tucker (MS non-thesis research, Summer 2017-Fall 2018).
8. Sofia Porush (FSN, MS non-thesis research, Summer 2017-Spring 2018).

Supervision of Cal Poly B.S. students

1. Katherine Mavrommati (BMED, BS research, Spring 2016-Winter 2018).
2. Elizabeth Heyde (BMED, BS research, Spring 2017-present)
3. Emily Hubbard (BMED, BS research, Spring 2017-present)
4. Jay Sterner (ME, BS research, Spring 2017-present)
5. Jonathon Stearns (ME, BS research, Spring 2017-present)
6. Emily Vassilev (BMED, BS research, Spring 2017-Winter 2018)
7. Shaida Biglari (BMED, BS research, Spring 2018-present)
8. Reymil Fernandez (ME, BS research, Spring 2018-present)
9. Scott Weinhardt (ME, BS research, Spring 2018-present)
10. Dalton Jennings (BMED, BS research, Spring 2018-present)

Supervision of non-Cal Poly student projects

1. Valentina Profiti (ME, Polytechnic University of Torino, Spring-Summer 2017)
2. Chiara Marino (ME, Polytechnic University of Torino, Spring-Summer 2017)
3. Jennifer Zakaria (SLO High School, Summer 2017).
4. Lizeth Murillo (Paso Robles High School, Summer 2017).
5. Lindsey MacLeod (SLO High School, Summer 2017).

Proposals and other Leverage

Active or submitted awards during the period of support (external awards only)

1. **National 4-H Council via The Regents of the University of California**. (PI Klisch)
5/1/17-10/31/17; $10,969 (direct costs). ***Title*****:** 4-H Career Readiness Pathway: HMB Lab Diversity Initiative. ***Status:*** submitted Mar 2017; awarded Jun 2017.

2. **W.M. Keck Foundation** – Undergraduate Education Program, Phase II Application. (PI Klisch, co-PIs Self, Hazelwood, Clark, Taylor)
1/1/16-6/30/19; $350,000 (direct costs only)
Title**:** Human Motion Biomechanics lab: Integrating research and education in an interdisciplinary setting. ***Status:*** awarded Jan 2016.

3. **US Army Medical Research and Materiel Command (AMRMC)**. (PI Klisch, co-PIs Hazelwood, Self)
3/15/16-3/14/19; $513,645 (total costs)
Title**:** Joint loads and cartilage stresses in intact joints of military transtibial amputees. ***Status:*** awarded Jan 2016.

4. **California Strawberry Commission** (PI Klisch, Co- PI Hazelwood)
6/01/18-3/31/19; $14,881 (direct costs)
Title**:** Motion analysis of low back loads in strawberry picking for injury prevention methods.
Status: awarded Jul 2018.

Russ Westphal, "Modular version of the boundary layer data system ", 14 WTUs

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Awardee

Russell V. Westphal, Donald E. Bently Professor, rvwestph@calpoly.edu

Award

14 WTU (18 requested; 3 in Summer 2017, 4 in Fall 2017, 4 in Winter 2018, 3 in Spring 2018)

Summary of Accomplishments

Restatement of Original Proposal Summary Paragraph (verbatim). The proposer requests Bently Center support totaling 18 WTU (4 WTU per quarter during the academic year, 3 WTU in summers) for the period summer 2017 through summer 2018 to lead students in the development of an alternative, modular version of the Cal Poly Boundary Layer Data System (BLDS), to be designated "BLDS-M". The proposed effort would result in the non-proprietary development of several prototype modules that would form the basis for proposed applications that would employ the BLDS-M strategy, closely aligned with the latest "internet of things" (IoT) concepts. Involvement of our students with IoT is especially timely and would help give this increasingly important area more visibility on our campus. The world-unique BLDS has already proven to be a most effective platform for student engagement in the conduct of project work that provides hands-on enhancement of their education; it has provided numerous opportunities for them to practice engineering while developing and applying an innovative, state-of-the-art measurement system/paradigm. The proposed work will support the continuation of this long-term project by developing a modern IoT version of BLDS that will expand the areas of its possible application while providing students with a project experience that promises to be attractive to a wider array of potential employers.

It has been my honor and privilege to hold the title of Donald E. Bently Professor, and to employ Bently Center support in the form of 14 WTU during summer 2017 through spring 2018. **The award supported a year-long effort that resulted in the successful development of a family of prototypes for a new, Modular version of the Boundary Layer Data System ("BLDS-M").** Development of BLDS-M, with its "IoT" approach, was undertaken to modernize BLDS in order to avail the project of emerging opportunities for flight and other high-value, full-scale testing in the future. Efforts to secure a "launch customer" for the new version of BLDS are well underway and promise to lead to exciting opportunities for student project work in the years ahead.

To prepare for the project, during spring 2017, undergraduate BMED student Isabel Jellen was recruited to work starting in summer; I also procured electronic parts and together with undergrad student Paul Kujawa from AE, did some very preliminary work to get things ready for summer. During the summer and continuing during the school year, student Isabel Jellen designed, assembled, programmed, and documented a working prototype BLDS-M that includes 4 modules: a "cricket" that can wirelessly broadcast pressure and temperature data, a "recorder" module that receives the wireless transmissions and saves time-stamped data to microSD media, a "console" module that can interface to a laptop for monitoring and configuring of the other modules, and a "GPS" module that can provide time and other GPS-derived information. She also programmed a basic cell phone app that enables wireless monitoring of the system on an iPhone.

A draft manuscript has been submitted for AIAA SCITECH 2019 describing the work (Bently Center support formally acknowledged in this paper), and the prototype hardware was demonstrated for Boeing personnel at Seattle (August 2017), to the Mechanical Engineering Industrial Advisory Board (Oct 2017), and for the Air Force Research Lab (May 2018). Ms. Jellen was also selected to participate in the campus screening of entries for the statewide CSU Student Research Competition, and was selected to present a poster at the More than a Motto: Cal Poly's Learn-by-Doing Conference. Ms. Jellen's effort and the cost of necessary electronic parts have been supported through two discretionary sources: my professional development account, and funds earmarked for my flow measurement projects donated by Northrop Grumman. In addition, working with an electronics consultant, we developed a design for a DC-DC converter that can be used with BLDS-M to reduce the required size of the onboard battery in each module. This new approach to powering BLDS-M, applicable to earlier BLDS units as well, will be tested this summer.

White papers were distributed to the ME Advisory Board, and separately to contacts at the Boeing, US Air Force Research Lab, NASA Armstrong Flight Research Center, Northrop Grumman Corp., Lockheed, and General Atomics. On-site hardware demonstrations of BLDS-M prototype hardware were conducted for the ME Advisory Board meeting (SLO), Boeing (Seattle), Northrop Grumman (Mojave), and the Air Force Research Lab (Dayton). Discussions are ongoing with these potential sponsors.

In anticipation of future sponsored work, BLDS-related projects were proposed to the COE's Summer Undergraduate Research Program and positions for 3 students were awarded. Students were recruited during Spring 2018, and these projects are in early stages of work now (June 2018) along with externally-sponsored work.

Publications and other Deliverables (students in bold)

Peer-reviewed conference papers

1. **Jellen, I.**, and Westphal, R. V. "A Modular Version of the Boundary Layer Data System", draft manuscript submitted for review for *AIAA SciTech 2019*, San Diego, CA, Jan 2019
2. **Jellen, I.**, and Westphal, R. V. "A New, Modular Modular Version of the Boundary Layer Data System" poster presentation for *More than a Motto: Cal Poly's Learn-by-Doing Conference*

3. Glen T. Duncan, Jr., Anne M. Sullivan, Cory J. Pomerantz, and Russell V. Westphal,"Flight Demonstration of Laminar-Flow Height Criteria for 2-D and 3-D Excrescences on an Unswept Wing"; *AIAA AVIATION 2018*, June 2018, Atlanta GA

4. Alexandre P. Antunes, Renato Cosin, Kevin M. Mejia, Charles Ulk, Russell V. Westphal, "Testing An Autonomous Boundary Layer Data System Device at the Transonic Flight Regime," AIAA-2018-4196, *AIAA AVIATION 2018*, June 25-29, 2018, Atlanta GA

Peer-reviewed journal papers

None.

Patent

"Directional Dynamic Absolute Pressure Sensor Shroud and Arrangement", Docket Number NGC-00215 (00869-0030) co-inventors Chris Harris, Yuan Li, **Htet Htet Oo**, Dan Cuppoletti, Russ Westphal, **Kris Lawrence**, Jim Gerhardt (patent owner: Northrop Grumman) US Patent number 9,869,570 granted January 16, 2018

Formal Presentations

1. Westphal, R. V. and **Jellen, I.** "The Boundary Layer Data System Project", presented to the Mechanical Engineering Department Industrial Advisory Board, Oct. 26, 2017
2. **Jellen, I.** "A Wireless Modular Version of the Boundary Layer Data System", paper presented at campus competition for the CSU Undergraduate Research Competition, Mar. 3, 2018
3. Westphal, R. V. "The Boundary Layer Data System" ME 562 Graduate Seminar, presented February 14, 2018
4. Drake, A., and Westphal, R. V. "The Boundary Layer Data System: A Proven Paradigm for Flight Test", Air Force Research Lab, Dayton, OH, May 17, 2018

Student Impact

Supervision of student projects (all students listed paid hourly)

1. **Isabel Jellen** (BMED undergrad—summer 2017-spring 2018)
2. **Thomas Niemisto** (ME undergrad—summer 2017-spring 2018)
3. **Josh Clemons** (ME undergrad—summer 2017)
4. **Andrew Elliott** (ME master's project—summer-fall 2017)
5. **Jensen Severance** (ME undergrad—summer 2017-fall 2017)
6. **Jarod Kinney** (ME undergrad—summer 2017 - present)
7. **Nathan Hoyt** (ME master's thesis—spring 2018 - present).
8. **Zach Wilson** (ME master's project—winter 2018 - present).

Proposals and other Leverage

Active awards during the period of support

1. **Boeing Commercial Airplane Company** (R. V. Westphal, PI, A. G. Drake, co-PI)
Dec. 2016-Dec. 2018; $104.1K
Title**:** Boundary Layer Data System 2018 ***Aims*****:** Develop and apply BLDS on 777 for 2018 EcoDemontrator. ***Status:*** submitted Nov. 2016, funded, in progress.

Proposals submitted during the period of support

2. **Northrop Grumman Corp**. from Air Force Research Lab (R. V. Westphal, PI)
Sept. 2017-July 2018; $46.3 K
Title**:** Excrescence Flight Test Study ***Aims*****:** Support flight test of excrescence tolerance criteria for unswept wings using existing BLDS v3b hardware ***Status:*** submitted Aug. 2017, funded, in progress.
2. **Northrop Grumman Corp**. from U S Air Force (R. V. Westphal, PI)
Jan 2018-July 2018; $30 K
Title**:** Global Hawk Icing ***Aims*****:** BLDS application for study of boundary layer behavior with wing icing. ***Status:*** submitted Jan 2018, funded, in progress.
3. **Cal Poly College of Engrg 2018 Summer Undergrad. Research Prog.** (R.V. Westphal, PI)
June 2018-August 2018;
Title: IoT for Fluids Lab & BLDS Project ***Aims:*** Leverage work on BLDS-M for application to ME 347 Fluids Lab, and, involve more students in BLDS-related non-proprietary project work ***Status:*** BLDS project (3 students) funded, in progress; IoT for Fluids Lab not funded

John Chen, "The role of grit in student achievement", 12 WTUs.

Awardee

John Chen, Professor, Mechanical Engineering, jchen24@calpoly.edu

Award

Total units (Originally granted 6 WTUs in 2018 Winter quarter and 6 WTUs in 2018 Spring quarter. Modified for Spring 2018 due to department request for additional teaching support to 3 WTUs, and 3 WTUs deferred to summer 2018)

Summary of Accomplishments

The overarching question motivating my research asks: Why do some students succeed in engineering studies while others, at least equal in talent and academic qualifications, do not? Why are intelligence and academic preparation – which every entrant to Cal Poly's engineering program possesses – not enough to guarantee success? Importantly, there is growing awareness that innate talent – i.e., IQ or intelligence – is neither the only nor the most important trait for predicting future success or a wide range of achievement outcomes in adults or younger populations from adolescents to university students. Many traits not directly related to knowledge acquisition have been shown conclusively to have a significant impact as well, including, for example, optimism, self-control, and self-efficacy. In addition to psychological traits, there are learning-related factors that impact academic success, such as study strategies and self-regulation of learning.

The Bently-supported projects during the past year can be grouped into three topics. These are (i) grit and how it is affected through students' learning experiences, (ii) the collection of non-cognitive (NCA) factors related to student success, and (iii) metacognition, or awareness and control of one's learning. In the following sections, I describe the accomplishments from this past year.

Grit

This project is continuing to collect data contributed by study participants in two groups: Undergraduate ME students taking the mechanics sequence and first-year ME students. The first group of participants is recruited in ME 211 (statics) and is tracked as each undertakes the mechanics sequence of ME 211 – CE 204/ME 212 – CE 207 – ME 326. Currently, this cohort consists of 70 students who have contributed data about their level of learning engagement while taking these courses. A smartphone app is provided to record these data. The second group, consisting of 40 first-year students recruited in winter quarter of 2018 and is going into their second year of ME studies. A second cohort of ~40 participants, to be recruited in fall 2018 from ME 128, will join this first cohort. This group is similarly contributing data through the smartphone app but all of their major courses are being tracked.

NCA factors

This project, which is a collaboration with Purdue University and University of Texas, El Paso, is proceeding into a second year of data collection at Cal Poly. During the past year, Cal Poly students contributed over 800 completed surveys to the study. The participants have been mainly first-year CENG students, broken into two cohorts. The first cohort's data (N=~350) was used to conduct an exploratory factor analysis to validate the survey instrument, while the second cohort

is being used to conduct cluster analysis to identify the typical NCA profile of engineering/computing students. The results from these efforts are documented in the conference publications listed below. In the coming academic year, the survey will continue at Cal Poly so that upper-years students will be added to the dataset.

Metacognition

A proposal was prepared and submitted in April 2018 to the National Science Foundation's Improving Undergraduate STEM Education (IUSE) program (see description below). Unfortunately, it was not funded. In the coming year, the proposal will be improved based on the reviewers' comments, and it will be resubmitted for consideration.

Publications and other Deliverables (students in bold)

Peer-reviewed conference papers

1. Chen, J.C., Janzen, D., Widmann, J., McGaughey, K., and Teramoto Pedrotti, J., "Measuring Active Learning at the Student Level," 2017 Research in Engineering Education Symposium, Bogota, Colombia, July 2017.
2. Scheidt, M., Godwin, A., Senkpeil, R.R., Ge, J.S., Chen, J., Self, B.P., Widmann, J.M., and Berger, E.J., "Validity Evidence for the SUCCESS Survey: Measuring Non-Cognitive and Affective Traits of Engineering and Computing Students," 2018 ASEE Annual Conference and Exposition, Salt Lake City, UT, June 2018.
3. (To be presented in Oct. 2018, but prepared and accepted in June 2018)
   a. Scheidt, M., Senkpeil, R., Chen, J., Godwin, A., and Berger, E., "SAT Does Not Spell Success: How Non-Cognitive Factors Can Explain Variance in the GPA of Undergraduate Engineering and Computer Science Students," 2018 Frontiers in Education Conference, San Jose, CA, October 2018.
   b. Ge, J., Berger, E., Chen, J., and Self, B., "Do Great Minds Think Alike? Racial/Ethnic and Gender Differences in Mindset of Undergraduate Engineering Students," 2018 Frontiers in Education Conference, San Jose, CA, October 2018.
   c. Berger, E., Godwin, A., Scheidt, M., Chen, J., Senkpeil, R., Ge, J., Self, B., Widmann, J., and Gates, A., "Collaborative Survey Construction for National Data Collection: Coordination, Negotiation, and Delivery," 2018 Frontiers in Education Conference, San Jose, CA, October 2018.

Student Impact

Supervision of student projects

1. M. Barkley, A. Ghazvini, and L. Kusakabe (undergraduate ME students, Cal Poly): Co-advised and -supervised these three undergraduates during the 2017-18 academic year for work described in the Bently proposal. Specifically, these students administered the surveys of engineering students, read research papers in support of the project, and participated in the creation and delivery of two conference presentations. One conference was the ASEE Pacific Southwest (Zone IV) conference in Boulder, CO, and the other was the CSU Teaching Symposium at Cal Poly Pomona.

Proposals and other Leverage

Active awards during the period of support

1. **National Science Foundation** (PI: John Chen, co-PIs: David Janzen (CSC), Karen McGaughey (Statistics), Jennifer Teramoto Pedrotti (Psychology & Child Development), Jim Widmann (ME))

Oct. 1, 2014 to Sept. 30, 2017 (extended to Sept. 30, 2019); $200,000
Title*:** Actively Building the Drive to Achieve through Everyday Engineering Learning. ***Aims*:** Grit – defined as passion and perseverance for long-term goals – is likely to be important to individuals trying to achieve the challenging, long-term goal of attaining an engineering degree, which requires not only talent but also its focused and sustained application over a long period. This proposed project will investigate the role of active learning in building grit. A longitudinal observational research design will be implemented to answer this question. California Polytechnic State University is an ideal place to conduct this study for several reasons: It is a large, state-supported, undergraduate-focused university typical of other large engineering programs; it has a diverse engineering student population; and it prides itself on the quality of the student experience, including many small, personalized classes and a "learn by doing" culture. As a result of their natural progression through the curricula, students will have widely varying experiences along the active-learning continuum, from low quantity and quality, to high. This highly diverse engineering-learning ecology presents a unique opportunity to study the association between active learning and grit growth. ***Status: Submitted Feb. 4, 2014, funded.

2. **National Science Foundation** (PI: John Chen, co-PIs: David Janzen (CSC), Karen McGaughey (Statistics), Jennifer Teramoto Pedrotti (Psychology & Child Development), Jim Widmann (ME))
June 1, 2016 to May 31, 2019; $499,275
Title*:** Does Active Learning Build Grit? ***Aims*:** The study uses a quasi-experimental design with treatment and control groups to determine if active learning, which acts as a proxy for deliberate practice, builds the character trait of grit in students while they learn in the domain of mechanics. A second research question is whether increased grit leads to other success outcomes such as retention in major and progress toward degree. These questions are investigated through a direct intervention that includes intensive, peer-based, active-learning experiences, along with activities designed to boost optimism and endorsement of growth mindset. A control group will also undertake learning activities to improve its mechanics learning, but in ways that do not meet the definition of deliberate practice. Grit is likely to be important to individuals trying to achieve the challenging, long-term goal of attaining an engineering degree. ***Status: Submitted Sept. 10, 2015, funded.

3. **National Science Foundation** (PI: Jim Widmann, co-PIs: John Chen, Brian Self)
Oct. 1, 2016 to Sept. 30, 2020; $479,351
***Title*:** IUSE:EHR: Collaborative Research: The Role of Non-Cognitive and Affective (NCA) Factors in Engineering and Computing Student Academic Performance. ***Aims*:** Understanding the ways in which students succeed and fail in STEM majors, and developing powerful ways to support them, will pay dividends for our students, our institutions, and our nation. Predictive models for student academic performance largely rely upon cognitive measures of achievement such as high school GPA, SAT scores, and similar measures of past performance. These models have consistently demonstrated that only a reasonably small part ($R^2 \sim 0.25$) of the total variance in predicted academic performance is explainable using cognitive factors. More recent work includes non-cognitive and affective (NCA) variables (such as mindset) to improve the predictive power of academic performance models. Nonetheless, there remain substantial gaps in our understanding of how NCA profiles of STEM students can be used to support their academic success. The central intellectual contribution of this research-to-practice project is the development, implementation, and evaluation of NCA-based interventions for diverse STEM students in multiple settings. This multi-institution research team engages student affairs practitioners in the development and delivery of NCA-based interventions. The unique coalescence of expertise and experience among the team strongly promotes the multiple

perspectives that are required to deploy interventions with diverse students in different settings. Importantly, the student affairs collaborations allow access to information about life events ("obstacles") faced by students, and this research explicitly connects student academic performance to such obstacles, as mediated by the NCA profile. This obstacle data, and its connection to both NCA profile and academic performance, represents a truly unique and deeply valuable contribution of this research program. ***Status:*** Submitted Jan. 13, 2016, funded.

Proposals submitted during the period of support

1. **National Science Foundation** (PI: John Chen, co-PI: Karen McGaughey)
Sept. 1, 2018 to Aug. 31, 2021; $274,220
Title**:** Exploring Effective, Adoptable Metacognitive Classroom Tools. ***Aims*****:** Metacognition – one's awareness, knowledge and control of one's thinking – is recognized as a fourth dimension of knowledge, alongside factual, procedural and conceptual knowledge. Its importance to learning across the entire age spectrum, from childhood to senior citizens, is widely recognized. At the college level, although notably less so in the STEM subjects, teaching practices that promote metacognition have been well documented. These practices have not been widely adopted, however, most likely because of several recognized impediments common to other effective, evidence-based teaching innovations. This proposed project seeks to test the efficacy and ease of adoption of three metacognitive teaching tools that may overcome these impediments. If proven effective in this environment, additional instructors in potentially different service courses will be recruited to further test each tool. Efficacy of each tool will be measured by their effects on students' problem-solving ability, conceptual mastery, and metacognition change. In addition, focus groups and surveys of students, and interviews of faculty testers will provide qualitative insights on the students' and faculty's experiences with the tools. ***Status:*** Submitted Apr. 9, 2018, not funded.

Patrick Lemieux, "Prognostic condition monitoring of distributed wind turbines & improving the gas turbine cycle with compressed air energy storage", 12 WTUs.

Awardee

Patrick Lemieux, Professor, Mechanical Engineering, plemieux@calpoly.edu

Award

12 units (4 Sm / 4 F / 4 W)

Summary of Accomplishments

The original Bently release time proposal focused on two general areas of research:

I. "PCM": Prognostic Condition Monitoring of Distributed Wind Turbines. 9 WTU requested;

II. "CAES": Improving the Gas Turbine Cycle with Compressed Air Energy Storage. 6 WTU requested.

Both research projects saw significant advances during the period of performance.

I. Windturbine LifeLine PCM System Development

Downtime, troubleshooting, and maintenance remain substantial components of wind energy costs, limiting locations where wind power can compete. Sophisticated remote monitoring systems can increase reliability; however, the investment commitments required prevent their widespread use with distributed wind (DW) turbines. The goal of this project was to develop an inexpensive health monitor with a base material manufacturing production price targeted at $100, minimizing the number of sensors and subsystems, while monitoring the most critical components of the machine, based on extensive surveys and studies of existing commercial systems. Expected to streamline maintenance and provide feedback on field performance, the concept was embraced by leading American and international manufacturers. One goal was to leverage Internet of Things (IoT) technologies – tying mechatronics to the mechanical design of DW turbines. The research work thus focused specifically on the development of a new type of monitoring system tailored for distributed wind turbines, one capable of providing warnings of impending malfunction, before such malfunctions create a catastrophic failure of the system. The prototype system (see Figure 1) developed during the period of support, accomplished this by focusing on a narrow set of goals. Using vibration spectrum recording as the primary measurement technique, it:

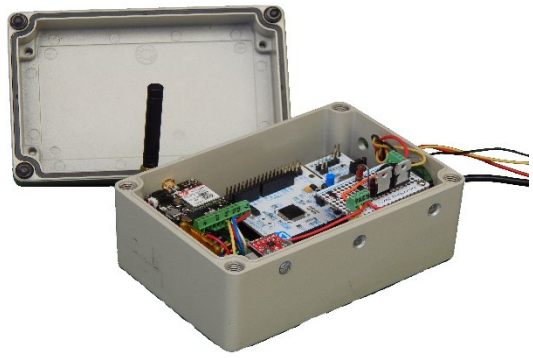


Figure 1: Windturbine LifeLine prototye

1) Validated the algorithms and methods (both designed at Cal Poly) for detecting trends, using approaches common in the gas turbine and reciprocating engines industry;

2) Demonstrated its capability through field tests at the Cal Poly Wind Power Research Center, set to operate both within expected parameters and with simulated defects. The prototype processed its data during normal operation to form a reference data repository that it used to infer

anomalies. Once the turbine was modified to simulate such anomalies (illustrated in Figure 2), the LifeLine successfully and reliably detected them, and issued wireless-cellular alerts describing the event. A Phase II proposal to enhance the algorithms developed and tested here, and optimize the manufacturing and commercialization of the unit, with significant support from the industry, and planned collaborations between the CENG and the College of Business was also prepared and submitted during the period of support.

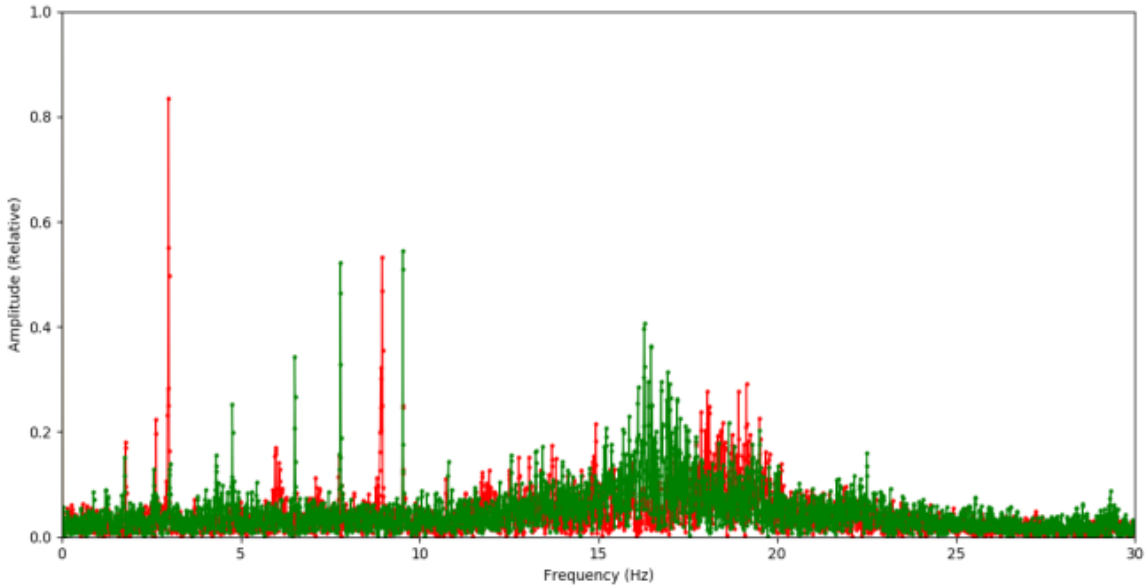


Figure 2: Field Test: 200 RPM vibration spectrum with balanced (green) and unbalanced (red)

II. CAES: Compressed-Air Gas-turbine Cycles

The CAES project advanced on two significant levels during the period of performance: an exchange MS student from Politecnico di Torino completed his research while at Cal Poly on gas turbine cycle modifications and develop an important analytical model of the new system. Two conference papers were prepared submitted following this work, and both were accepted at international conferences. Unfortunately, outside constraints forced the withdrawal of both papers. A US Patent was filed – and already awarded! – by Cal Poly on the Gas Turbine cycle modification. A new area of research, with another international collaborator stemmed from the work done on this project. The new area focused on applying the same concept to reciprocating internal combustion engines; Cal Poly filed a separate patent on that idea during the period of performance as well. 3 undergraduate students worked directly on related aspects of the projects throughout the period of support; 1 graduate student worked on a detailed analysis of one of the proposed methods for 6 months.

Publications and other Deliverables (students in bold)

Peer-reviewed conference papers

15. **Avigliano AG,** Lemieux P, Pastrone DG "CAES-GT: The New Frontier of Renewables" *Proceedings of ASME Turbo Expo 2018: Turbomachinery Technical Conference & Exposition,* Oslo, Norway 2018.

16. Lemieux P, **Avigliano AG,** Pastrone DG "Compressed Air Energy Storage – Gas Turbine Cycles: a Study on the Effects of Ambient Temperature, Injection and Intercooling", *Propulsion and Energy Forum, 54th AIAA/SAE/ASEE Joint Propulsion Conference,* 2018

Patents filed/awarded (Cal Poly Corporation)

1. "System, Method and Apparatus for Improving Gas Turbine Performance with Compressed Air Energy Storage", U.S. Department of Commerce, U.S. Patent and trademark Office; Pub. No.: US 2017/0254265 Al, Sept. 2017

2. "Air-Cycle Environmental Control Systems and Methods for Automotive Applications", Patent No.: US 9,249,998 B2, 17 additional claims allowed for Method, Sept. 2017

3. "Windturbine LifeLine", U.S. Department of Commerce, U.S. Patent and trademark Office; Filed (Provisional) April 2018

Student Impact

Supervision of non-Cal Poly M.S. student projects

6. Antonio Avigliano (MS, Politechnico di Torino, Summer/Fall 2017). Antonio worked on the CAES-GT project and helped draft two conference papers.

Supervision of Cal Poly undergraduate student projects

1. "Cal Poly Polyboost Team". Sponsored and advised a Senior Project team on the development of a fast-acting valve for the CAES project.

Proposals and other Leverage

Active awards during the period of support

1. **U. S. Department of Energy SBIR/STTR FY 2017 Phase I Release 2** FOA Number: DE-FOA-0001619. (PI Lemieux)
October 2017-May 2018; $150,000 (total cost)
Title*:** "SMART Wind Health: Development of an Inexpensive Prognostic Condition Monitoring/Control System for Distributed Wind Turbines" ***Aims*:** Develop a flexible, inexpensive health monitor and control system for wind turbines of many sizes, with a base material manufacturing production price targeted at $100. System aims at streamlining maintenance and provide feedback on field performance. ***Status: submitted February 2017, funded.

Proposals associated with projects:

1. **U. S. Department of Energy SBIR/STTR FY 2017 Phase II Release 2** FOA Number: DE-FOA-0001795. (PI Lemieux) $1,000,000 (total cost) ***Title*:** SMART Windpower "LifeLine" Phase II: Expanding Markets, Improving Reliability and Reducing Costs ***Aims:*** to design and produce a small, inexpensive device, using a minimal set of vibration transducers sufficient to properly monitor and evaluate the overall health of wind turbines, and to rapidly communicate warnings to operators. ***Status:*** submitted April 2018; not funded.

2. **California Strategic Growth Council: Climate Change Research Program.** A California State University Climate Change Research Consortium (CCRC) of 3 campuses (CSULA, CPSLO, SDSU) submitted proposal for 7 projects totaling $4,000,000. Project 2: "Development of Compressed Air Energy Storage (CAES)-Enhanced Diesel Engine" submitted by P. Lemieux (PI) ***Status:*** Submitted April 2018; not funded.

Eltahry Elghandour, "Incorporation of bio-composite materials in structural applications", 10 WTUs.

Awardee

Eltahry Elghandour, Associate Professor, Mechanical Engineering, eelghand@calpoly.edu

Award

10 Units (2017-2018 Summer quarter)

Summary of Accomplishments

The primary objective of the assigned release time was primarily to investigate "*Incorporation of Bio-Composite Materials in Structural Applications*," as stated in the project proposal. Most of my time was used to supervise and support thirty two students: 25 graduate and undergraduate Cal Poly students (11 ME, 3 MATE, 9 AERO, and 2 CE), 4 high school students, and 3 community college students. The project activities included 1) designing molds for composite materials; 2) writing a proposal for external funding from NSF and industrial companies; 3) developing a new course titled "Introduction to Manufacturing Composite Materials"; and 4) writing a manuscript related to the incorporation of bio-composite materials in structural applications. During this time, I accomplished the following:

1. I prepared and submitted 9 papers: one to the International Journal of Sustainable Materials and Structural Systems (IJSMSS); two to the SAMPE conference in Seattle May 22-25, 2017; and 6 to CAMX conference in Orlando, Florida. All papers were accepted. My graduate and undergraduate students and I presented the papers at the SAMPE and CAMX conferences.
2. I, along with four undergraduate students, have been awarded summer research grants to develop a fabrication technique using biomaterial/aerogel integrated into composite materials.
3. Dr. Noori and I prepared and submitted two proposals to Maxon Technology. As a result, we were awarded three donated machines— two are housed in the Materials Engineering Laboratories and one is housed in a Civil Engineering Laboratory. Furthermore, we also received a funding of $22,000 from Maxon Technology to sponsor five students to study the efficiency of a green material developed by the company to inhibit metal corrosion. We have also submitted a third proposal in 2017-2018 to the company to request a funding of $112,000.00 to continue testing their green corrosion inhibitor product.
4. I also worked on preparation of a proposal to develop a new ME-161 level course: "*Introduction to Composite Manufacturing Methods."*
5. I recruited 4 graduate students to continue working on the biocomposites material project.
6. I served as a co-adviser for two master's students who completed their thesis on this project during the summer 2017.

Publications and other Deliverables (students in bold)

Peer-reviewed conference papers

1. **Christopher Ostrom, Jason C. Starnes, Bradley S. Schab**. And Eltahry Elghandour "Study of Varying Fiber Orientation and Notch and Diameter in Semicircular Side-Notched Composite Laminates under Static Loading" Published in the Proceeding of the International SAMPE Symposium and Exhibition Seattle, May 22-25, 2017.
2. **Mateja Andrejic**, Faysal. Kolkailah and Eltahry Elghandour "Effects of Curing Cycle and Loading Rates on the Bearing Stress of Double Shear Composite Joints," Published in the proceedings of the International SAMPE Symposium and Exhibition Seattle, May 22-25, 2017.

3. **Juan Lazarin**, Eltahry Elghandour and Faysal Kolkailah "Optimum Design of Composite Wing Spar subjected to Bending Loads" Published in CAMX, December 11-14, 2017, Conference and Exhibits, Orange County Convention Center, Orlando Florida.
4. **Colby Hashimoto, Jinhua Lee, Van Macasaet, Jorge Phuma Reyes,** Eltahry Elghandour and Faysal Kolkailah "The Effect of Integrated Bio-Composites into Composite Structures". Published in CAMX, December 11-14, 2017, Conference and Exhibits, Orange County Convention Center, Orlando Florida.
5. **Isaac Bludell, Riley Hillike, Jalen Mano**, Eltahry Elghandour and Faysal Kolkailah "Optimum Design of Trapezoidal Corrugated Composite Structures" with. CAMX, December 11-14, 2017, Conference and Exhibits, Orange County Convention Center, Orlando Florida.
6. **Will A. McGehee**, Eltahry Elghandour and Faysal Kolkailah "Fiberglass Corrugated Sandwich Panels Under Compression Loading" Published in CAMX, December 11-14, 2017, Conference and Exhibits, Orange County Convention Center, Orlando Florida.
7. **Justin Fukada, Ariel Raley, Kinsie Ward,** Eltahry Elghandour and Faysal Kolkailah "Corrugated Composite Cylinder Under Compression Loading" Published in CAMX, December 11-14, 2017, Conference and Exhibits, Orange County Convention Center, Orlando Florida.
8. **Kevin Cuevas, Airianna Hernandez, Nathan Gherke,** Eltahry Elghandour and Faysal Kolkailah "Out-of-plane Compressive Testing on Fiberglass Corrugated Panel" Published in. CAMX, December 11-14, 2017, Conference and Exhibits, Orange County Convention Center, Orlando Florida

Peer-reviewed journal papers

1. **Ben Sweeney**, Eltahry Elghandour and Faysal Kolkailah "The Effect of Bio-Composite Materials in a Composite Structure Under Compression Loading" International Journal of Sustainable Materials and Structural Systems (IJSMSS). In progress.

Miscellaneous Presentation/Activity

1. **Eltahry Elghandour** and **Joe Vanherweg**. Two presentations at Society of the Advancement of Material and Process Engineering, SAMPE May 22-25, 2017, Seattle Washington.
2. **Eltahry Elghandour, Colby Hashimoto, Justin Fukada, and Ariel Raley** Three presentations at The Composites and Advanced Materials Expo**,** CAMX December 11-14, 2017, Orlando, Florida.
3. **Eltahry Elghandour**. Three presentation overseas at AASTMT university in Egypt February 15-25, 2018.

Student Impact

Supervision of Cal Poly M.S. student

1. Jalen Mano, *Effects of biocomposites in sandwich panels with an optimum corrugated core under compression loading*. M. S. Thesis, California State University, San Luis Obispo, CA March 2017-present).
2. Jacob Chess, *Effect of aerogel on the thermal performance of corrugated composite structures*. M. S. Thesis, California State University, San Luis Obispo, CA. March 2017-present).
3. Jorge Phuma Reyes (ME, MS. thesis project, March 2017 -present).
4. Thomas Juhl Robhrbach (ME, MS thesis research, March 2017-present).
5. Wesley Powell (Mate, MS research, Fall 2017-Winter 2018).
6. Ali Roger (ME, MS non-thesis research, Spring 2017).

Supervision of Cal Poly B.S. student

1. John Niemoller, Alden Simmer, Dallas Johnson and Alex Bartlett (ME, BS research, Winter 2017-Fall 2017)
2. Thomas Headland (ME, BS research, Fall 2016-Winter 2018).
3. Tanner Jolly, Stuart Ross (Mate, BS research, Spring 2017-present).
4. Anthony Thomas Trujillo (CE, BS research, Fall 2017-present).

5. Jose Urizar (CE, BS research, Fall 2016-Winter 2018).
6. Sean Gager (ME, BS research, Winter 2017-present).
7. Colby Hashimoto, Jinhua Lee, Van Macasaet, Riley Hillike, Will A. McGehee, Justin Fukada, Ariel Raley, Kinsie Ward, Kevin Cuevas (Aero, BS, research, Spring to Fall 2017).

Supervision of non-Cal Poly students

1. Lauren Frost, Emile Naccasha, Analise Kunkel and Daniel Svitek (HS, Research, Fall 2017-Spring 2018).
2. Austin Gasbarra, Ryan, Shomsky and Jhon Anaya (Community College, research Winter 2017-Fall 2017).

Proposals and other Leverage

Active awards during the period of support

1. **Request for Proposal for Funding from R-IDC Pool**, College. of Engineering Learn by Doing, Lead with Innovation. (PI: Eltahry Elghandour), 1/1/2017-6/29/2017: $5,400.

Title: Design of bio-composite material and for structural applications.

Aims: This paper presents the investigation of utilizing natural fibers and rice derived silica aerogels in bio-composites as a structural material for corrugated walls to be used as a green building material. Rice derived aerogels are being incorporated in this design due to their desirable structural and thermal properties

2. **Request for Proposal for Funding from R-IDC Pool,** College. of Engineering Learn by Doing, Lead with Innovation. (PI: Eltahry Elghandour), 1/1/2017-6/29/2017: $8,891

Title: Integrated bio-composites applications in industrial structures.

Aims: The main objectives of this study will be to optimize the structural design of a wall application for long term durability, ease of maintenance, low production costs, and to significantly minimize the weight of the structure without compromising structural performance such as structural stiffness. Additionally, the walls will be coated with layers of aerogels, made from recycled crop residues, and will be tested for improvements in thermal insulation properties.

3. **Maxon Technologies, LLC**. (Director: Eltahry Elghandour and PI- Mohammad Noori). March 1,2017-December 31, 2018: $25,000.

Title: An Experimental study on corrosion mitigation assessment of Maxon CRS green materials.

Aims: In this research, an experimental study will be performed on using the Maxon CRS green materials and how it penetrates in the metal through concrete using the SEM measurement. A steel rebar corrosion monitoring technique for steel reinforced concrete structures will be used to test the corrosion mitigation effectiveness of Maxon CRS, an anti-corrosive agent is proposed and designed. This technique is based on Scanning Electron Microscope (SEM) testing which will increase the accuracy of energy-dispersive X-ray spectroscopy (EDS) measurements.

4. **RSCA-RFP, Research, Scholarly and Creative Activities Grant Program of University of California**. (PI Eltahry Elghandour-Co-PI El-Badawy) 7/1/2018-6/1/2019: $ 15,891.

Title: Developing effective crack arresters to decrease crack propagation in structures subject to fatigue loading.

Aims: To develop innovative crack arresting materials (including engineered nanomaterials) and designs for improving mechanical properties and increasing fracture energy needed to prolong the life of structures subject to cyclic loading. The products of this research will provide innovative solutions and designs for fracture in structures and can be applicable in a large number of industries.

5. **NSF-Research Instrumentation (MRI) program Competition** (PI-Elghandour and Co-PI Mahadev, Lanny Griffin, Blair London, Amro El Badawy, Andrew Davol, Faysal Kolkailah and Ashraf Rahim) 9/1/2017-9/1/2020: $631,411.

Title: VIC-3D high speed digital image correlation (DIC) measurement system.

Aims: Obtain a high speed digital camera for serving inter-disciplinary research projects. ***We were nominated to submit this proposal to represent Cal Poly for NSF-MRI.***

Sthanu Mahadev, "Incorporation of bio-composite materials in structural applications", 6 WTUs.

Awardee

Sthanu Mahadev, Assistant Professor (Tenure-track), Mechanical Engineering,
smahadev@calpoly.edu

Award

6 units (6 in 2017 Summer quarter.)

Summary of Accomplishments

This document outlines an abridged summarized version of my research work associated with the Bently summer 2017 appointment. As a part of this endeavor, I was actively involved in developing a novel comprehensive mathematical framework for predicting the sectional properties and stress-strain based mechanical response in thin-walled unsymmetrical composite beam cross-sections using the fundamentals of composite material mechanics. Thin-walled anisotropic composite beams possessing open-ended cross sections are used extensively in the aeronautical/aerospace industry as primary load bearing mechanical members and as reinforcing stiffener members. Thin-walled composite beam models have been widely utilized to simulate the behavior of such engineering structural elements.

I was successful in formulating an elaborate procedure that accurately quantifies the mechanical response of such composite configurations under externally subjected hygrothermomechanical loading environment. The analytical results obtained by tuning a host of mechanical parameters was further substantiated with a Finite Element based ANSYS routine. Excellent agreement was achieved between the analytical predictions and numerical estimates. The overarching goals of this exercise were a) To provide composite material based structural designers with an effective mathematical tool that is able to serve as a viable means to generate preliminary structural behavior data and assist in performing broad parametric studies with hopes to alleviate the need to immediately resort to complex FEA analysis. b) Incorporate the research findings toward developing an advanced level composite class for Fall-2019 ME curriculum c) Develop a custom computational algorithm in C or FORTRAN that can be later complied into a ready-to-use app based problem-solver d) Systemic translation of this work into an international conference paper at the next ASME or AIAA or SAMPE conference.

One of my undergraduate students from ME 412 was involved in assisting with the numerical analysis of this work. Her efforts and learning outcomes will be extended in designing and developing a testing platform in the near future. Some of the funding provided will be utilized towards developing an experimental routine to generate test results.

Publications and other Deliverables (students in bold)

Peer-reviewed conference papers

1. Sthanu Mahadev, Wen S Chan, Melanie Lim. A Simple Analytical Modeling of Sectional Properties in Thin-walled Unsymmetrical Composite Beam Cross-Sections. SAMPE Conference 2018 (to appear).

Student Impact
Supervision of Cal Poly B.S students

1. Melanie Lim (ME, Bachelor of Science, Cal Poly, Spring 2017-Summer 2017).

Other Leverage

Successful completion of this research has built confidence in developing an experimental methodology to further validate and reinforce the potential of my previously developed mathematical model. This avenue has generated further interest from students in my ME 412 class to participate in undergraduate scholarly research. Secondly, A NSF material acquisition proposal was developed based on the successful outcomes of this project that supplemented previous research from the primary authors. Although the proposal was not accepted, it provided me further motivation to scour for other possible funding sources such as the local California based composite industries to sponsor small undergraduate projects.

NSF funded MRI grant program 2017 (unfunded)

Principal PI: Dr. Sthanu Mahadev & Dr. Wen Chan

The aim of this grant was to develop a comprehensive material characterization platform utilizing a state-of-the-art Digital Image Correlation (DIC) based full-field strain measurement system. One of my professorial goals as the PI were to make strategic efforts in seamlessly integrating this equipment with the currently existing lab equipment at Cal Poly. More importantly, this addition would advance my ability to incorporate my research into the classroom. This avenue will hope to effectively provide a broad exposure to students and expand their knowledge horizon.

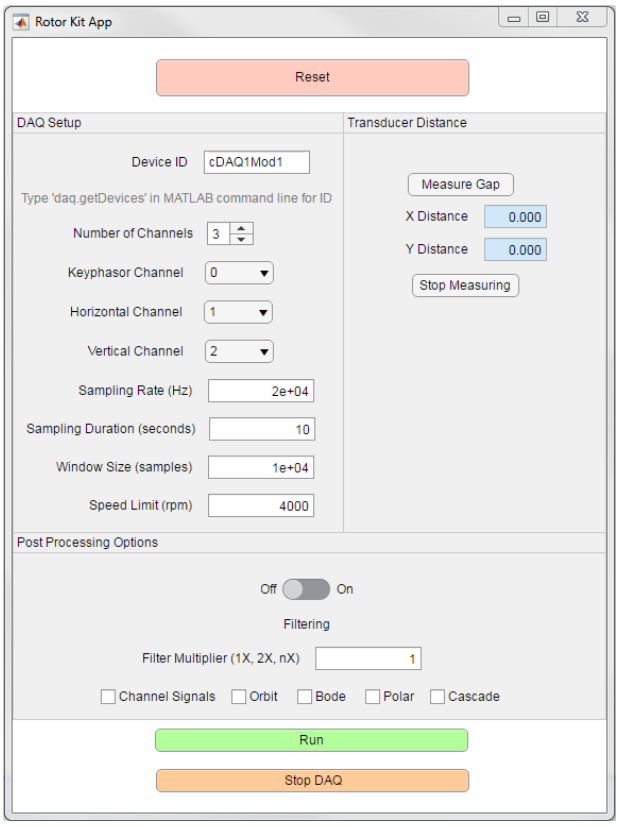
Julia Wu, "Build a data acquisition system to replace ADRE208 using MATLAB/Simulink", 7 WTUs.

Awardee
Xi Wu, Professor, Mechanical Engineering, xwu@calpoly.edu

Award
Total 7 WTUs.

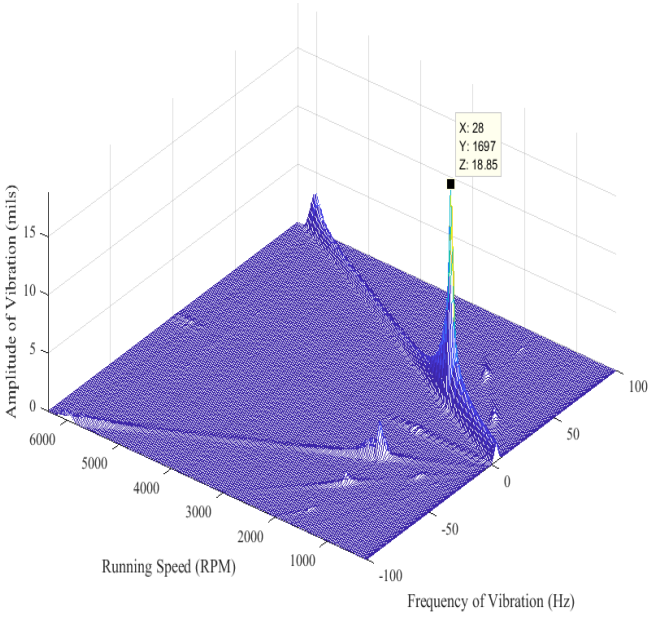
Summary of Accomplishments
During 2017-2018 academic year, our research focused on building new independent Data Acquisition Cards for Bently rotor kits in vibration lab (continuous project), developing Finite Element Analysis of rotor kits, identifying vibration signatures of planetary gears, analyzing flexible engine connecting rods and controlling a MIMO Balancing Cube. Most of our supported time was spent in the following areas and activities:

(1). New Independent Data Acquisition System for Bently Rotor Kits.



The goal of this research alternative option to the Bently Nevada DAIU and ADRE application was to be less expensive and contained as many if not more capabilities than ADRE. With some research done on the different brands of compatible DAQ cards commonly available, the National Instruments cDAQ-9174 module installed with NI 9215 cards was chosen. With the combination of MATLAB and a National Instruments data acquisition card, a signal processing program in real-time was developed and tested for health monitoring of the rotor dynamic systems. A MATLAB graphic user interface application was developed to work with the source codes in order to run the program without having to understand the codes behind it. The application designed presented the main adjustable parameters in an intuitive way and was built using the "App Designer" tool in MATLAB, which drastically cuts down on the time and effort spent on formatting and editing the physical layout of the application. The finished interface is shown in the above figure.

Compared with Bently's ADRE system, we have dramatically reduced the cost of the data acquisition system for rotor kits by using only a commercially available data acquisition card that interfaces directly with MATLAB. The real-time methods introduced in this research proved to be an efficient way of streaming and saving data from rotor dynamic tests. Experimental amplitude, phase, and speed information that is generated in real-time with the MATLAB program has its accuracy verified when compared with the results produced with the ADRE system.



The bode, polar, full spectrum, and orbit plots all agree with those displayed in the ADRE application within a small percent error and contain additional post-processing capabilities as a result of being based in the MATLAB environment. In addition, our new system can produce 3-dimensional full-spectrum cascade plots using complex FFT through MATLAB programing and filter the transducer data to nX components of rotor speed when the rotor starts up or runs down using tracking windows. We developed theoretical models of the two-disk rotor to estimate the unknown physical parameters of the system. By simulating the rotor with and without gyroscopic effects included, estimates for the stiffness, damping, eccentricity, initial phase, and initial skew values present in the system were determined. Having the different plots available from the experiment allowed for the unknown physical parameters to be determined through the theoretical models. Theoretical models provide insight into some of the physical parameters of a rotor dynamic system that are not easily determined through direct measurement. Theoretical results of two-disk rotor are converted into 3D full spectrum plots which match very well with experimental data with confidence. This new system can be applied to dynamic analysis of rotating machinery in industry.

(2). Finite Element Analysis of Rotor kits with MATLAB Codes.

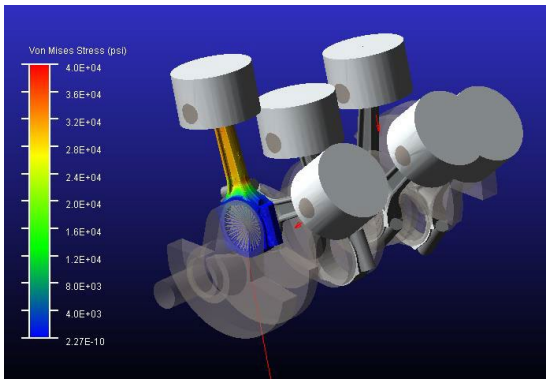
Theoretical models are formulated from the kinematic constraints to form a robust finite element model suited well for expansion. Analysis techniques for multiple degrees of freedom models with arbitrary damping are derived and demonstrated. These techniques include eigenvector and eigenvalue analysis of the complex state space equations. Furthermore, analysis techniques are developed for analyzing experimental data and comparing to theoretical models. All of the material is here to create a finite element model, compare its results to experimental results, and tune the design parameters. The sophisticated FEA codes can be easily modified to apply in active magnetic bearings with different controllers.

(3). Vibration Signatures of Planetary Gears.

We have realistically modeled 3-stage planetary gearbox of Nordex N90 using both ADAMS and FEA software Patran/Nastran. The model is created to show the vibration patterns of a healthy gearbox with rigid bodies, with a flexible body, and with a crack propagated on a particular gear in the planetary gear systems. The flexible body incorporation allows for stress analysis of different gear

teeth at different locations. Based on the practical gearbox, we carefully choose several important parameters. Comprehensive frequency-domain analysis of dynamic contact forces reveal unique vibration spectra at different speed, which were not observed before. These spectral lines comprise a substantial portion of the vibration and are closely related to the complicated nonlinear dynamics induced by the interaction between backlash and damaged teeth at different locations on different components of the transmission system. Those simulation results could serve as good references for the engineers in wind turbines.

(4). Dynamic Analysis of Flexible Connecting Rods of Engine.



This research simulated the loading and stresses experienced by connecting rods in automotive combustion engines. A dynamic rotating model of a Ford Vulcan V6 engine cranktrain assembly was created using ADAMS multibody simulation software (MBS), and loading was characterized across a range of cycle positions, engine speeds, and throttle. A detailed friction model and cylinder pressure curve were incorporated. The modal synthesis structural reduction technique for modeling flexible body behavior, implemented by linking Patran/Nastran finite element analysis (FEA) software with ADAMS, was applied to generate accurate stress results with high computational efficiency relative to traditional FEA. The modal reduction method was validated by creating a fixture and conducting an experimental compression test. At critical points, ADAMS flexible body results were compared to a static structural FE model which used equivalent boundary conditions, loading, and dynamic effects.

(5). Optimal control of a Multiple-input and Multiple-output Balancing Cube.

This research developed a multibody dynamics simulation of an actively stabilized multiple-input, multiple-output, coupled, balancing cube and the process of verifying the results by implementing the control algorithm in hardware. A non-linear simulation of the system was created in Simscape and used to develop a Linear Quadratic Gaussian control algorithm. To implement this algorithm in actual hardware, the system was first designed, manufactured, and assembled. The structure of the cube and the reaction wheels were milled from aluminum. DC brushless motors were installed into the mechanical system. In terms of electronics, a processor, orientation sensor, motor drivers, analog to digital converters, and a pulse width modulation board were assembled into the cube. Upon completion, the software to control the cube was developed using Simulink and run on a Raspberry Pi computer within the mechanism.

Other Deliverables (Graduate Students' Theses)

The papers based on the following theses from my graduate students could be published on peer-reviewed journals

Thesis 1. David Baker, "Development of a Rotordynamic Signal Processing Interface and its application on a Two-Disk Rotor Model", December, 2017.

Thesis 2. Cameron Naugle, "Advancement of Rotordynamic Topics", April, 2018.

Thesis 3. Gordan Bradaric, " Dynamic Analysis of Connecting Rods using MSC ADAMS Modal Synthesis Method for Flexible Bodies", December, 2017.

Thesis 4. Felix Haimerl, "Dynamics simulation and optimal control of a multiple-input and multiple-output balancing cube", June, 2018.
Thesis 5. Tananant Boonya-ananta, "Vibration analysis of a wind turbine multi-stage planetary gearbox incorporating a flexible body component", December, 2017.

Student Impact

Supervision of Cal Poly Graduate Students

1. Cameron Naugle (ME, MS research, Defended on April, 2018).
2. Pedro Rivera (ME, MS research, Fall 2015-present).

3. David Baker (ME, MS research, Defended on December, 2017)

4. Gordan Bradaric (ME, MS research, Defended on December, 2017)
5. Benny Morris (ME, MS research, Winter 2017-present)
6. Gregory Pellegrino (ME, MS research, Spring 2017-present)
7. Tananant Boonya-ananta (ME, MS research, Defended on December, 2017)
8. Felix Haimerl (ME, MS research, Defended on June, 2018)

9*. Defense Committee member of "Patrick Hutchinson" (July, 2018)

Proposals and other Leverage

Proposal awarded during the period of support

Proposal for Bently Nevada GE Oil & Gas Measurement & Control, GE

Bently Nevada donated SCOUT200 series, which is comprised of easy to use, small form-factor portable vibration data collectors, and system1 software. The total equipment are worthy of more than $30,000.

Andrew Davol, "Enhancing the exchange program at the Munich University of Applied Sciences", 6 WTUs.

Awardee
Andrew Davol, Professor, Mechanical Engineering, adavol@calpoly.edu

Award
6 Units, Spring 2018

Summary of Accomplishments
As part of my efforts to increase international opportunities for Cal Poly students I was interested in contributing to the expanded collaboration between Cal Poly and the Munich University of Applied Sciences (MUAS). This proposal requested release time to support a semester of teaching and collaboration at MUAS in the spring of 2018.

I taught a required aerospace engineering class in lightweight design. The final project was completed by 58 students, the majority of which were from MUAS. This offering was an experiment as it was the only section of the class offered for this semester so the MUAS students had to take the course in English if they needed it.

I also introduced an elective in single-track vehicle design. Students were given the option to build a physical prototype. Two teams of 2 took advantage of this and an additional 10 students did an individual design of a single-track vehicle. Dr. Johannes Mintzlaff of MUAS is interested in offering this class at MUAS in the future.

One area of interest for this proposal was increasing opportunities that would help students stay on track for a 4-year graduation. I was able to talk to administrators, professors and Cal Poly ME students and advocated with MUAS to offer Mechanical Component Design in English in their summer semester. This would allow ME students to return to Cal Poly with all the prerequisites for our senior project sequence.

Student Impact
Master's Exchange Program in Automotive Engineering
8. I was able to interest MUAS in the establishment of an exchange program with Cal Poly at the masters level with a focus in automotive engineering. Dr. Johannes Mintzlaff has agreed to be the contact at MUAS for this program. The program would include an internship in an automotive company where the bulk of the work for a master's thesis would be completed. Each student would have faculty representation on their thesis committee from both institutions. I was able to identify 2 groups at BMW that would like to participate in this program and I plan to identify 2 US positions this fall quarter. The proposed start of this program is Fall 2019. We would like to have 2 students from each institution participating.

Proposals and other Leverage
Active awards during the period of support
1. **MUAS Fellowship**

Summer Semester, 2018; Support for travel and housing with a small stipend to spend a semester at MUAS.