UVA

SCHOOL of ENGINEERING & APPLIED SCIENCE
Department of Mechanical and Aerospace Engineering
Rotating Machinery and Controls Laboratory

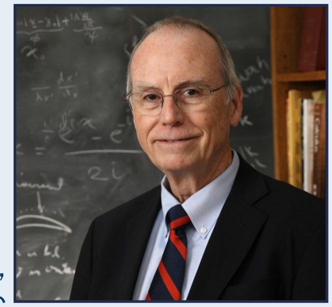
ROMAC NEWSLETTER

FALL 2019

SPECIAL POINTS OF INTEREST

- **ROMAC People**
- **A busy Summer**
- **2020 Membership Information**
- **Looking Ahead**
- **Student Research Projects**
- **ROMAC Software Update**
- **ROMAC Undergraduate Research Assistants**

From our Director



Houston Wood

The summer of 2019 might be known to ROMAC faculty, staff, and students as the busiest in memory. The ROMAC Annual Meeting was June 10-14 in Charlottesville, two weeks later was our Rotordynamic and Magnetic Bearings short course. Then just before the fall semester started in late August, we offered a newly designed short course on CFD Modeling for Industrial Machine Components.

In between those events ROMAC faculty, staff and students helped plan and some of us participated in the 2019 International Conference on Rotating Machinery, Transmission, and Controls in Beijing, China. The conference was attended by over 150 academics, researchers, students and industry personnel. The conference was in collaboration with our colleagues at the Beijing Institute of Technology. I was honored to be a keynote speaker at the conference and was in the good company of other members and friends of ROMAC. You'll see more about this on page four and five.

We also said good bye to two students who successfully defended their dissertations during the summer and have gone on to begin their careers. Michael Branagan, is working with Pioneer Motor Inc., previously a ROMAC industry member, and Benny Schwartz, has joined Pratt & Whitney, a long time ROMAC member company.

In between these events many of our students attended conferences to present their research and network with experts in their field.

You should have received your 2020 membership invoice in October. Paying your membership fee on time is important to the ongoing strength of ROMAC. We are offering the same incentive for paying on time as last year. Your invoice will reflect your on time payment discount.

If you have not yet had the opportunity, please navigate over the newly designed ROMAC website. The ROMAC reports and software are protected and available to ROMAC member company personnel only. If you have questions about access please email us.

Houston

Houston Wood, Professor
Mechanical & Aerospace Engineering
Director, Rotating Machinery & Controls Consortium & Laboratory

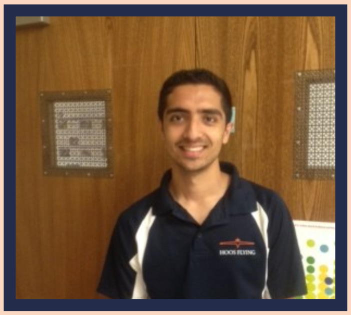
ROMAC Students Complete Their Degree

Michael Branagan, Ph.D.

A few days prior to the annual meeting in June, Michael successfully defended his dissertation entitled: "**Computational Modeling of Pad Surface Irregularities in Fluid Film Bearings"**. He is currently working with Pioneer Motor Bearings, a previous ROMAC industry member.

Benstone Schwartz, Ph.D.

In early July, Benny defended his dissertation: **"Application of Uncertainty Analysis to Tilting-Pad Journal Bearing Dynamic Coefficient Identification for Model Validation."** In August, he began his career with long time ROMAC industry member Pratt & Whitney in Hartford, CT.



Wisher Paudel, M.S.

Wisher completed his Master's degree in Mechanical and Aerospace Engineering. He is continuing his research in Seals; Seals Test Rig; Nuclear Non-proliferation and Safeguards pursuing his Ph.D.

Introducing the new

<u>ROMAC Website</u>

www.engineering.virginia.edu/ROMAC

The new ROMAC website is live and can be reached via the new web address above. Be sure to bookmark it. We will continue to add to the website so plan to check back often. Reports, ROMAC Software, ROMAC Advisory Board minutes and other member only information can be found only with permitted access. ROMAC members can gain access by having your email address added to the site. If you'd like to be added please email Lori Mohr Pedersen.

Graduate Student: Nathaniel Gibbons

Nathaniel entered UVA as a graduate student following his May 2018 graduation from Lebanon Valley College in Annville, PA. with B.S. degrees in both Physics and Mathematics. He was initially working with Professor Chris Goyne in the Aerospace Research Laboratory, (ARL).

During his first semester realizing his primary interests lie in CFD and aerodynamic measurement techniques with the support of Chris Goyne and other ROMAC faculty he joined the ROMAC Lab in January 2019. He is currently a UVA Engineering Distinguished Fellow.

Visiting Scholar: Qingfang Liu

Qingfang Liu is an associate professor at Xi'an Jiaotong University in the School of Mathematics and Statistics. In 2010 she received her Ph.D. in Computational Mathematics from the same University. Her research interests include: computational fluid dynamics, numerical methods with spectral methods and finite element methods for PDEs and multi-grid methods for PDEs.

Prof. Liu is accompanied by her daughter, Mochen Ding who is attending kindergarten in Charlottesville. Her appointment is through the end of August 2020.

ROMAC Advisory Board Update

We extend our appreciation to Christoph Hentschke, RENK Hanover, and Kris Altiero, Bechtel Plant Machinery, Inc. who have recently concluded their three-year term of service to the ROMAC Consortium through the ROMAC Advisory Board (RAB).

New members, Leonardo Ishimoto, Petrobras and Chris Zuck, Pratt & Whitney, join Phil Johnson, Daikin–Applied and Bruce Fabijonas, Kingsbury, Inc., who have completed their first year of a three-year term.

If you have something to share, a question, suggestion or concern with the RAB, please reach out via email.

ROMAC — the Summer of 2019

The Annual Meeting was held June 10-14 at the OMNI Charlottesville Hotel. ROMAC faculty, students and industry members came together to present new research, updates on continuing research projects, and to discuss and vote on upcoming research projects. Later in the month, June 24-28, members and non-members, attended the Rotordynamic and Magnetic Bearings short course. Then, August 19-23, we offered a new short course: CFD Modeling for Industrial Machine Components.

In the midst of the above events and the usual activities the summer brings to all, many of us were preparing for the Rotating Machinery Transmission and Controls Conference held in Beijing, China, July 20-21, 2019. The conference was initiated by the Rotating Machinery Joint Lab, between Beijing Institute of Technology, (BIT) National Key Lab of Vehicular Transmission, (NKLVT) and ROMAC, and sponsored by the Fluid Power Transmission and Control Institution of China.

The conference was attended by ROMAC industry members: Hunter Cloud, BRG Machinery Consulting, Christophe Hentschke, RENK Hanover, and Norbert Hölscher, recently retired from RENK Hanover. Both Hunter and Norbert joined Houston as a keynote speaker. Additional attendees from the ROMAC Lab were: Roger Fittro, Minhui He, Cori Watson-Kassa, Benny Schwartz, Xin Deng, Jeff Bennett and Lori Mohr Pedersen.

Houston Wood, Director of ROMAC giving his keynote speech.

ROMAC faculty and students addressing attendees of the ROMAC Forum

Overall, in addition to the keynote speeches, ROMAC members, faculty and students presented 23 talks. A block of time was designated to a ROMAC Forum with information on membership, research and the benefit of joining the consortium. It was attended by over 45 interested industry members, academics and students.

Participating in and attending the conference demonstrates the collaboration and opportunities that active member involvement in the ROMAC consortium offers. The conference brought together our colleagues at Beijing Institute of Technology.

Including the list below of recent visiting scholars to the ROMAC Lab from BIT as well as other universities in China.

Tianwei Lai, *(Sep. 2014—Sep. 2015)*
Xi'an Jiaotong University
Refrigeration and Cryogenic Engineering

Yu Yuan, (Feb. 2015—Jan. 2016)
Beijing University of Chemical Technology
College of Mechanical & Electrical Engineering

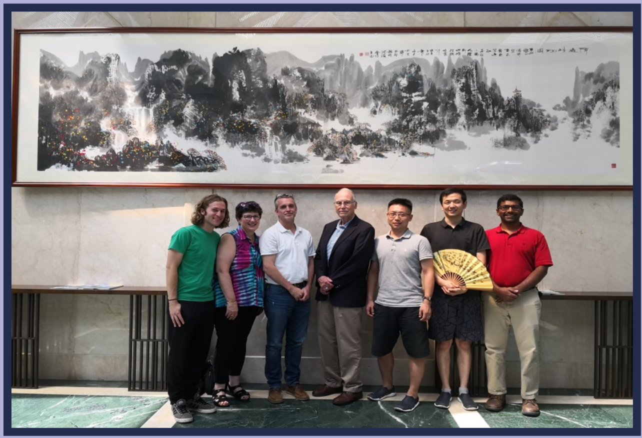
Fengxia Lu, (*Nov. 2015—Oct. 2016)*
Nanjing University of Aeronautics & Astronautics
College of Mechanical and Electrical Engineering

Wei Wei, *(Jun. 2014—Jun. 2015)*
Beijing Institute of Technology
Dept. of Vehicle Engineering

Cheng Liu, (*Dec. 2015—Dec. 2017)*
Beijing Institute of Technology
Dept. of Vehicle Engineering

Hui Liu, (Mar. 2017—Mar. 2018)
Beijing Institute of Technology
Dept. of Vehicle Engineering

The conference begins with an opening ceremony.



Some of the ROMAC lab group, with Cheng Liu and Zhifang Ke in the lobby of the Friendship Hotel

The ROMAC faculty, students and staff express our sincere gratitude and appreciation to our BIT colleagues for hosting us for the conference., especially, Cheng Liu and Zhifang Ke .

Looking ahead

2020 ROMAC Annual Meeting

June 8—12

OMNI Charlottesville Hotel

2020 ROMAC Consortium Membership Fees
are due March 31, 2020
invoices went out in October

2020 ROMAC Membership Fees

Standard Membership

- Initiation Fee: $28,500
- Annual Membership Fee: $30,000
- $28,500 if payment is received on time (by 3/31/2020)
- Two (2) Company representatives may attend the ROMAC Annual Meeting at no cost.
- Additional attendees may participate for nominal fee
- Company representative is eligible to serve on the ROMAC Advisory Board

*Small & Medium-sized Enterprise (SME) Membership (< 250 employees)

- Initiation Fee: $10,000
- Annual Membership Fee: $21,000
- $20,000 if payment is received on time (by 3/31/2020)
- One (1) Company representatives may attend the ROMAC Annual Meeting at no cost
- Additional attendees may participate for a nominal fee
- Eligible to serve on the ROMAC Advisory Board
- Proportional Research Project Voting

*Small Business Membership (< 50 employees)

- Initiation Fee: $5,000
- Membership Fee: $14,250
- $13,500 if payment is received on time (by 3/31/2020)
- One (1) Company representative may attend the ROMAC Annual Meeting at no cost
- Additional attendees may participate for a nominal fee
- Not eligible for membership on the ROMAC Advisory Board
- Proportional Research Project Voting

Academic Educational Membership

- Membership Fee: $2,500/semester
- Access and use of RotorLab+ software for Educational purposes
- Representatives may attend the ROMAC Annual Meeting for a nominal fee
- Not eligible for membership on the ROMAC Advisory Board or in Research Project Voting

If you would like additional information regarding membership under these guidelines contact us:

(434) 924-3292 | romac@virginia.edu | ROMAC Website

ROMAC

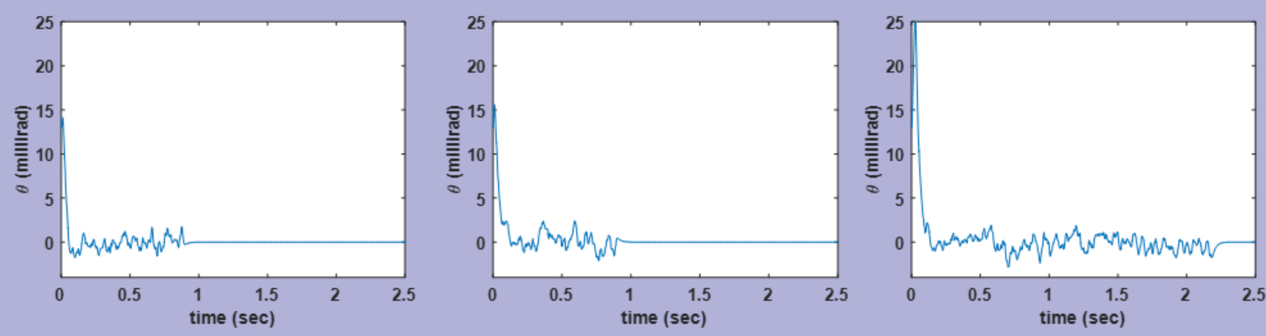
Graduate Student Research Projects

Reinforcement Learning for Model-Free Output Feedback Optimal Control

Student: Syed Ali Asad Rizvi
Expected Degree: Electrical Engineering, Ph.D. Dec. 2019

This research focuses on the design of model-free optimal control algorithms based on the reinforcement learning theory of artificial intelligence. Applications involving large modeling uncertainties such as magnetic bearings can benefit from these control algorithms as the requirement of the perfectly known models is obviated in these techniques.

Recently, we have extended our designs to incorporate control loop delays arising in remotely controlled offshore applications. A delay compensated Q-learning algorithm has been developed that requires neither the knowledge of the system dynamics nor the exact knowledge of the time delays. Convergence to the optimal control parameters is achieved based on the real-time data. This work has been accepted for publication and presentation in the premiere *IEEE Conference on Decision and Control (CDC)* to be held in Nice, France in December this year.



Some results for the AMB supported balance beam application are presented below.

It can be seen that the Q-learning algorithm is able to handle different amounts of delays and maintain the closed-loop system stability.

The design is being further extended to the case of output feedback, in which the requirement of full state measurement is also obviated. These new results will be published in the following upcoming book chapter,

S. A. A. Rizvi, Y. Wei and Z. Lin, "Reinforcement learning for optimal adaptive control of time delay systems," in *Handbook on Reinforcement Learning and Control*. D. H. Cansever, F. L. Lewis and Y. Wan, Eds. Springer*, to be published in 2020.*

Validation of Smooth Seal Models Using ASME Standard V&V-20

Student: Madeline Collins
Expected Degree: MAE M.S. 2020

This project will introduce an emerging field of research called validation and verification (V&V) to rotating machinery component modeling. V&V aims to develop mathematical methods for quantifying the reliability of computational models. This development will improve ROMAC modeling capabilities and quantify the codes' reliability.

Traditionally, experimental data is required to properly validate software capabilities. Rotordynamic measurements require high precision and costly instrumentation; therefore, little experimental data is available, and experimental uncertainties are often large and unknown. The scarcity of data introduces a "small sample" statistics problem. To fill this data gap, ROMAC has recently begun to use CFX, a commercial computational fluid dynamics (CFD) simulations, as a supplementary resource for validation. CFD provides the opportunity to software data for nearly any set of physical conditions. Unfortunately, ANSYS simulations can be time-consuming, so our ROMAC software developers must select a finite set of CFD simulations for model validation. Computational simulations, whether in ANSYS or ROMAC codes, introduce numerical, user-input, and model error. When validating against an experiment, the experiment itself introduces experimental error. Uncertainties are estimates of error or deviation from truth.

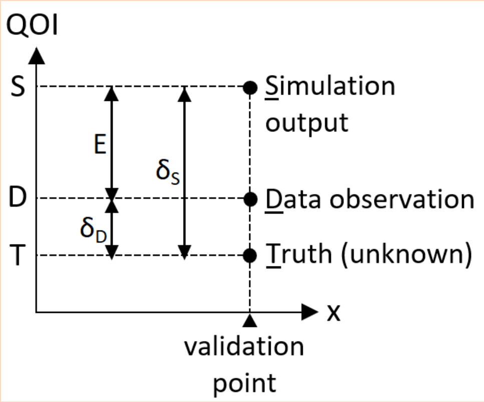


Figure 1: Visualization of Error Sources in Validation: QOI=Quantity of Interest, δ=error (deviation from truth), E=comparison error (difference between experiment and simulation)

The focus of this research is to build a foundation for quantifying these uncertainties. Future students in ROMAC will apply this method to existing and future ROMAC codes. As this validation process develops and improves, ROMAC software will produce more accurate and statistically reliable rotordynamic predictions for engineering design and analysis. Accurate prediction enables engineers to prevent machine failure and downtime thus saving money and improving safety. Knowledge of model uncertainty enables engineers to design machinery closer to operating limits and thus achieving higher performance and efficiencies.

This research demonstrates the methods of validating and quantifying uncertainty, based on ASME Standard V&V-20, for a CFD model and a ROMAC code. The amount of uncertainty contributed by each source of uncertainty will inform the code developer of ways to improve the code accuracy. This method is demonstrated on a simple case: a smooth, incompressible seal, but is broadly applicable to all of the numerical methods developed at ROMAC.

Annular Seal Modeling in Two Dimensions

Student: Neal Morgan
Expected Degree: MAE Ph.D. 2020

Annular pressure seals are used in turbomachinery to reduce the flow of working fluid across a pressure differential. The annular seal is created through the application of a reduced radial clearance over an axial length. This region is sometimes augmented by additional features that cause the working fluid to expand and contract, or be pumped against the pressure gradient. The primary performance characteristics of an annular seal are leakage, or supported pressure differential, power loss, and rotordynamic stiffness and damping coefficients. The rotordynamic stiffnesses of the seal occur due to the same converging/diverging wedge of working fluid that occurs in a journal bearing, though typically with less magnitude due to larger radial clearance. Of particular interest is the seal's tendency to produce cross-coupled stiffness forces that can be destabilizing to a system. The impact of annular pressure seals on the efficiency and safety of a turbomachinery system requires sufficiently accurate analysis.

Experimental testing of annular seals is expensive and published results are sparse. CFD results for annular seals are becoming more common in the literature, however, CFD techniques require considerable computational resources, time, and user expertise to obtain accurate rotordynamic forces and coefficients. These costs drive many industries and researchers to use bulk-flow methods instead. Bulk-flow analysis methods have been used to model thin film lubricants and seals since the 1960's. The bulk-flow method relies on a thin film approximation, empirical factors to describe shear stresses, and an assumption of small circular orbit eccentricity. The method has been improved from one control volume to two and three control volumes over time, but many weaknesses are still maintained.

The goal of this work is to develop a two-dimensional seal code that maintains full CFD accuracy in the radial-axial directions while applying the perturbation assumptions of bulk flow to reduce the size of the computational domain. This will avoid the assumptions in bulk-flow related to the radial averaging of flow and the simplification of shear stress modeling to be dependent on friction factors. Additionally, once the numerical method is proven, it can be expanded to include various turbulence models and seal geometry conditions. This method will benefit seal designers with an analysis tool that will balance the accuracy and computational requirements of CFD and bulk flow methods and enable more inclusive optimization and experimental design studies to be performed. Additionally, the training necessary to use the new code should be on the order of the training needed for bulk flow methods, much less demanding than full commercial CFD software.

Trade-offs Between Emissions, Cost and Resilience in Load-balancing Technologies Supporting Deep Deployment of Intermittent Renewable Generation

Student: Jeff Bennett
Expected Degree: Civil Engineering, Ph.D. 2020

Wind and solar power are currently the least expensive forms of new power generation in many parts of the world. Their intermittent nature, however, requires technical innovation before the electric grid can operate with high levels of deployment. In addition to reduced electricity costs, high deployment of solar and wind power is necessary to limit climate change. The two approaches for load-balancing intermittent renewables are fast-acting power plants and energy storage. Existing power plants cannot change power output at a rate suitable for load-balancing, and battery-based energy storage is not currently affordable at the grid scale. I am analyzing three emerging technologies that could enable the deployment of intermittent renewables: supercritical carbon dioxide power cycles (sCO_2), distributed electric grids, and isothermal compressed air energy storage (ICAES), technologies that could be deployed independently or in tandem. sCO_2 cycles offer efficiencies greater than 50% and have compact machinery making them of interest for fast response. Distributed electric grids are expected to be more resilient to severe weather and may be well-suited to wind turbines and solar photovoltaics which are inherently distributed, requiring large areas of land. ICAES is a type of energy storage that is expected to have high round-trip efficiencies, is constructed with environmentally benign materials and does not require the use of fossil fuels for operation. It is understood that energy technologies are not selected for technical feasibility alone, thus the proposed work utilizes a systems perspective to interpret results, considering environmental impact, cost, and grid resilience. To date, the evaluation of sCO_2 cycles is complete, and preliminary results generated for the use of distributed electric grids. To evaluate sCO_2 cycles, a characteristic-based transient model was developed to evaluate the impact of machinery ramp rates, minimum part loads, and cycle efficiencies (Figure 1). The results suggest that under high deployment of solar power, sCO_2 cycles and steam combined cycle systems with ramp rates greater than 5.75%/min can balance load and provide comparable levelized costs of electricity.

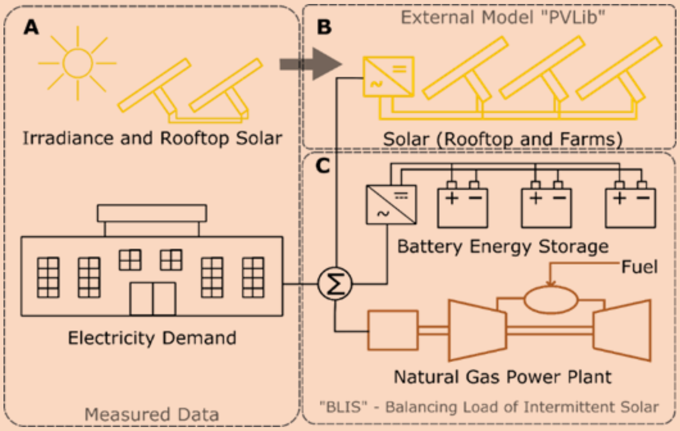


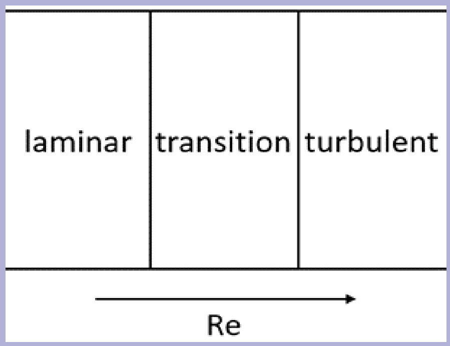
Figure 1: To compare power plant technologies, A) Measured data from UVA, B) Solar generation modeled using PVLib, and C) BLIS, a mathematical model developed here, were combined

Modeling Second Derivative of Kinetic Energy Turbulence Boundary Conditions for Sector Pad Thrust Bearings

Student: Xin Deng
Expected Degree: MAE Ph.D. 2021

The zero equation turbulence model is currently widely used by bearing FE codes. However, one equation turbulence models have better accuracy and adaptability than zero equation turbulence as the zero equation turbulence model is an algebraic approximation. Because of increased computer capabilities, the application of one and two equation turbulence models in FE codes is now feasible.

The inevitable weakness of the current zero equation turbulence model used in FEA bearing codes is that it uses two arbitrary thresholds to control the boundaries for laminar and turbulent flow, shown in Fig 1. As shown in the Fig 1, the two vertical lines represent the two thresholds, and there are three situations for the flow pattern: if the maximum Reynolds number is smaller than the boundary between laminar and transition, the flow is all laminar; if the minimum Reynolds number is larger than the boundary between the transition and turbulent regions, all of the flow is modeled as turbulent; if the maximum and minimum Reynolds number are within the two thresholds, the flow is in the transition region. The problem with these assumptions is that the exact values of those two thresholds numbers are not known in advance. Simply guessing these two thresholds numbers would therefore result in significant errors.



Figure– Diagram for two thresholds for controlling laminar and turbulent flow

In recent studies, it has been found that one equation turbulence model can be applied to both laminar flow and low Reynolds number turbulent flow. This discovery coupled with the shortcomings of the zero-equation turbulence model with the two threshold numbers, creates the potential advantage to replace the zero equation turbulence model with a one equation turbulence model. This would remove the requirement of the two thresholds numbers and is the focus of this study.

New Thrust Bearing Modeling Tools: ThrustX

Student: Xin Deng
Expected Degree: MAE Ph.D. 2021

The focus of this project is on developing a new fluid film thrust bearing code that performs comprehensive Thermo-elasto-hydrodynamic (TEHD) analysis. Like the current ROMAC code for thrust bearings (THRUST), the lubricant would be incompressible, and the operation would be steady state. However, this new code will address the weaknesses of THRUST in areas including turbulence modeling and numerical robustness. It will also expand the capabilities to model some geometries that cannot be modeled by THRUST. Moreover, this new code will be made flexible enough to allow future improvement of various theoretical models, for example, groove mixing and direct lubrication. To achieve all these goals, modifying the existing THRUST code was determined not to be cost effective. A better approach is to develop a new analytical software tool utilizing advanced techniques only available in recent years.

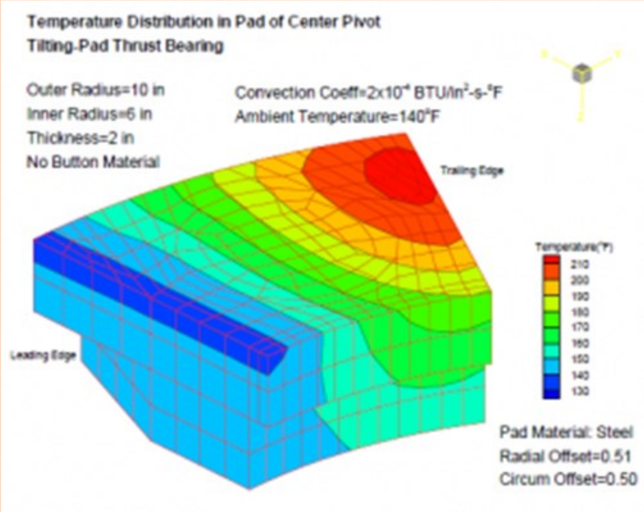


Figure – Diagram for temperature distribution in pad of center pivot in THRUST

The solution of Reynolds equation has been finished. The solution of one equation turbulence model is currently being developed. To finish the coding of this part, the general process of FEA modeling of thrust bearings, including FEA equations and boundary conditions, needed to be achieved. Starting from a flat pad case, a preliminary code is nearly completed, and the boundary condition for the trailing edge is the current focus.

Two Dimensional Multi-Isotope Separation in a Gas Centrifuge Using Finite Element Analysis

Student: Wisher Paudel
Expected Degree: MAE Ph.D. 2022

A finite element model of a gas centrifuge is developed to compute the optimal multi-isotope separation. The mass flow field generated using Onsager's equation without the pancake approximation is used as an input to the diffusion equation for each isotope in the initial form of partial differential equations (PDE). The PDEs are reduced to their weak forms and the resulting integrals evaluated using gauss quadrature. The solutions obtained can provide a holistic view of isotopic diffusion inside the centrifuge and the ability to quantify the molecular fraction of various uranium isotopes at a given radial and axial location for the certain initial and operating conditions. There are no current numerical models in literature that calculate the multi-isotopic diffusion inside a gas centrifuge. The findings of this work, therefore, would not only be significant for the applications of nuclear non-proliferation but also a great analytic tool for the nuclear scientific community.

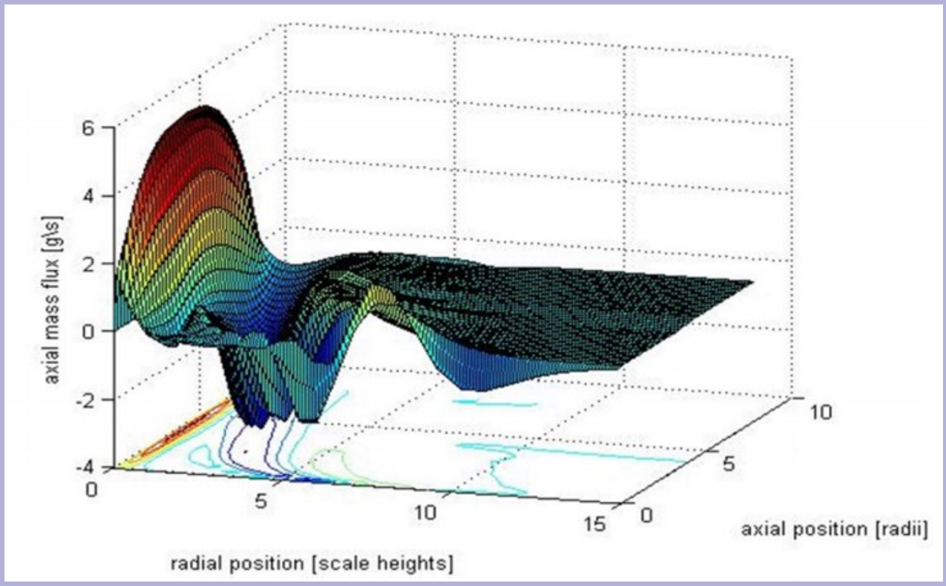


Figure: Axial mass flux of the cross-section of the Iguaçu centrifuge that is used as input to the multi-isotope diffusion code (Thomas 2019).

Fluid Film Bearing Test Rig

Student: Pedro Herrera
Expected Degree: MAE Ph.D. 2023

The objective of the Fluid Film Bearing Test Rig is to build a test rig to experimentally determine the dynamic coefficients (stiffness and damping) of a fluid film bearing with an acceptable (~<20% up to 500 Hz) coefficient uncertainty level.

Based on the design and uncertainty analysis studies performed by Benstone Schwartz, detailed drawings, part/component suppliers, costs and a complete bill of materials is in the process of being developed, in anticipation of component purchasing and part manufacturing scheduled to commence during the Spring semester of 2020.

In addition to the baseline design (refer to the Figure below), a slight variation of the test rig design is being compared, which would eliminate the need for the use of a gearbox in the drive system. Elimination of the gearbox would simplify the lubrication system requirements, greatly reduce the required facilities related work as well as potentially reduce the total test rig costs and commissioning time.

Technical and economic impacts of the 2 variations are presently being reviewed before beginning the procurement process. The main focus is to have two parallel options which meet the desired bearing coefficient identification specifications, such that the total test rig costs and build/commissioning time can be minimized.

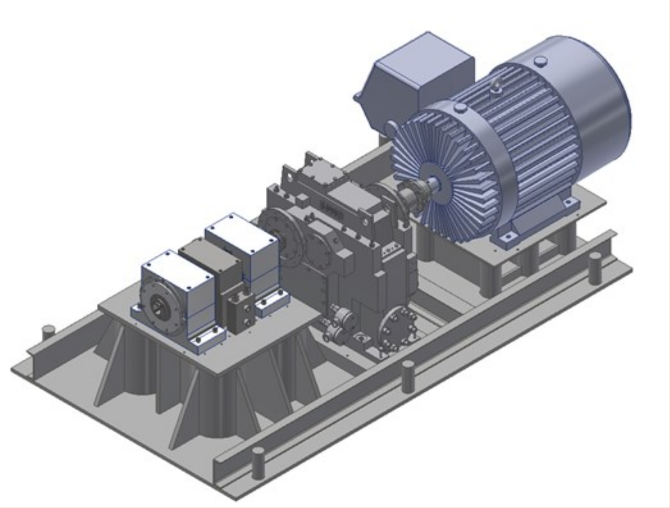


Figure: Existing design for the fluid-film bearing test rig (2019)

Labyrinth Seal Flow Field Analysis for Improvements in Bulk Flow Code Predictions

Student: Nathaniel Gibbons
Expected Degree: MAE Ph.D. 2023

Bulk flow codes are often the analysis method of choice over experimental or computational fluid dynamics (CFD) methods because of their ease of use and fast computation time. Existing labyrinth seal bulk flow codes use constant or linear values for the fluid film thickness and display inaccuracies in their prediction of velocity and pressure profiles and rotordynamic coefficients. In this project, we seek to implement an effective film thickness definition that more closely matches the physical fluid behavior into a new bulk flow code to improve these predictions.

Using ANSYS CFX, a series of simulations were run for an axisymmetric single groove sector of a liquid labyrinth seal to characterize the effective film thickness under a range of operating conditions. The effects of pressure differential, rotor speed, and inlet circumferential velocity on the maximum film thickness were studied and compared to results from the literature. This indicated a need for a more comprehensive investigation on the behavior of the effective film thickness for different operational parameters and geometries. Streamlines were used to extract an effective film thickness for each simulation, as shown in Figure 1. A modified set of bulk flow governing equations was developed, and a preliminary bulk flow code that implements these equations and the CFD-derived effective film thickness was written. Initial results from this code indicate a far better ability to match the static pressure and velocity profiles in a single groove when the effective film thickness is implemented (see Figure 2 for a sample comparison). Current work seeks to extend this comparison to the prediction of rotordynamic coefficients for this single groove case.

Future work will move towards the development of an effective film thickness model that can be implemented in a bulk flow code without the need for an initial CFD simulation. An experimental investigation will employ particle image velocimetry (PIV) for validation of the effective film thickness models. Ultimately, this work will lead to the development of new ROMAC liquid and gas labyrinth seal bulk flow codes, Seal5 and Laby5, that utilize the new effective film thickness theory.

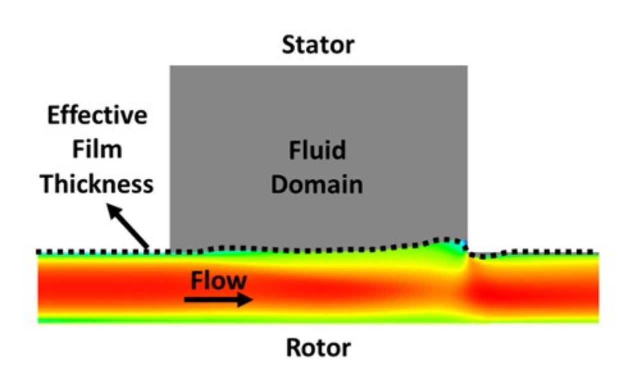


Figure 1. Extraction of effective film thickness from CFD results using streamlines.

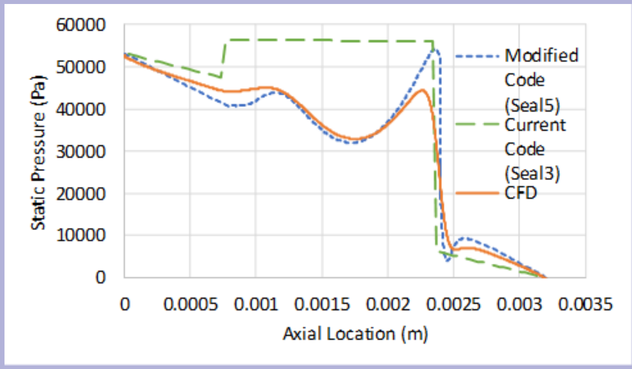


Figure 2. Static pressure profile prediction comparison for a single groove liquid labyrinth seal case.

ROMAC Software

Fall 2019 Software update:

RotorLab+ v4.4 – The next release of RotorLab+ is presently in the testing phase with a plan to be released before the end of the year. This latest version (v4.4) will contain the following updates…

- Bug fixes and minor interface improvements for Maxbrg.
- Bug fixes for Rostb and Forstab's use of linked component bearings.
- Plotting improved for mode tracking in Rotstb.
- Bugfixes for handling mass distribution of overlapping geometry disks. RotorLab+ now warns the user when geometry disks overlap.
- Re-wording of Disk component definition labels and Tilting Pad Radial Bearing component input labels, and SQFdamp setup labels for clarity.
- Bug fix for SQFDamp saving inputs.

Ongoing plans for future releases:

- RotorSol inclusion into Rotorlab+ :
    - Initial switch of Lateral modes should be transparent to end user. Validation and implementation of the solver is in process. (EST by Annual Meeting 2020)
    - Axial and Torsional modes will be included by year end 2020
- SmoothSeal, Seal4, Laby4 are in validation testing for inclusion into upcoming RotorLab+ versions.

For questions about RotorLab+ or any ROMAC software visit our website or contact us at romac@virginia.edu.

ROMAC Undergraduate Research Initiative

Given the success of ROMAC's undergraduate student researchers over the last three years, we are excited to announce an extended undergraduate research program at ROMAC for the 2019-2020 academic year. The goal of this program is to bring more value to the consortium by utilizing UVa's exceptional undergraduate students to extend the research conducted at ROMAC and the diversity of our research projects. We also hope this will help us recruit students into the field of rotating machinery for both ROMAC and industry.


Hannah Boyles


Aviv Gigi


Emily Hubbard


Landry Myers


Joe Orrico


Riley Roe


Pascale Starosta


Troy Meuer


Jimmy Smith


Tryston Raecke

Evaluation of CFD for Centrifugal Compressor Rotordynamics

Student: Pascale Starosta
Expected Degree: BS Mechanical Engineering, minor in German May 2021

Recent experimental work by Song et al. (2019) shows that as much as half the aerodynamic cross-coupling in a centrifugal compressor stage is contributed by the gap between the shroud and the housing rather than the labyrinth seal. To investigate this, the experimental setup has been recreated in ANSYS CFX and the rotordynamic coefficients will be calculated numerically and validated against the experimental results.

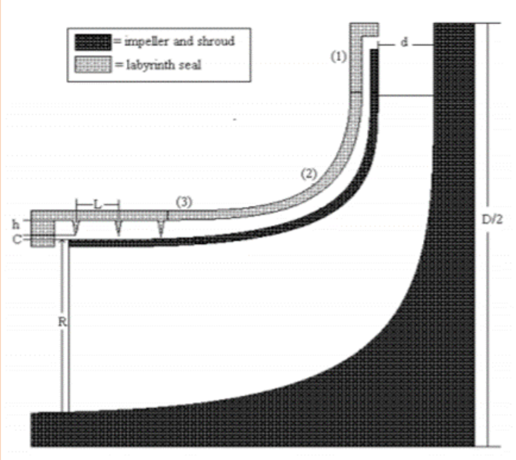


Figure: Numerical impeller model considered in analysis.

Shroud Surface Texturing to Improve Compressor Stage Efficiency and Cross-Coupling

Student: Pascale Starosta
Expected Degree: BS Mechanical Engineering, minor in German May 2021

Most research on centrifugal compressor stage rotordynamics focuses on the seal's effect on the aerodynamic cross-coupling. This project researches the effects of surface texturing of the shroud-housing gap on reduced vibration and improved efficiency. Manufacturing of these surface textures is made economical with additive manufacturing.

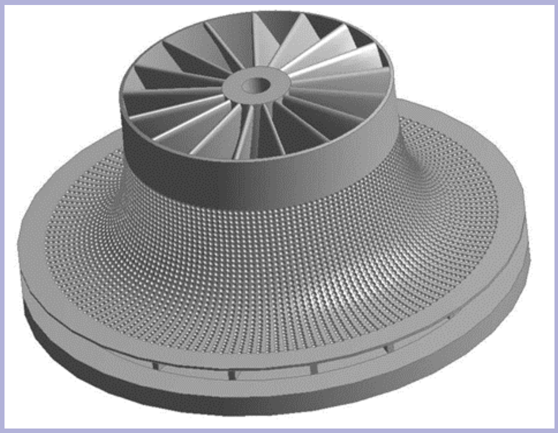


Figure: Potential surface textured impeller shroud

Influence of Inertia on Rotordynamic Coefficients of Water Lubricated Sleeve Bearings with High Ambient Pressure

Student: Emily Hubbard
Expected Degree: BS Mechanical Engineering May 2021

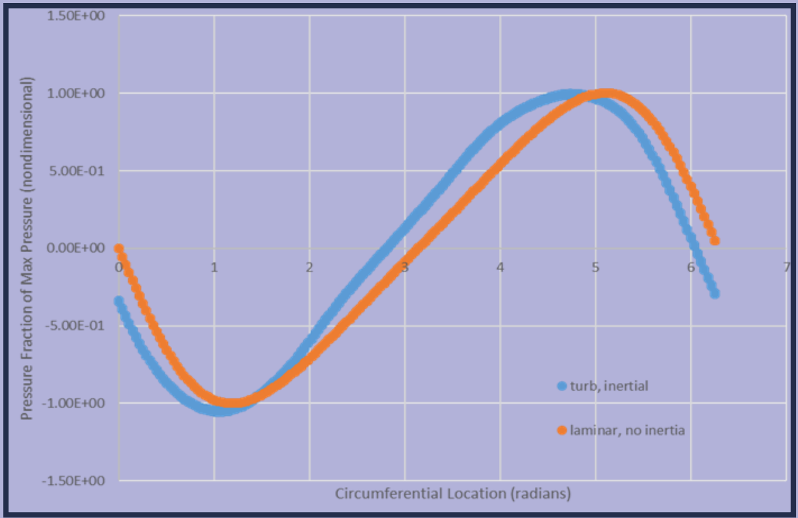


Figure: Pressure profile with and without inertia

Initial research into water lubricated sleeve bearings with high ambient pressure (2π film) reveals that inertia produces a non-skew symmetric pressure film that results in load position above the x-axis. The goal of this research is to understand how this affects the bearing's rotordynamic coefficients and produce CFD data to validate a new sleeve bearing code.

Assessing Bearing Pockets, Scratches and Textures Impact on Pressure Solution

Student: Jimmy Smith
Expected Degree: BS Aerospace Engineering, minor in Astronomy May 2021

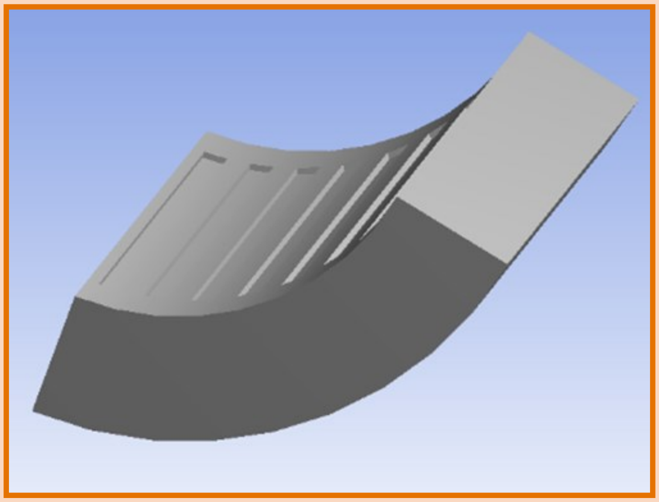


Figure: Potential surface textured bearing pad

Initial work has shown that adding surface textures to the bearing pads can significantly increase the bearing's load capacity. However, the right choice of texture is essential to this as many textures will actually decrease the bearing load capacity. This work will first focus on adding grooves to the bearing surface as this is easy to machine. We will determine what fluid dynamics cause surface texture variation in performance and optimize the textures.

Comparison of Turbulence Model Selection for Dry Gas Seal CFD

Student: Landry Myers
Expected Degree: BS Aerospace Engineering, minor in Engineering Business May 2021

Dry gas seals are used in compressors and turbines as end seals due to their ability to sustain a large pressure drop. A recent review of turbulence model selection reveals that different turbulence models are preferred at Reynolds numbers above and below 1600. Unfortunately, dry gas seals operate at Reynolds numbers of 1000-10000 because of the variable density, surface speed and film thickness. The goal of this work is to extend the turbulence modeling theory of fluid film bearing and non-contacting annular seals to dry gas seals.

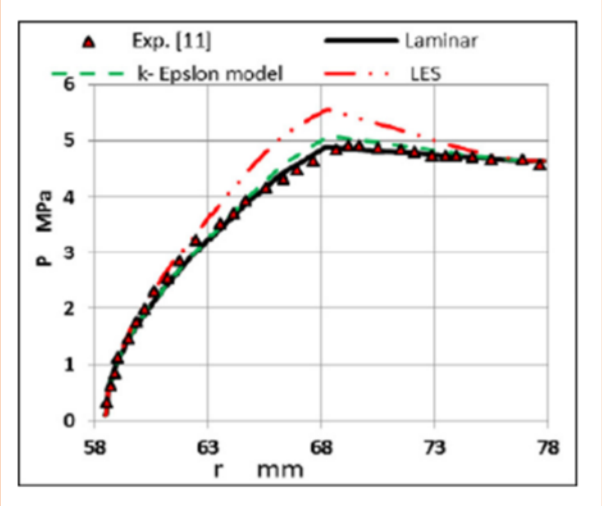


Figure: Dry gas seal turbulence comparison (Shahin 2013)

Comparing Analytical Models, SQFDamp, CFD, and Experiments of Squeeze Film Dampers

Student: Riley Roe
Expected Degree: BS Mechanical Engineering, minor in Material Science May 2021

Squeeze film dampers are used in a variety of rotating machinery to add damping to the system. There are many ways to analyze a squeeze film damper including analytical models, ROMAC codes, and CFD. This project compares all of these options with experimental data to provide insight into future code development needs.

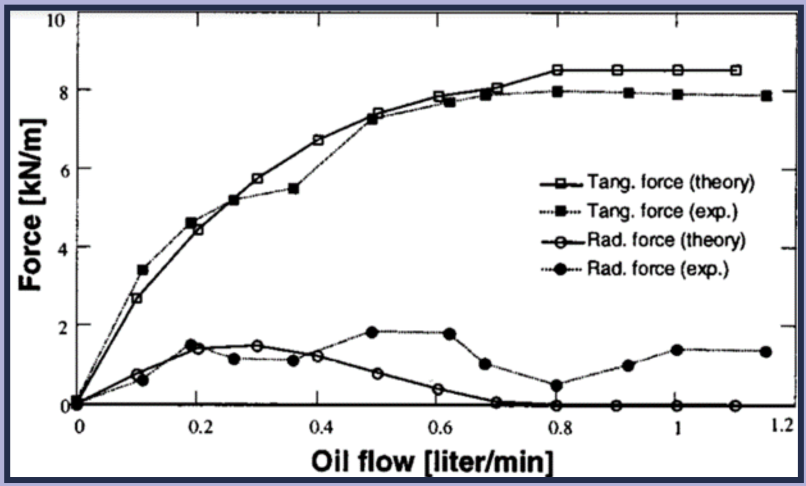


Figure: Squeeze film damper forces from experiment (Diaz and Sand Andres 2001)

Numerical Experiments on Journal Bearing Hot-Oil Carry-Over

Student: Joseph Orrico
Expected Degree: BS Aerospace Engineering May 2022

The goal of this work is to determine the hot-oil carry-over factor as a function of operating conditions and supply geometry. This hot-oil carry-over function will be implemented in MAXBRG+ to improve the thermal modeling of the code. Initial results also indicated an interesting phenomenon: that hot oil does not recirculate in the groove, but does cool down significantly due to the conduction with the cold oil in the groove. This finding will aid the development of a new thermal and multiphase bearing modeling code.

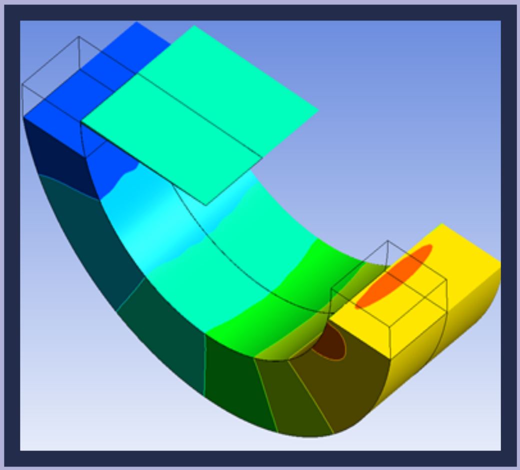


Figure: CFD Results of thermal profile on centerline.

Investigating Streamlets in Cavitated Region and their Impact on Bearing Temperature

Student: Tryston Raecke
Expected Degree: BS Mechanical Engineering and Astronomy-Physics, minor in Architecture May 2021

Considering a single pad of a bearing with a convergence and divergence film, when do multiple streamlets occur and when is it just one large streamlet. This is the first step in understanding how cavitation and starvation affect bearing temperature, which is an operational limit of the bearing and limits bearing speed and thereby machine efficiency.

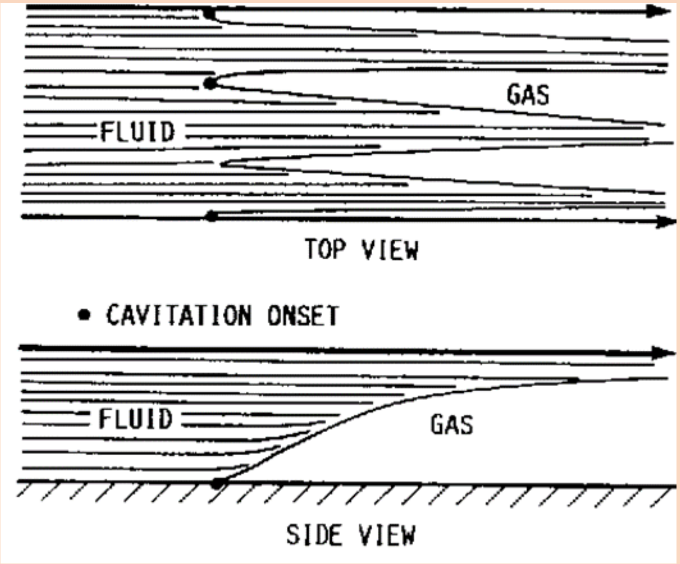


Figure: Hypothesized streamlets in cavitated region (STLE 1988)

Genetic Algorithms to Improve Speed of ROMAC Bearing Codes and CFD Modeling

Student: Aviv Gigi
Expected Degree: BS Aerospace Engineering May 2021

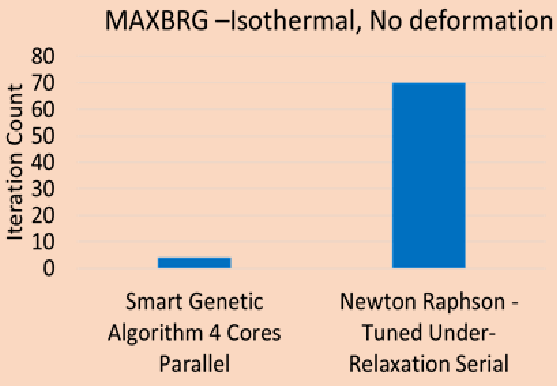


Figure: Initial results comparing computational time of genetical algorithm vs. Newton-Raphson method (Gates 2019)

Because CFD and bearing codes assume a film shape and obtain a force on the rotor, (with the known quantity in the bearing being the load, not the film shape),1 an iteration must occur to solve for the loaded position of the rotor. There are many ways to do this iteration such as Newton-Raphson, response surface mapping, the genetic algorithm, etc. The Newton-Raphson method is the standard approach used, but in our initial work, we found that genetic algorithms can be more than 10x faster due to their ability to take advantage of parallel computing. This work will investigate the algorithms for FSI in the most efficient way by implementing them in CFD and determining what works the best.

CFD Analysis of Centrifugal Pump Stage

Student: Hannah Boyles
Expected Degrees: BS Aerospace Engineering, minor in Astronomy May 2022

This work extends on Daniel Baun's 2002 ROMAC dissertation by redoing the CFD analysis with 2019 computational capacity. One main interest is understanding how turbulence model selection affects the rotordynamic performance predictions.

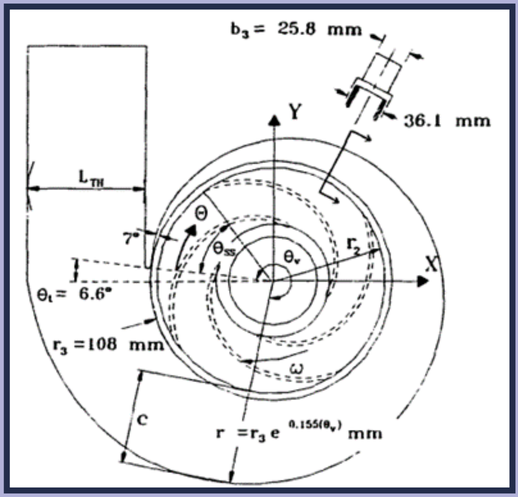


Figure: centrifugal pump model (Baun 2002)

V-Grooved Sleeve Bearings for Improved Rotordynamic Performance under High Ambient Pressure

Students: Jimmy Smith and Emily Hubbard
Expected Degrees: BS Aerospace Engineering, minor in Astronomy May 2021 and BS Mechanical Engineering May 2021, respectively

Initial work on sleeve bearings under high ambient pressure demonstrates that they have attitude angles greater than 90 degrees. This is detrimental to the rotordynamic performance of the bearing. A concept V-grooved sleeve bearing has been designed that reduces the attitude angle in this operation significantly.

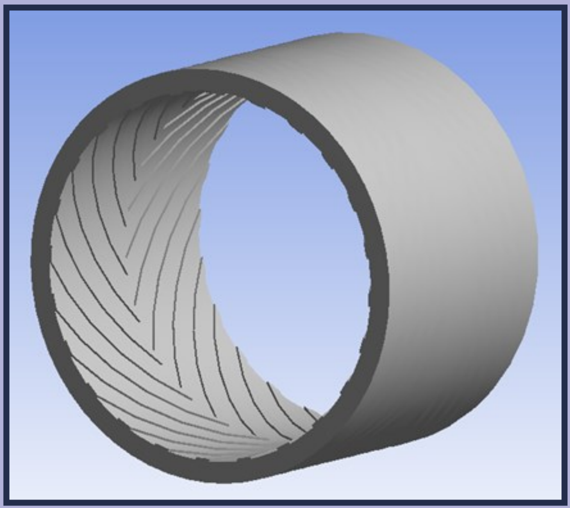


Figure: Concept V-grooved sleeve bearing

Development of Generalized Matlab/dSpace Architecture for Magnetic Bearing Controls

Student: Troy Meurer
Expected Degree: BS Mechanical Engineering May 2021

Previous ROMAC magnetic bearing control designs have primarily been implemented via one-off Assembly language or C/C++ coding. As computer processing speed and software capabilities have continued to advance, graphical-based programming has become a practical alternative. dSpace is a hardware/software real-time control system platform which ties directly into the Matlab/Simulink environment, enabling the control design and hardware implementation processes to be substantially integrated. Based on this hardware/software platform, a generalized control architecture is being developed which will be able to be more rapidly implemented on multiple, diverse applications.

Figure: dSpace and Matlab/Simulink control hardware/software architecture

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