ROMAC NEWSLETTER FALL 2021

WHAT'S INSIDE

- Letter from our Director
- 2022 Membership Fees
- Research Projects
    - Grad Students
    - Undergrad Students
- ROMAC Software Update and Announcements

IMPORTANT DATES

- March 15, 2022

  ROMAC Membership Fee Due for on time Incentive

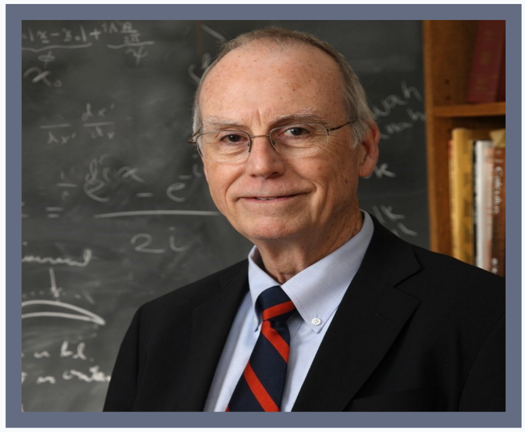
- June 20—24, 2022

  ROMAC Annual Meeting

  at the Charlottesville OMNI

University of Virginia
ENGINEERING
Department of Mechanical and Aerospace Engineering
Rotating Machinery and Controls Laboratory

From our Director



Houston Wood
Director of ROMAC

UVA students, faculty and staff arrived back on Grounds for the Fall 2021 semester. The COVID 19 pandemic continues to affect daily activity, primarily regarding vaccination status and the need to wear masks in buildings and when in the presence of others. We are meeting in person weekly, some are coming in everyday, while others are choosing to work a more hybrid version, splitting their time between in office and remote work. A bit of normalcy has been good for all of us. The University continues to monitor the status of the pandemic and we will continue to abide by the guidelines set forth by UVA administration,

I am very pleased to announce that the ROMAC faculty and students have been working diligently to update and improve our software for Seals (AnnularSeal), Journal Bearings (MAXBRG+), and Thrust Bearings (ThrustX). Each code will be released as part of a new RotorLab+ update as they are completed and become available. Each release will be announced on the ROMAC website. We intend to have all updates available not later than spring 2022.

Your 2022 membership invoice was sent out in mid-October, please begin the payment process to take advantage of the incentive of a reduced payment if paid by March 15, 2022. The details are on your invoice.

The 43rd ROMAC Annual Meeting is planned to take place at the Charlottesville OMNI Hotel, June 20—24, 2022. We will follow the familiar format from recent meetings, beginning with a welcome reception on Monday evening. Tuesday, Wednesday and Thursday research talks will be presented and the meeting will close by Friday around noon. The links for meeting registration and lodging reservations will be on the website in January as well as in the ROMAC spring 2022 newsletter.

On a more personal note, this is the last ROMAC newsletter that I will be writing for this page. I am stepping down as Director of ROMAC at the end of the year. I have been director for 9.5 years and have enjoyed the experience. I thank each of our present and past industry member companies for your support, collaboration, and engagement. I will continue as a member of the ROMAC faculty supporting the future work of ROMAC. I am working with Eric Loth, MAE Chair, and the new dean of engineering, Jennifer West to develop a succession plan to guide ROMAC into the future.

Houston Wood

Director, ROMAC Lab

2022 ROMAC Annual Meeting June 20—24 2022

We are moving forward with our plan to hold the ROMAC 2022 Annual Meeting in Charlottesville at our member preferred hotel on the beautiful and convenient Charlottesville Downtown Mall.

Make your room reservation via this link to the special ROMAC Annual Meeting overnight room portal.

Registration for the meeting will be available in January.

OMNI Charlottesville Atrium

Charlottesville Downtown Mall

Fall 2021 Software Update

RotorLab+ 5.0 to be released early Spring, will contain the following feature improvements and updates

◊ Forstab will be upgraded within RotorLab+ to include the code's full functionality with regards to transfer functions, modeling the effects of annular pressure seals, and any other inputs currently included in RotorGUI 2.0 but not in RotorLab+ 4.6.
◊ RotorSol lateral undamped mode analyses will be added to duplicate existing functionality from CrtSpd2. No rotordynamic analysis tools are to be removed.
◊ AnnularSeal will be added containing modernized annular pressure seal bulk-flow codes that are applicable to smooth, circumferentially grooved seals. Note, Laby3 and Seal3 will not be removed at this time.
◊ Annular pressure seals in RotorLab+ assembly and API projects will be able to link to AnnularSeal component analyses and will include added mass coefficients for use with Forstab

Ongoing plans for future RotorLab+ releases:

◊ Lateral Stability analysis from RotorSol to duplicate existing functionality of Rotstb and Forstab is scheduled for validation testing and inclusion in the 5.1 release.
◊ MAXBRG+ is planned for inclusion in RotorLab+ 5.1 release.
◊ Axial and Torsional mode analyses from RotorSol are scheduled for validation testing and inclusion and planned for inclusion in RotorLab+ 5.2 release.
ThrustX is planned for inclusion in RotorLab+ 5.2 release.

As part of our ongoing plans for improving the user experience, the RotorLab+ documentation is being updated. These updates will include features listed below:

◊ Clear descriptions and figures to relate each component input to physical system.
◊ Short Tutorials with clear time requirements and learning goals for each bearing and seal component analysis and for simple assembly analyses.
◊ Descriptions of each user input and recommendations on values for troubleshooting where appropriate.
◊ The next documentation to be updated will cover bearing analyses in RotorLab+
Subsequently, each individual analysis code will have its manual updated

Ongoing plans for executable code releases:

◊ Prior to the releases of AnnularSeal, MAXBRG+, and ThrustX in RotorLab+, executable forms of the codes will be released that can be run independently and the results imported into RotorLab+ for rotordynamic analysis

Software Development Strategy

ROMAC announced at the 2021 Annual Meeting that the software strategy has shifted. The plan is to center our analyses around flexible “base” codes such as RotorSol, AnnularSeal, MAXBRG+, and ThrustX. Base codes will be developed by ROMAC research staff. ROMAC graduate students will focus on cutting edge research that can be added to the base codes as updated and new features. Some benefits of this strategy are:

- Graduate students are not repeating parts of existing codes, which takes time away from their research
- ROMAC software will be consistent for users, which allows for better structured codes and consistent user experience
- Software updates will be more frequent
- Research staff have greater expertise and are not under pressure to graduate, which allows for greater care and validation

Planned Feature Developments In 2022

Based on current ROMAC research and feedback in the 2021 Annual Meeting Survey, the following features have been selected for development:

- ThrustX
    - Groove turbulence calculator
    - Pad features
    - Hydrodynamic jacking pockets
    - Axial misalignment
- MAXBRG+
    - Groove turbulence calculator
    - Direct lubrication groove velocity algorithm
    - Direct lubrication pressure calculator
    - Hydrodynamic jacking pockets
    - Transient analysis
- AnnularSeal
    - Helical groove seals
    - Damper seals
    - Improved shear stress calculation

ROMAC Software

AnnularSeals

Updates Soon to be Released

<u>AnnularSeal</u>

Released in RotorLab+ 5.0

Capability

◊ Handles:
  - Smooth and labyrinth seals
  - Compressible and incompressible fluid

Technical Highlights

◊ Improved theory and accuracy with a more user friendly with unified user interface

◊ More robust and efficient numerical methods and improved iterative algorithm which results in better convergence

◊ 3 control volumes used to model labyrinth seals
  - Greater accuracy in modeling the interaction between the groove and jet stream regions

◊ Numerical error checking feature by automated mesh independence for all outputs
  - Default feature to check uncertainty to ensure accurate output data

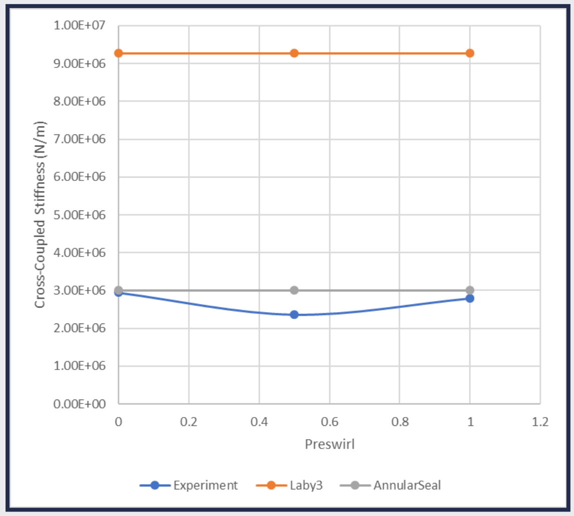
◊ Ensures that uncertainties for outputs for the power loss, leakage, and rotordynamic forces are below a user threshold

◊ Automated inlet loss and exit recovery factor calculation
  - Reduces uncertainty
  - No need for user estimated input

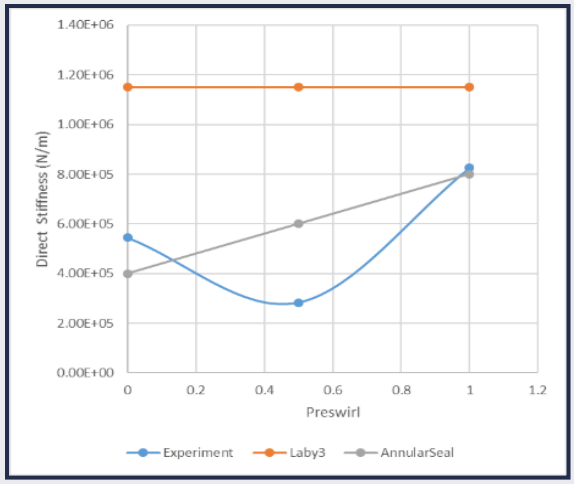
Validation

◊ Validated against multiple experimental case studies

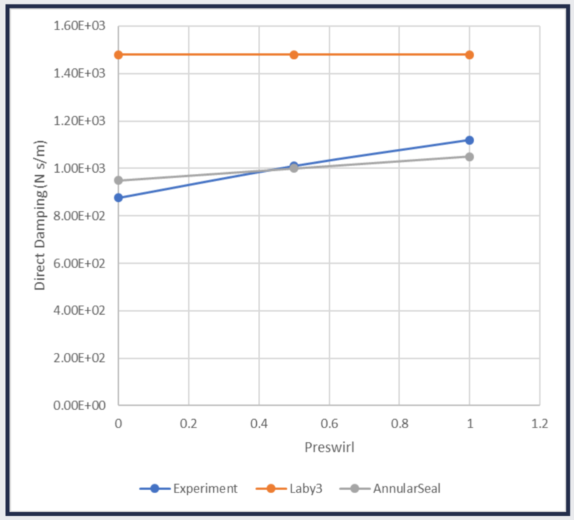
◊ Example: Picardo and Childs Gas Labyrinth Seal Stiffness and Damping results match experimental results closer than Laby3



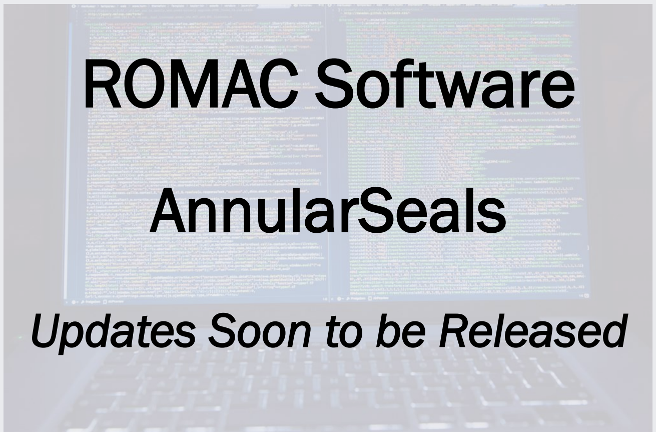
Direct Stiffness

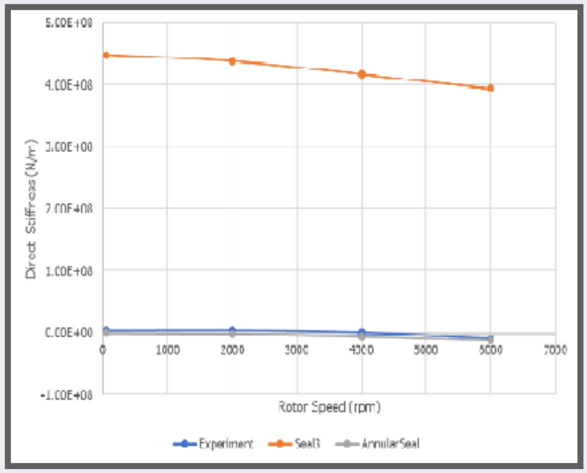


Cross-Coupled Stiffness



Direct Damping





Direct Stiffness

AnnularSeal

Released in RotorLab+ 5.0

Capability

◊ Handles:
- ♦ Smooth and labyrinth seals
- ♦ Compressible and incompressible fluid

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◊ Improved theory and accuracy with a more user friendly with unified user interface

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◊ 3 control volumes used to model labyrinth seals
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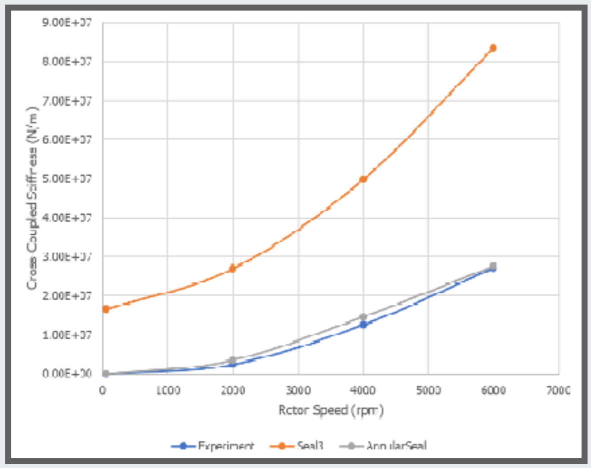
◊ Numerical error checking feature by automated mesh independence for all outputs
- ♦ Default feature to check uncertainty to ensure accurate output data
- ♦ Ensures that uncertainties for the power loss and leakage ad force outputs are below a user set threshold

◊ Automated inlet loss and exit recovery factor calculation
- ♦ Reduces uncertainty
- ♦ No need for user estimated input

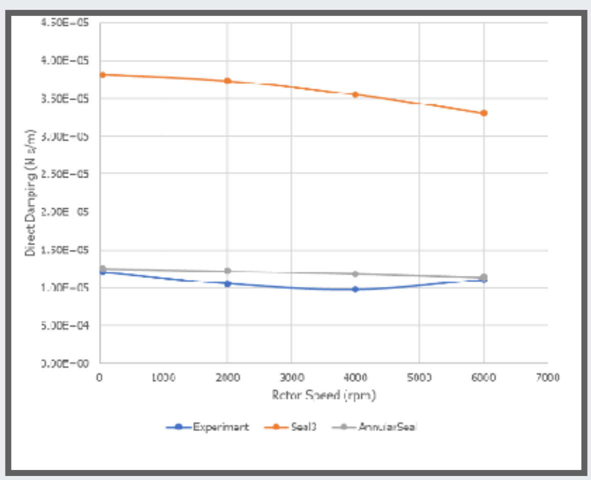
Validation

◊ Validated against multiple experimental case studies

◊ Example: Jolly Smooth Liquid Seal Stiffness and Damping results match experi-mental results closer than Seal3



Cross-Coupled Stiffness



Direct Damping

ROMAC Software

ThrustX

Updates Soon to be Released

Technical Highlights

- 3D thermal and deformation analysis
- Thermal modeling with Conduction-Convection Method
- One-equation turbulence model
  - ◊ Improves accuracy
  - ◊ Minimizes empirical user inputs
- Efficient computational analysis with:
  - ◊ Mesh Determination with Grid Adaptive Method
  - ◊ Iterative method options include Genetic algorithm or Newton-Raphson

Validation

- Validated against multiple experimental case studies
- Examples:

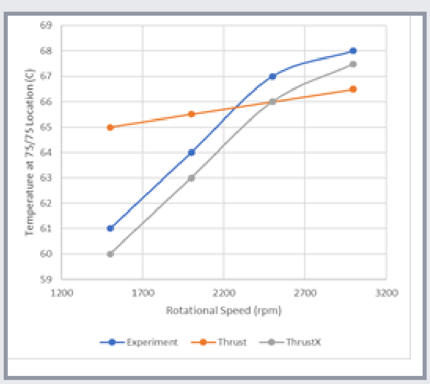
ThrustX trends match the experimental values much closer than Thrust

<u>ThrustX</u>

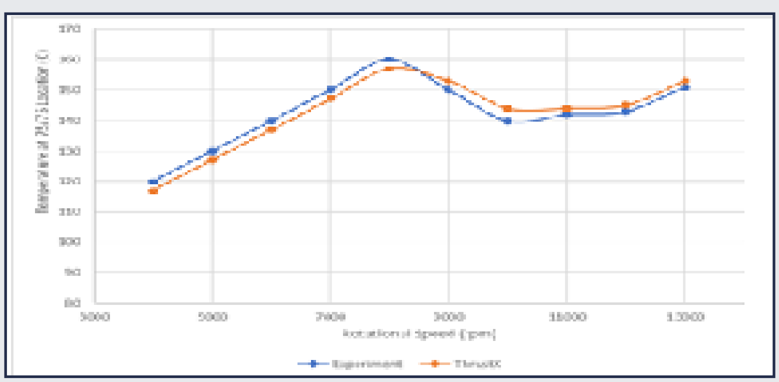
- Planned for RotorLab+ update 5.2

Capabilities

- Handles:
  - ◊ Fixed geometry and tilting pad bearings
  - ◊ Thermal, hydrodynamic and deformation modeling



Glavitskih Bearing 1 MPa Load



Mikula Bearing Transitional Turbulence

ROMAC Software

MAXBRG+

Updates Soon to be Released

Technical Highlights

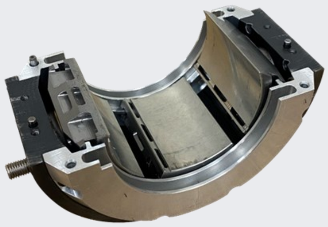
- ◊ 3D thermal and deformation analysis
- ◊ Models for direct lubrication and ram effect
- ◊ Axial shaft misalignment
- ◊ Axial edge starvation
- ◊ Thermal modeling with Conduction-Convection Method
- ◊ One-equation turbulence model
    - ♦ Improves accuracy
    - ♦ Minimizes empirical user inputs
- ◊ Efficient computational analysis with:
    - ♦ Half bearing models where applicable
    - ♦ Mesh Determination with Grid Adaptive Method
    - ♦ Iterative method using genetic algorithm or Newton=Raphson

Validation

- ♦ Validated against multiple experimental case studies

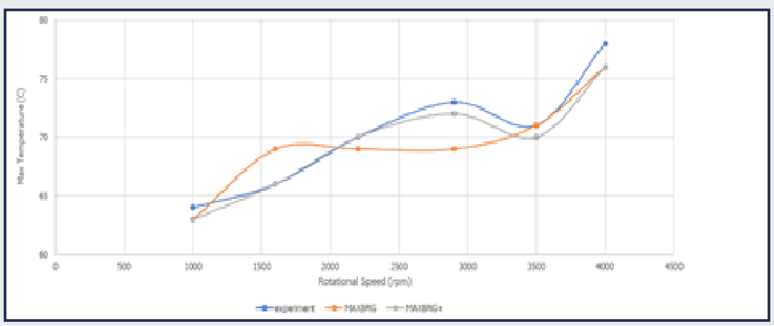
<u>MAXBRG+</u>

Planned for RotorLab+ update 5.1, 2022

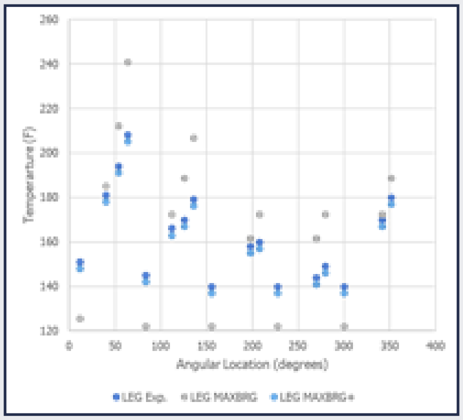


Capabilities

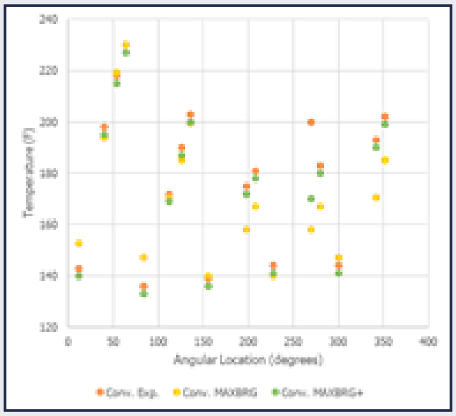
- ◊ Handles:
    - ♦ Fixed geometry and tilting pad bearings
    - ♦ Thermal, hydrodynamic and deformation modeling



Taniguchi Temperature vs. Operating Speed



Direct Lubrication Temperature



Conventional Lubrication Temperature

2022 ROMAC Consortium

Membership Fees

Due March 15, 2022

Standard Membership

- Initiation Fee: $28,500
- Annual Membership Fee: $30,000
- $28,500 if payment is received on time (by 3/15/2022)
- 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 3/15/2022)
- 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 3/15/2022)
- 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: $3,000/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

*USA Government Definition: Ownership structure, Revenue, Number of Employees

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

CFD Model Simplification Strategies for Annular Seals

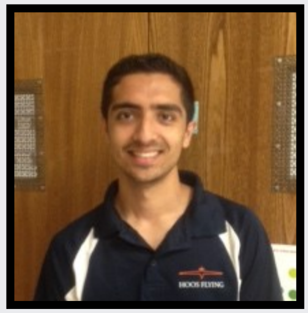
Neal Morgan
Expected Degree:
MAE PhD
May 2022

Annular pressure seals are critical components used in turbomachinery. The annular seal is a thin annular clearance region "sealing" between a high-pressure region and a low-pressure region of a rotating machine by limiting the leakage of the working fluid. The working fluid leakage is limited by the cross-sectional area allowed to the flow, and frequently further limited by axisymmetric grooves machined into the rotor or stator within which the fluid expands, contracts, and recirculates. Modern analysis techniques of such seals tend to fall into two categories. Either the seal model is greatly simplified through assumptions and application of empirical factors, or the seal is modeled using 3-D CFD techniques in generalized fluid dynamics codes. The method of simplification is referred to as "Bulk Flow" analysis due to the use of radially averaged "bulk" values for flow variables. This model takes those radially averaged values and assumes a circumferential solution based on small orbit circular whirling motion. The 3-D momentum equations are thus reduced to a series of 1-D equations in the axial direction with shear forces modeled empirically through Blasius type friction factors. These 1-D equations can be solved rapidly at the expense of accuracy and flexibility in seal geometry types. Comparatively, 3-D CFD codes require large 3-D meshes and the solution of the full 3-D Navier-Stokes equations accompanied by turbulence model. The CFD solutions are accurate within the precision of the boundary conditions used at the expense of much greater computational cost and engineer expertise requirements.

This work demonstrates methods of reducing the complexity of annular pressure seal modeling with minimal losses to solution accuracy. A 2-D seal code is under development with an axial-radial grid to strike a balance between the 1-D bulk flow method and 3-D generalized CFD. This 2-D seal code distinguishes itself through rigorous application of modern numerical and code techniques. The code allows the 0^{th} and 1^{st} order solution of the geometrically perturbed and incompressible cylindrical Reynolds Averaged Navier-Stokes equations to model the seal's eccentric annular region with an assumed small and circular whirl orbit. Currently a single one-equation turbulence model is included to model the transport of turbulent kinetic energy for high Reynolds number flows. The 0^{th} order solution provides the user with leakage results, wall shear stress, and initial pressure differential estimates. The 1^{st} order solution refines the pressure differential estimate and models the circumferential variation to obtain rotordynamic coefficients from multiple whirl speed cases. For additional comparison, the 2D zeroth-order turbulent solution was fed into bulk-flow first-order equations to make a hybrid method for the prediction of rotordynamic coefficients.

The current state of the 2-D seal code consists of laminar solutions for zeroth and first order perturbation results and zeroth order solutions with the Reichardt and the Prandtl one-equation turbulence models included. The zeroth-order concentric flow solution is then validated against experimental velocity profiles, leakage data, and shaft torque from four literature sources. Three of these sources are then applied to validation of the first-order results prediction of rotordynamic coefficients.

Uncertainty Quantification of the Finite Element Model for Multi-Component Isotope Separation in a Single Gas Centrifuge



Student: Wisher Paudel
Expected Degree: MAE PhD May 2022

The complex isotopic physics inside a gas centrifuge rotor requires numerical modelling tools due to the lack and expensive nature of experimental work on the field. The two-dimensional multi-component diffusion equation has been solved by developing a finite element (FE) model. While the FE code has been verified for numerical accuracies through spatial grid independence study and rigorous convergence criteria, it is lacking a proper validation study because of the unavailability of experimental data. In order to ensure that the prediction regarding the separation of isotopes produced by the code is as accurate as possible, it is important to consider the uncertainty in the input data and quantify its effect on the output. In this paper, the propagation of uncertainty associated with the physical centrifuge parameters as well as gas properties of uranium hexafluoride (UF_6) is investigated. The quantities of interest (QoIs) include the separative work (ΔU) and the overall separation factor (γ). The statistics of the problem response functions are evaluated according to the "Surrogate-Based Uncertainty Quantification." The general approach of the study includes: (1) The generation of response surface starting from Design of Experiment (DoE) to approximate the multi-component separation in the gas centrifuge FE model to reduce computational efforts. (2) The application of the UQ technique based on the Latin Hypercube Scaling (LHS) to the meta-model. Probability Density Functions (PDFs) are introduced for the input parameters to quantify their effects on the output machine performance. The simulation of the DoE sample is conducted on the FE code while the development of the surrogate model and UQ analysis is completed using Matlab based UQLab framework developed at ETH Zurich as well as the Dakota software developed by Sandia National Lab. The analysis conducted here is the first of its kind on the field of isotope separation and highlights the practical use of uncertainty quantification techniques in predicting the performance of gas centrifuges and also provides confidence in the results obtained using the new finite element model.

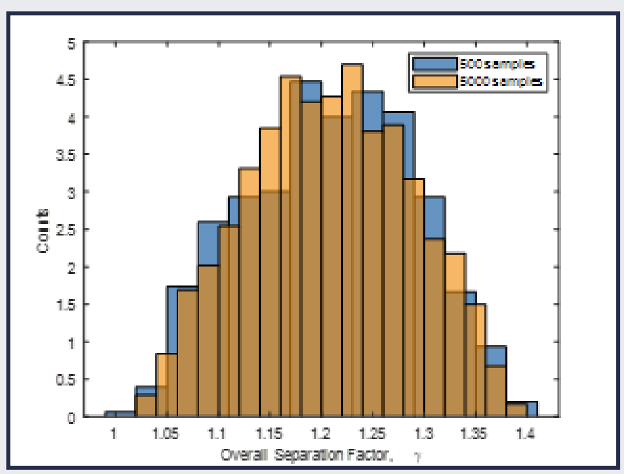


Figure: Comparison of PDFs between 500 and 5000 samples for the LHS based UQ analysis of the overall separation factor in a fictitious Iguaçu gas centrifuge

Active Magnetic Bearing Test Rig

Student: William Arcand
Expected Degree: MAE MS.2022

Modern industrial high-speed machinery often operates above multiple shaft critical speeds and requires in-depth rotordynamic modeling and analysis. Active Magnetic Bearings (AMBs) have proven to be a compelling alternative to traditional bearings for many such high-speed, high-performance applications. AMBs apply attractive magnetic forces to support and center a rotor shaft within the machine clearance. They can maintain contactless, friction-free operation and handle the varying dynamic unbalance forces that are generated throughout the operating range. However, AMBs require implementation of a feedback controller due to their inherent open-loop unstable nature. In this project, a scaled version of an industrial high-speed vertical shaft spin test rig supported by magnetic bearings is being developed. The main goals of this project are to predict and successfully demonstrate the capabilities of AMBs for this application as well as developing a general platform for future learning and experimentation.

Requirements of the test rig specify that the rotor will operate above the first and second flexural critical speeds. The system will operate with the shaft in the vertical position and it will be able to handle an external load on the order of 5 to 10 lbf. The system will have an additional AMB located at the shaft midspan that can be used to apply various arbitrary external loads to the system. Finally, it will have a motor, bearing controls, and the instrumentation for basic rotor operation characterization.

All system-level hardware has been manufactured and/or acquired. Hardware assembly and subsystem testing has commenced in preparation for system-level testing, which is anticipated to begin later this fall. A system model has been developed and will be used to implement two model-based control designs: independent SISO control and coupled tilt-translate (modal) control. The performance of both controller designs will be evaluated directly on the hardware and compared with theoretical predictions.

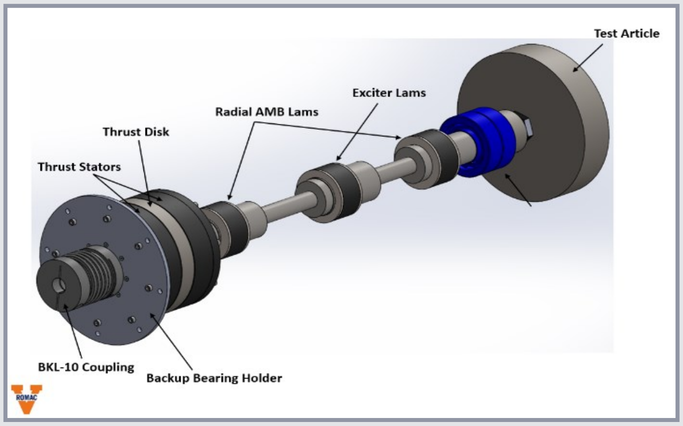


Figure: Rotor System Model

Temperature Drop in Transitional Turbulence

Student: Xin Deng
Expected Degree: MAE PhD 2022

The working fluid in a thrust bearing goes through laminar, transitional, and fully turbulent flow regimes with increasing shaft speed. There are existing turbulence models available for use in thrust bearing modeling, such as Shear Stress Transport (SST) and Eddy Viscosity Transport (EVT). However, SST tends to overpredict the film temperature while EVT underpredicts the film temperature. Because temperature is the most critical performance characteristic in a thrust bearing, these models are inadequate for bearings with high levels of turbulence. This study uses a new hybrid turbulence model over a range of operating speeds in thrust bearings. The new model results in better predictions of temperature compared to experimental data than either SST or EVT. The purpose of this study is to better understand transitional turbulence in thrust bearings. Specifically, the relationship between turbulence and the drop in temperature associated with turbulent transition is considered (see figure 1). Initial results indicate that turbulent variation in viscosity is a significant mechanism for this temperature drop. An expected outcome of this study is an improved TEHD Thrust bearing code with more accurate thermal predictions that better reflect turbulence transition.

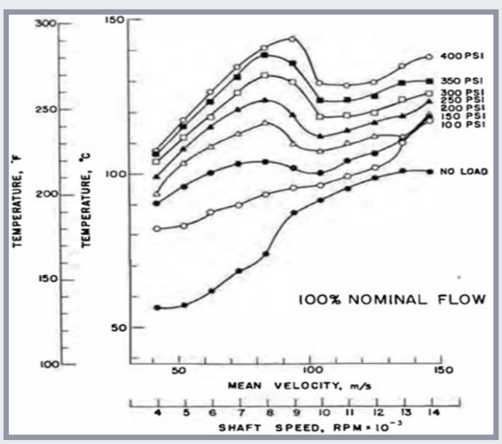
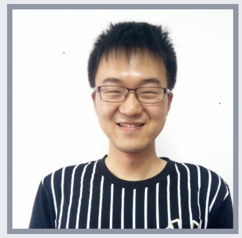


Figure: Temperature vs. shaft speed showing a drop in temperature in transitional turbulence [1]

[1] Capitao, J. W., R. S. Gregory, and R. P. Whitford. "Effects of high-operating speeds on tilting pad thrust bearing performance." (1976): 73-79.



Accounting for Bearing Groove Turbulence

Student: Xin Deng
Expected Degree: MAE PhD 2022

Traditionally, bearing models have used the zero-equation turbulence model, which does not include turbulent kinetic energy and therefore precludes the influence of groove turbulence on the film. This means that while groove turbulence may affect turbulence within both the film and groove mixing, it has never been properly accounted for.

In a group study of ROMAC about ram effect versus groove turbulence in journal bearings, a new finding is that the "ram effect" is due to convection of turbulence from the groove to the leading edge. This continuing study is to achieve a proper formulation for groove turbulence using published research (for example, lid driven cavity research [1-2] is a good reference) and CFD results. The outcome of this study should inform groove turbulence modeling for ROMAC codes and remove the empirical k-ratio parameter in MAXBRG+ and ThrustX.

[1] Botella, O., and R. Peyret. "Benchmark spectral results on the lid-driven cavity flow." Computers & Fluids 27, no. 4 (1998): 421-433.

[2] Bruneau, Charles-Henri, and Mazen Saad. "The 2D lid-driven cavity problem revisited." Computers & fluids 35, no. 3 (2006): 326-348.

CFD Analysis of Grooved Seal Flow to Improve Bulk Flow Code Predictions

Student: Nathaniel Gibbons
Expected Degree: MAE PhD 2023

This project continues computational fluid dynamics (CFD) investigations into flow phenomena in circumferentially grooved seals in an effort to improve bulk flow code predictions of leakage and rotordynamic coefficients. Of particular interest is the effective film thickness, a physical flow boundary separating the jet and recirculating flow regions, and its relationship to leakage, shear stresses, and other quantities.

Recent work has leveraged a single groove CFD model (see Fig. 1 for diagram) to analyze the relationships between film thickness, effective shear stress, and flow patterns with changes in pressure differential and rotor speed. Links between the strength and/or presence of separation and recirculation regions and the film thickness shape were observed. The ratio of circumferential to axial momentum was found to be a highly influential parameter on both the film thickness and the effective shear stress. Figure 2 shows one such example for the maximum film thickness. An increase in net expansion of the film into the groove was accompanied by a decrease in leakage, as observed in previous work for hole pattern seals, making net film expansion a quantity of interest. Figure 3 shows the nondimensional expanded area as a function of both circumferential to axial momentum ratio and total momentum, indicating a clear dependency on both. The flow patterns, and thus the film thickness and net expansion, are known to depend on the aspect ratio of the groove or hole, which we hypothesize is also correlated to the stability coefficient of the seal.

The factors that affect this net film expansion is a focus for this year's work, along with a movement towards a universal formulation for the shape of the film thickness that can be implemented in ROMAC bulk flow codes in the future. Also being explored is the dependency of CFD derived rotordynamic coefficients, specifically using ANSYS, on grid metrics and model setup parameters. This will ultimately highlight potential sensitivity to modeling choices that vary widely between studies and serve as guidelines for future studies of this nature.

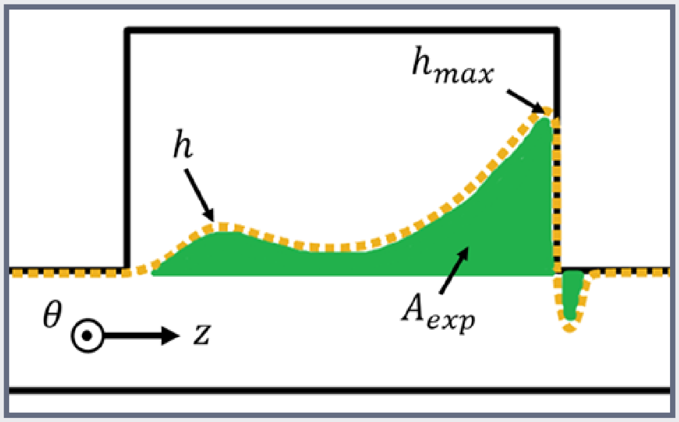


Figure: Single groove model diagram showing the film thickness (yellow dotted), maximum film thickness location, and expanded area (green).

Fluid Film Bearing Test Rig

Student: Pedro Herrera
Expected Degree: MAE PhD 2023

The objective of the Fluid Film Bearing Test Rig Project is to finalize the design, manufacture and assembly of a test rig to experimentally determine the dynamic coefficients (stiffness and damping) of a fluid film bearing with an acceptable (approximately: <20% up to 500 Hz) coefficient uncertainty level.

Based on the previous work and preliminary design by Benstone Schwartz, the work has been continuing in the following areas: developing component and subsystem specifications and detailed designs/drawings, building costs and a complete bill of materials, and defining/checking additional technical details. This work is the basis for the future purchasing, part manufacturing, and assembly processes.

During this past year, the detail design of the bearing housing for the test bearing has been worked on extensively, with the main focus on two areas: dimensional details and sizing of the lubricant draining system. A preliminary design has been developed and hydraulic calculations (using guides from industrial standards) have been performed to ensure a suitable size to drain the lubricant out of the bearing housing under all potential future operating conditions. Kingsbury Inc. has graciously agreed to assist in this effort by reviewing and contributing to the final design details, which based on their extensive industrial and test rig experience will help ensure the final design meets all future system operational requirements.

Dynamic analyses have also been performed, using ANSYS and INVENTOR software, for each of the main system components as well as the entire test rig as an assembly in order to find any potential conflicts at various operational speeds (RPM) or frequencies of excitation of the dynamic force (i.e. resonances or large vibrations of the test rig). Two potential issues have been identified: a possible lateral resonance of the test assembly (bearing housing + mag. bearing + test rotor), and a possible vibration transmissibility between the gearbox and the test assembly in a defined frequency range. However, it has been determined that their only consequence would be to limit the operation of the rig over one or two small speed ranges. In addition, there is a plan to validate these results experimentally as the test rig assembly begins to take place.

Work will continue on finalizing designs for the test bearing, bearing housing, test shaft, magnetic bearings and shaft couplings. Final detailed specification of the sensing and Data Acquisition system, commissioning requirements related to existing equipment in preparation for system assembly and start-up tests.

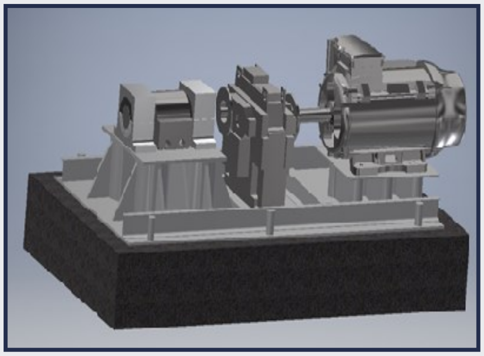


Figure: Model of the fluid-film bearing test rig used for dynamic

Zihao Huang recently completed his M.E degree in UVA MAE He joined the ROMAC Lab in pursuit of a PhD degree working with Chris Goyne, Associate Professor, Director of the UVA Aerospace Research Laboratory and Cori Watson-Kassa, Research Scientist.

Fluid film tilting-pad journal bearings: influence of supply geometry on groove flow and hot oil carry-over

Student: Zihao Huang
Expected Degree: MAE PhD 2025

In conventional lubrication bearings, hot oil from previous pad, instead of mixing with the cold supply oil, travels directly to the following pad. This phenomenon is called hot oil carry-over (HOC). This phenomenon substantially rises the temperature of the next pad, causing thermal deformation of pads and it is detrimental to bearings. Direct lubrication designs, however, such as spray bar design and inlet groove supply design, are known for their capability of affecting thermal distribution of pads and reducing peak temperature. Many efforts have been made on investigating individual designs, but few compared them within the same dimension of bearings. Laminar results show groove flow patterns are strongly correlated to supply geometries, and turbulent models are developed for further investigation. Initial results show that the streamlines are much more organized in direct lubrication designs as shown in *Figure 1*.

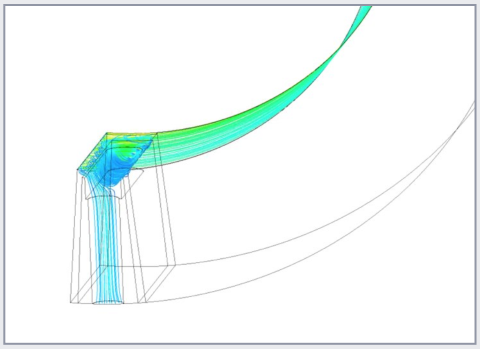


Figure 1: Streamlines in spray bar supply design

Current progression is to validate a full bearing model with pad deformation considered. A combination of hybrid turbulence model and air mixing model is studied as a method to approximate experimental results. Specifically, the ram pressure effect observed from experiment needs to be reproduced (shown in Figure 2). Believed to be induced by a change of turbulence model, this ram pressure effect was seldom reported in previous studies. The hybrid turbulence model developed in this study is to approximate this change of turbulence, and fill in the blank in this field. Upon completion of development of the turbulence model, it will be applied to direct lubrication CFD models, and accurate results from direct lubrication designs can be obtained. These results will serve as reference to validate the accuracy of the improved ROMAC code mentioned later.

The long-term goal of this project is to understand the performance of direct lubrication, especially when the bearing is also starved. The next step of this project will look at velocities in the groove for both conventional and direct lubrication designs. This will then be used to improve the thermal model in MAXBRG+ by knowing the velocity distributions better.

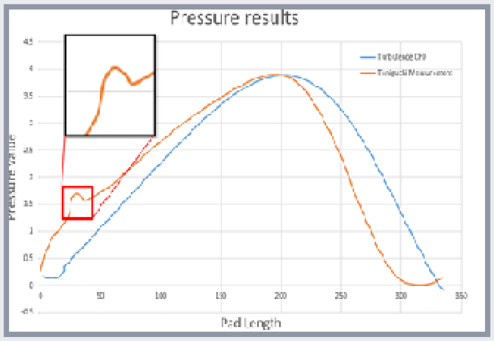


Figure 2: Ram pressure effect (zoomed out)

ROMAC Undergraduate Research 2021—2022

For the last several years, ROMAC has had a successful undergraduate research program. 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.

Kevin Moccia
has worked with ROMAC since he was a second year. He is expected to graduate in May 2022 with a B.S in Aerospace Engineering, minor in Astronomy.

Thermal Influence of Bearing Jacking Pockets

MAXBRG3D was developed to include jacking pockets in its analysis. However, in its thermal analysis of jacking pockets, the thermal rise on the pad surface is considered zero in the pocket region. The goal of this project is to test out this hypothesis by thermally analyzing bearings with jacking pockets using CFD. Based on the results of this study, the thermal model of jacking pockets in MAXBRG3D can be adjusted to improve accuracy. Additionally, this project will show the impact of the thermal trends on the results of Branagan et al for stiffness coefficients of the bearings

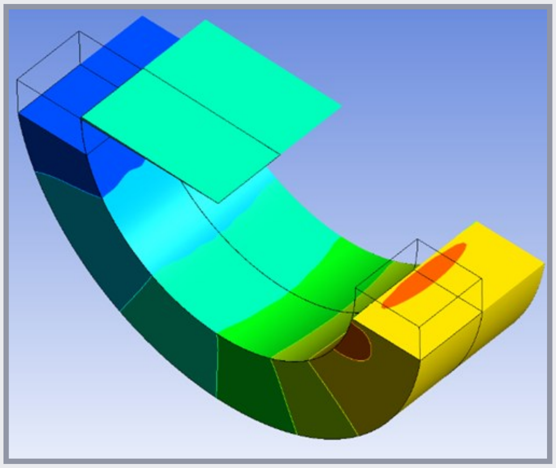


Figure: Thermal variation on pad surface

Greg Breza
has worked with ROMAC since he was a second year. He is expected to graduate in May 2022 with a B.S in Mechanical Engineering and Physics.

Multiphase Modeling of Squeeze Film Dampers

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. Specifically, this project will investigate the influence of oil flow rate on the performance of squeeze film dampers.

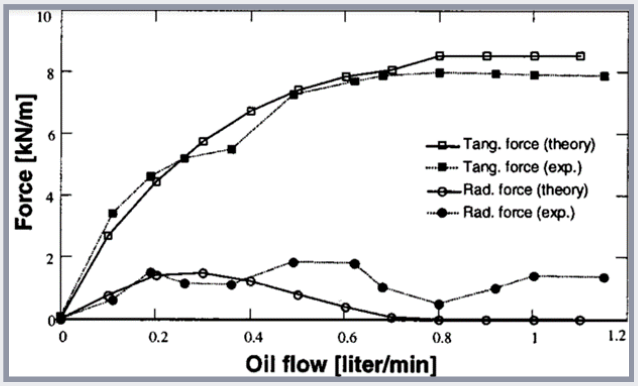


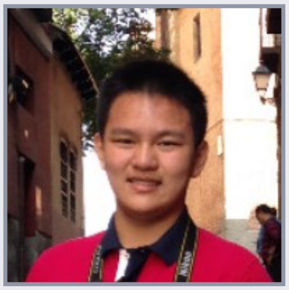
Figure: Squeeze film damper forces from experiment (Diaz and San Andres 2001)

ROMAC Undergraduate Research *con't*

Astrid Henkle
began working with ROMAC during the summer of 2021. She will be graduating with a B.S in Mechanical Engineering in May 2022.

ROMAC Software Testing and Documentation Improvements

ROMAC software documentation is in the process of being reviewed and updated. The goal of this project is to improve the end user experience with new documentation guides and tutorials for each of the ROMAC individual codes included in RotorLab+. The new documentation includes bearing component analysis with MAXBRG, THPAD, and THBRG; the creation and general analysis of rotor FEA models in RotorLab+; the application of RotorLab+'s API Spec Check projects to API rotor analysis; and other ongoing updates



Kangyi Peng
is a second year, this is his first semester working with ROMAC. He is expected to graduate in May 2023 with a B.S in Aerospace Engineering

Modeling the Effects of Fluid Inertia on Squeeze-film Damper Performance

Squeeze film dampers (Figure 1) 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. Specifically, this project will look at the impact of fluid inertia on the dynamic performance of squeeze film dampers. Similar work has shown substantial change in rotordynamic coefficients predictions when inertia is included in the numerical model.

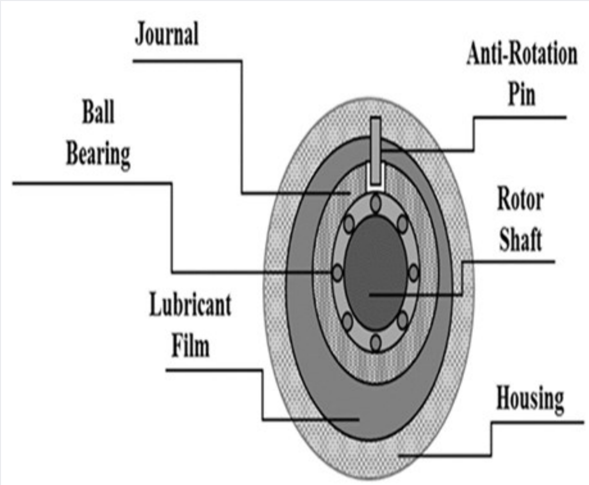


Figure: Squeeze film damper geometry

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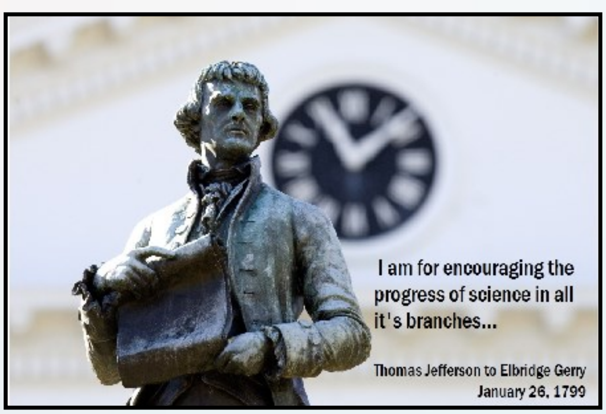
- Fluid Film Bearings
- Seals
- Squeeze Film Dampers
- Rotordynamics
- Magnetic Bearings and Controls
- Optimization of Rotor-Bearing Systems
- Experimental, Computational, and Theoretical Studies



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