Mechanical Engineering Department
Texas A&M University

2011/2012
Research Progress Report
Tribology Group

Year XXI

32nd Annual
Turbomachinery Research Consortium Meeting

May 2012

Luis San Andrés
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Leader

http://rotorlab.tamu.edu

Tribology Group

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FOREWORD

Texas A&M University went through stormy times this past year (June 2011-May 2012). Persistent budget cuts from the State, frozen salaries since 2008, and the increased public perception that professors in Tier 1 universities only do research (state or federally funded) with little teaching, have lowered the morale of most faculty, in particular the young ones. Higher education is losing a battle in a State where a $10,000 B.S. degree will soon become a political mandate. The quality of education our undergraduates receive will continue to deteriorate. This is not good news when US engineers must compete globally!

In spite of the hardships and tumultuous times where everyone but the teachers knows how to produce professionals, I continue to build a meaningful research program that addresses to the needs of industry by preparing experienced graduates, team players and leaders with professional integrity and a ready *can do* attitude. I continue to chase after funds to support the students' work, policing and motivating them and editing/writing, rewriting, and rewriting^n their technical output. It is a labor of love that demands patience, tons of it! I sound like an old man.

Last Fall I enjoyed immensely teaching the undergraduate course PRACTICES OF MODERN ENGINEERING. The class teaches to *learn how to learn* and fosters professional practice skills including team work, communication, work ethics and professional integrity, understanding innovation and the management of intellectual property. The students, the guests (practicing engineers) and a few faculties considered the course very important and most rewarding. However, the ME Education Curriculum Committee declined a request to make the class permanent as a technical elective. The shallow decision is based on the course content not providing depth. I leave to the experts the education of the UG ME students. I've resumed fully my research & teaching of engineering fundamentals.

In March 2012, with the sponsorship of the Turbomachinery Laboratory, Daniel Lubell from Capstone Turbine and I offered a 1 ½ day short course on *Gas Foil Bearings.* Twelve attendees from industry participated in the short course which offered a sober and unbiased evaluation of the novel bearing technology. The attendees' reviews were excellent recommending the course be offered to a larger audience.

I also was selected (twice) as a member of the ME committee searching for a Department Head. The first search was stopped last June 2011 since at the time the College of Engineering (COE) was also searching for a Dean. Dr Catherine Banks, the new Dean began her term in January 2012 fully pledging to support the COE Strategic Plan and Vision[1]. Starting in early 2012, the second committee conducted an international search for an individual with outstanding recognized scholarship and experience in administration in higher education. From a pool of well over three dozen qualified applicants, the committee selected eleven for phone interviews, and chose four for Campus interviews. The candidates visited A&M in April to deliver their vision on education, research and service. All candidates offered to make us one of the top five public ME schools, but did not state the resources to get the job done except for more work. No news on that pearl of wisdom. Presently, the faculty has voted on the acceptability of the candidates to lead the department and the committee prepared a recommendation. We hope to have a ME Department Head sometime this Fall 2012.

In 2011 the TRC funded four projects out of four proposals. Only one project had funding by September 1, 2011. The other projects were funded in December 2011 with an effective start date of January 2012. In spite of the late funding and start, the students made significant progress in a short time. Borg-Warner Turbo, Honeywell Turbocharging Technologies and Pratt &Whitney Engines fund separate efforts addressing their particular needs. Income from licensing software amount to $68,000 mainly from the gas foil bearing and gas/liquid seal (HsealH) codes. The added income helps to maintain the laboratory facilities and continuously upgrade the computer equipment.

[1] Document available at http://engineering.tamu.edu/strategicplan/ The plan recognizes the need for long life learning and experiential learning. The means to complete the vision are not detailed.

- **Thrust foil bearings for oil-free turbochargers**

  OBJECTIVE: Model FE code for prediction of dynamic forced response of bump-type thrust foil bearings.
  STATUS: Predictive tool under development and validation to published test data.
  SPONSOR : BORG-WARNER TURBO, **$90,441** Project started September 1, 2011 (1 year).
  Student: Owen Zhang (Ph.D.)

- **Squeeze Film Damper – Identification of dynamic forced performance**

  OBJECTIVE: To assess novel SFD designs for aircraft applications.
  STATUS: Test rig operational (500 lbf dynamic force). Measurements and force coefficients identification completed in a 5" OD open ends SFDs with central groove. Effect of fluid inertia dominates SFD forced response.
  SPONSOR: PRATT & WHITNEY ENGINES, **$97,214** Project started January 1, 2012 (1 year).
  TURBOMACHINERY RESEARCH CONSORTIUM, **$37,108** Project started January 1, 2012 (1 year).
  Students: Gary Bradley (M.S.), Sung-Hwa Jeung (M.S.)

- **Thermal Energy Transport Analysis for (Semi) Floating Ring Bearings in Turbochargers**

  OBJECTIVE: Integrate thermal energy transport for prediction of forced response in turbocharger bearings
  STATUS: Completed code for semi-floating ring bearings. Validations with test data awaiting.
  SPONSOR : HONEYWELL TURBOCHARGING TECHNOLOGIES, **$208,340** Project started October 1, 2010 (2 years).
  Student: Feng Yu (M.S.)

- **Metal mesh foil bearings (MMFB) for high speed turbomachinery**

  OBJECTIVE: Continue to advance gas bearing technology for high temperature, high speed microturbomachinery applications (power < 400 kW).
  STATUS: Completed tests to verify performance of MMFB at high temperature(200 C) & rotor speed (50 krpm)
  SPONSOR: TURBOMACHINERY RESEARCH CONSORTIUM, **$38,608** Project started Dec 1, 2011 (1 year).
  Student: Thomas Chirathadam (Ph.D.), Joshua Norsworthy (M.S.)

- **Measurement of leakage in a novel all-metal non-contacting annular seal at high temperature**

  OBJECTIVE: revamp high temperature gas seal test rig for high speed operation and to measure leakage for a labyrinth seal and a HALO™ seal
  STATUS: Completed leakage measurements w/o rotor spinning. Revamping of rig for high speeds in the works.
  SPONSOR : TURBOMACHINERY RESEARCH CONSORTIUM, **$74,863** Project started September 1, 2010 (2 years).
  Student: Alain Anderson (M.S.)

- **Computational Model for Tilting Pad Journal Bearings**

  OBJECTIVE: Develop code for prediction of tilting pad bearings forced response accounting for thermal effects and including pivot radial and transverse flexibility.
  STATUS: Completed. TPJB© code shows +good correlation with test data for bearings with very flexible pivots.
  SPONSOR: TURBOMACHINERY RESEARCH CONSORTIUM, **$70,421** Project start September 1, 2010 (2 years).
  Student: Yujiao Tao (M.S.)

- **Automated Analysis of XLTRC^2 Time Transient Responses in Nonlinear Rotor Bearing Systems**

  OBJECTIVE: Modeling of NL rotor-bearing systems and GUIs for data handling of XLTRC^2 nonlinear transient rotor response output data.
  STATUS: GUIs developed for automated analyses with minimum User interaction. Applications sought
  SPONSOR: TURBOMACHINERY RESEARCH CONSORTIUM, **$34,863** Project start May 1, 2011 (2 year).
  Student: Qing Liu (Ph.D.)

- **Computational Model for Textured Surface Gas Face Seals**

  OBJECTIVE: Develop code for leakage and forced response in textured gas face seals for steam turbines.
  STATUS: Code SpiralG extended to model T groove textured surfaces and GUI completed. Start Sept 1, 2011
  SPONSOR : CIATEQ A.C. (MX),
  Student: Jose Hernandez (M.S. sponsored student)

Enjoy the 32nd TRC Annual Meeting. This year you can either attend to the presentations or play golf. A no brainer choice! The students and I hope to count with your continued support in 2012-13.

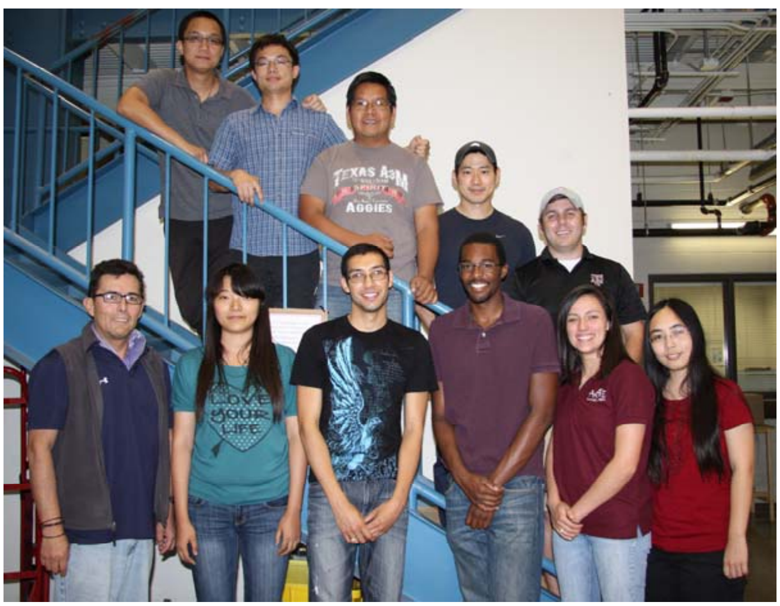
Luis San Andrés, Mast-Childs Tribology Professor May 20, 2012

Tribology Group

Team Members 2011-2012

Name	Research project	Degree	Graduation date
Thomas Chirathadam Joshua Norsworthy* Gary Daigle*	Metal Mesh and Bump-type Foil Bearings: Identification of Rotordynamic Force Coefficients	Ph.D. B.S. B.S.	August 2012 May 2012 May 2012
Alain Anderson+	Measurement of leakage in a novel all metal non contacting annular seal at high temperatures	M.S.	August 2012
Sung-Hwa Jeung Gary Bradley	SFD Test Rig & Measurements: Pratt & Whitney & TRC	M.S. M.S.	August 2013 August 2013
Feng Yu	Turbocharger Bearing Code Development	M.S.	August 2012
YuJiao Tao+	Computational Model for Tilting Pad Bearings	M.S.	August 2012
Qing Liu+ Stephanie Simerskey	Nonlinear Dynamics of Rotor-Bearing Systems	Ph.D. B.S.	May 2014 May 2012
Owen Zhang	Analysis for Thrust Foil Bearings	Ph.D.	May 2015
Jose Hernandez+	Analysis of textured gas face seals	M.S.	August 2012

(*) undergraduate student, (+) minority student (female, Hispanic, Asian, African-American)



Top:	Feng Yu	Owen Zhang	Jose Hernandez	Sung-Hwa Jeung	Gary Bradley
Luis San Andrés	Yujiao Tao	Alain Anderson	Joshua Norsworthy	Stephanie Simerskey	Qing Liu

(*) Tomas Chirathadam and Gary Daigle not pictured. They are out in the real world making a difference!

2012 RESEARCH PROGRESS REPORTS

FORCE COEFFICIENTS FOR A LARGE CLEARANCE OPEN ENDS SFD WITH A CENTRAL FEED GROOVE: TEST RESULTS AND PREDICTIONS

TRC-SFD-01-12

Luis San Andrés

MEASUREMENTS OF ROTORDYNAMIC RESPONSE IN A HIGH TEMPERATURE ROTOR SUPPORTED ON TWO METAL MESH FOIL BEARINGS

TRC-BC001-12

Luis San Andrés and Thomas Chirathadam

In the works (Summer 2012) after n+1 revisions
Tao Y., M.S. thesis on computational model for tilting pad bearings with pivot effects, and
Liu. Q., technical report on updates to XLTRC^2 for automated NL RBS responses.

2012 RESEARCH PROPOSALS

CONTINUATION	# years	Cost
AUTOMATED ANALYSIS OF TIME TRANSIENT RESPONSES IN NONLINEAR ROTOR BEARING SYSTEMS (YEAR II)	2	$ 41,484
COMPUTATIONAL MODEL FOR TILTING PAD JOURNAL BEARINGS (YEAR III)	4	$ 40,984
LINEAR-NONLINEAR FORCE COEFFICIENTS FOR SQUEEZE FILM DAMPERS (YEAR II)	2	$28,470
NEW **MAKING A WET (FOAMY) SEAL AND ESTIMATING ITS DYNAMIC FORCED COEFFICIENTS**	2	$ 44,984
NEW **ENGINEERED ANALYSIS FOR POCKET DAMPER SEALS AND COMBINED LABYRINTH-BRUSH SEALS**	2	$40,984

PROPOSALS –SUMMARIES

COMPUTATIONAL MODEL FOR TILTING PAD JOURNAL BEARINGS (YEAR III)

Accurate prediction of the static and dynamic forced performance of tilting pad journal bearings is necessary to design, troubleshoot and predict the dynamic response and stability of rotor-bearing systems. In 2011, the TRC funded a two-year proposal to produce a new computational tool (TPJB®) for accurate prediction of tilting pad bearing force coefficients operating under heavy loads. The model includes the most common pivot type configurations. In addition, the model includes simple formulations for estimation of the operating clearance as a function of local thermal expansion and mechanical deformation. Correlations of predictions with published test data for force coefficients is excellent provided that the user knows a-priori the actual bearing/pad clearances at the operating temperatures and has an accurate formulation, preferably empirical, for the pivot deformation. Clearly, predicting accurately force coefficients demands to know the heat flow paths through the journal and bearing and the exact boundary conditions.

The computational analysis will continue in the next two years to enhance the predictive tool by including (1) pad surface and pad pivot deformations due to pressure and temperature changes, and (2) a model for LEG injection in the bearing pads. The model will rely on commercial software to build the structural 3D FE model of a bearing pad to calculate deformations from the mechanical and thermally induced stresses. Guyan reduction will simplify the model to its active degrees of freedom on the pad surface and pivot only. Further eigenvalue analysis will reduce the pad structural model into its fundamental modes for quick estimation of deformations for any type of forcing function (pressure or temperature). The numerical procedure will be performed off-line, that is outside of the main **TPJB®** code, to save resources and expedite the numerical solution of the fluid flow equations in the thin film region. Next, **TPJB®** will **i**mplement various oil feed arrangements in the FE model to represent leading edge groove supply systems and scrapers. The mesh generation and shape of the elements will be tailored to accommodate practical configurations.

The enhanced computational program will enable TRC members to model commercial tilting pad journal bearing configurations. The tool will reduce the burden on the unseasoned user by calculating the actual operating clearances and reducing to a minimum the specification of empirical parameters and guessing the correct boundary conditions for a proper thermal analysis.

AUTOMATED ANALYSIS OF TIME TRANSIENT RESPONSES IN NONLINEAR ROTOR-BEARING SYSTEMS (YEAR II)

XLTRC^2© predicts the dynamic forced response of realistic rotor-bearing systems (RBS). The tool includes linear analyses showing undamped critical speed maps, eigenvalues (critical speeds and damping ratios) and synchronous imbalance response. XLTRC^2© also promises to evaluate time transient RBS responses and includes a few idealized nonlinear effects such as a plain journal bearing or a rub simulator. Running XLTRC^2© to predict transient RBS responses is a major task, often frustrating; and when successful, the amount of data spit by the code is enormous with a few graphical traces showing blurs.

In 2011, the TRC funded a 2010 proposal to construct GUIs integrated into XLTRC^2 nonlinear analysis feature to perform automated (point & click) and meaningful transient response analyses. After one year of work, additional worksheets are already in place to perform complete transient response analysis with a minimum of User frustration and a maximum efficiency in output handling for storage and post-processing that performs frequency domain analysis to generate waterfall plots and displays rotor motion amplitudes versus whirl frequency and rotor speed. Cases include multiple constant rotor speeds and ramp-up or down rotor speeds. In the second year of the project, the following tasks will be completed:

a) Upgrading XLTRC^2 FE code XL_PressDm_TH®, released in 2009, into an impedance model for prediction of instantaneous bearing reaction forces as a function of journal center position (X,Y) and velocities (V_X,V_Y). XL_PressDm_TH® models radial bearings with multiple pads (offset and preload) and pressure dam bearings. A squeeze film damper option, i.e. without journal or bearing rotation, will be built into the updated code. This feature will enable modeling SFDs and semi-floating ring bearings.

b) Integration of XL_PressDm_TH® into XLTRC^2 for nonlinear RBS analyses of actual rotor bearing systems

c) Conduct linear and nonlinear rotordynamic response analyses of a multiple-stage submersible pump.

The products of the research will enable TRC members to use efficiently XLTRC^2 for frequency domain analysis of the time response of nonlinear RBS. The research is of immediate applicability into high speed RBS such as turbochargers, for example.

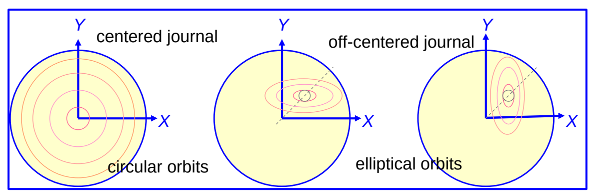
LINEAR-NONLINEAR FORCE COEFFICIENTS FOR SFDS (YEAR II)

High performance turbomachinery demands high shaft speeds, increased rotor flexibility, tighter clearances in the flow passages, advanced materials, and increased tolerance to imbalances. Operation at high speeds induces severe dynamic loading with large amplitude journal motions at the bearing supports. Squeeze Film dampers (SFD) aid to reduce rotor vibrations due to imbalance and other sources and also serve to isolate the rotor(s) from the engine frame or casing. Energy efficient and reliable rotordynamic operation of aircraft engines calls for detailed understanding of SFD forced performance. Predictions derived from classical SFD analyses fail to accurately predict the force coefficients for SFDs.

TRC funded in 2011 an experimental program to identify force coefficients in a large load Squeeze Film Damper (SFD) test rig. The rig permits the excitation of the BC with large amplitude whirl motions of arbitrary shape. In practice this is a normal occurrence. However, predicted (linear) SFD force coefficients may not represent with fidelity the actual forced response of a SFD, in particular for off-centered journal motions. Recall that rotordynamic force coefficients are derived from infinitesimally small amplitude motion about an equilibrium condition. These conditions are often violated in SFD operation.

In 2012-13 work is proposed to:

(a) Test a short length (1 inch) open ends damper with dynamic loads (20-300 Hz) inducing off-centered elliptical orbital motions with amplitude ratios as large as 5:1 to reach 60% of the bearing clearance (see inset).



(b) Extract SFD force coefficients from test impedances obtained over a frequency range and correlate coefficients with predictions of linear coefficients and other experimental coefficients.

(c) Perform computational model numerical experiments, similar to the physical tests, to also extract linearized SFD force coefficients from the nonlinear forces and valid within a frequency range.

The proposed research is of interest for SFD applications in gas turbines, semi-floating ring bearings in turbochargers, hydrodynamic bearings in compressors, etc. Since 1990, TRC sponsors the SFD research program with many practical advances derived from planned experiments and computational analysis.

MAKING A WET (FOAMY) SEAL AND ESTIMATING ITS DYNAMICS FORCE COEFFICIENTS (NEW)

As oil fields deplete, in particular in deep sea reservoirs, pump and compression systems work under more strenuous conditions with gas in liquid and liquid in gas mixtures, mostly inhomogeneous. Off-design operation affects system overall efficiency and reliability, including penalties in leakage and rotordynamic performance of secondary flow components, namely seals. Designing and constructing compression systems handling wet gas conditions will eliminate L/G separators, reduce weight and parts, increase reliability and extend operation hours (five year desired).

The Turbomachinery Laboratory has advanced HSEALMIX® to predict the leakage, power loss and force coefficients of two-fluid component annular flow seals (gas in liquid and liquid in gas). The predictions show leakage and power loss decreasing with the gas in liquid volume content and seal force coefficients with a strong dependency on the excitation frequency. To date there is no experimental results validating the computational mixture model predictions. A test program is urgently needed to satisfy the current needs of sub-sea pumping and compression systems, in particular with *wet* (foamy) seals operating with small liquid volume contents (5% or less).

In the late 1990s, NSF supported a comprehensive research to elucidate the effects of bubbly oil mixtures on the generation of dynamic film pressures in SFDs. Over the course of six years, test rigs and measurement procedures evolved to offer sobering pictures on the affect of air ingestion and entrapment in SFDs,

Experiments will be conducted to characterize the forced response of a short length annular seal operating with a foamy mixture (small contents of liquid in a gas stream). An existing TRC vertical test rig holding a short length annular seal (*L*=1 inch, *D*=5 inch, *c*=5mil) will be used to perform measurements of leakage and dynamic force response. A fixture mixing pressurized air with a mineral oil lubricant stream could be easily manufactured using a sparger element. However, the difficulty lies in making homogenous mixtures with little liquid, i.e., gas volume fractions >95% to make a foamy substance. Keeping the bubbles small and homogenous and traveling (slowing down) at the same speed as the liquid content are challenges to overcome.

During the first year the research will focus on (a) readying the test rig for measurements with rotor speed to 6,000 krpm (surface speed 40 m/s) and with supply pressures to 100 psig (7 bar), and (b) making the air/oil mixing fixture that will produce consistent wet (foamy) mixtures. The bearing/seal cartridge is made of Plexiglas; hence, digital video recordings of the mixture flowing through the seal gap will reveal pooling at the seal inlet, collapsing and merging of bubbles to make fingering and striations, etc. The test rig has all the instrumentation needed including two 100 lb_f electromagnetic shakers and the ancillary lubrication supply and return system. (c) Perform dynamic load measurements to record the seal forced response. Based on the measurements, conducted over many-many cycles of forced functions, a signals ensemble procedure will extract the seal average force coefficients.

The results of the experimental effort will serve to benchmark the predictive tool HSEALMIX® bringing a physics based understanding on the generation of bubbly mixtures, and the quantification of the force coefficients of *wet* seals applied to deep-sea (submersible) compressors, for example.

ENGINEERED ANALYSIS FOR POCKET DAMPER SEALS AND COMBINED LABYRINTH-BRUSH SEALS (NEW)

Parasitic secondary flows (seals leakage) in centrifugal compressors and turbines represent a substantial loss in efficiency and power delivery with an increase in specific fuel consumption. Labyrinth seals (LS) are the most common and inexpensive means of reducing secondary leakage, albeit wearing out with operation and thereby penalizing performance and even affecting rotordynamic stability. Improperly designed and operated labyrinth seals can be the source of rotordynamic instabilities.

Pocket damper seals (PDS), adding baffles in (alternating) circumferential cavities of a LS and engineering the inlet and exit tip clearances, have demonstrated enormous benefits in seal stability by providing physically large damping coefficients. Analysis for fully partitioned PDS is presently lacking. Brush seals (BS) have leakage as little as 10% of that in a similar size labyrinth seal. Retractable gland packing and inter-stage packing seals in steam turbines incorporate a hybrid seal composed of a BS installed mid-way of a multiple-teeth labyrinth seal. benefit most from the change in seal configuration. Predictive tools for this seal type are proprietary.

A two year effort is proposed to develop computational models for prediction of leakage, drag power loss and force coefficients of fully portioned PDS and combined labyrinth-brush seals. In the first year, leakage models will be developed and verified, and in the second year the computational models will advance to predict rotordynamic force coefficients. The models will integrate real gas properties, including steam and supercritical CO_2. The analysis will be limited to centered rotor operation.

The products of the research will enable TRC members to upgrade their arsenal of predictive tools for ready integration into their engineering design and practice processes. The Tribology Group has an outstanding reputation in developing computational models to engineer, design and troubleshoot bearings and seals in modern high performance turbomachinery.

Tribology Group - Funded Research 2012

External NEW funds (2011) $ 187,619

Principal Investigator(s)	Sponsor Project #	Amount	Project	Dates (GS support)
L. San Andrés 32525/B4770/ME	Borg-Warner Turbo Technologies	**$ 90,441**	Analysis of Thrust Bearings for Oil-Free Turbochargers	09/01/11 – 08/31/12 (1)
L. San Andrés 32525/39600/ME	PRATT & WHITNEY	**$ 97,178**	Squeeze Film Damper – design of test rig for high frequency & high load operation	09/01/10 – 08/31/12 (1)

Internal: $146,274 (TRC 2011)

Principal Investigator(s)	Sponsor	Amount	Project	Dates (GS support)
L. San Andrés	TRC 32514/1519X5	**$38,608**	Metal mesh Foil Bearings – Operation at High Temperatures	10/01/11 08/31/12 (1)
L. San Andrés	TRC 32514/15193S	**$35,000**	High Temperature Low Leakage Seals (Y II)	11/01/11 08/31/12 (1)
L. San Andrés	TRC 32514/1519SF	**$37,108**	Linear-Nonlinear Force Coefficients for SFDS	11/01/10 08/31/12 (1)
L. San Andrés	TRC 32514/15196B	**$35,558**	Computational Model for Tilting pad Bearings (Y II)	09/01/11 08/31/12 (1)

Software licensing through TEES, $68,000 project 32271/84390 (since June 2011)

Licensee	Amount	Software	Date
Becker Turbo	**15,000**	XLGFBTH	Aug-4-11
GE Nuovo Pignone	**18,000**	PDSeal source	Aug-10-11
R&D Dynamics	**9,000**	GFBPress	Aug 29-11
Sigma Group	**3,500**	HsealH	Aug-19-2011
Echogen R&D Dynamics	**4,000**	Pdseal exec	Aug-30-2011
LaunchPoint Tech	**3,500**	HsealH	Nov-11
KIST	**15,000**	XLGFBTH	Jan-12

Research Expenditures Fiscal Year 2011 & 2012: ~ $ 246,384+182,235

Source: TEES portal May 6, 2012

Tribology Group Publications 2011/2012

	2008	2009	2010	2011	2012	Total 2011-2012
Journal (peer reviewed)	5	6	11	6	2	**8**
Conference (peer reviewed)	6	7	7	5	5	**10**
Conference (NOT peer reviewed)	2	2	2			
Book Chapters		1	1		3	**5**
Accepted/awaiting publication					4	**4**

below **bold face**=student co-author

Journal publications (peer reviewed)

2012 San Andrés, L.., and Delgado, A., "A Novel Bulk-Flow Model for Improved Predictions of Force Coefficients in Grooved Oil Seals Operating Eccentrically," ASME J. Eng. Gas Turbines Power, vol. 134 (May), 022509 [ASME Paper GT2011-45274] **2011 Best Rotordynamics Paper Award –ASME (IGTI)**

San Andrés, L., 2012, "Rotordynamic Force Coefficients of Bubbly Mixture Annular Pressure Seals, "ASME J. Eng. Gas Turbines Power, vol. 134 (Feb), 022503 [ASME Paper GT2011-45264]

2011 San Andrés, L., and **Chirathadam, T.,** 2011, **"**Metal Mesh Foil Bearings: Effect of Excitation Frequency on Rotordynamic Force Coefficients," ASME J. Eng. Gas Turbines Power, vol. 133 (Dec), 122503, [ASME Paper GT2011-45257]

San Andrés, L., and **Chirathadam T.A**., 2011, "Identification of Rotordynamic Force Coefficients of a Metal Mesh Foil Bearing Using Impact Load Excitations," ASME J. Eng. Gas Turbines Power, Vol. 133 (Nov), p. 112501 [ASME paper GT2010-22440]

San Andrés, L., **Ryu, K.,** and **Kim, T-H,** "Thermal Management and Rotordynamic Performance of a Hot Rotor-Gas Foil Bearings System. Part 1: Measurements", ASME J. Eng. Gas Turbines Power, **vol. 133** (June), 062501 [ASME paper GT2010-22981]

San Andrés, **Kim, T-H**, and **Ryu, K**., "Thermal Management and Rotordynamic Performance of a Hot Rotor-Gas Foil Bearings System. Part 2: Predictions Versus Test Data," ASME J. Eng. Gas Turbines Power, , **vol. 133** (June), 062502 [ASME paper GT2010-22983]

Howard, S., and San Andrés, L., 2011, "A New Analysis Tool Assessment for Rotordynamic Modeling of Gas Foil Bearings," ASME J. Eng. Gas Turbines Power, **vol. 133** (Feb.), 022505 [ASME paper GT2010-22508 (NASA/TM-2010-216354)]

San Andrés, L., **Ryu, K**., and Kim, T.H., 2011, "Identification of Structural Stiffness and Energy Dissipation parameters in a 2nd Generation Foil Bearing; Effect of Shaft Temperature", ASME J. Eng. Gas Turbines Power, vol. **133** (March) **,** pp. 032501

Peer reviewed Conference publications

2012 ASME Turbo Expo Gas Turbine Conference, Copenhagen (June 2012)

Jauregui, J.C., DeSantiago, O., and San Andrés, L., 2012, "Identification of Bearing Stiffness and Damping Coefficients Using Phase-Plane Diagrams," ASME Paper GT2012-69980.

J **Ryu, K.,** and San Andrés, L., 2012, "Effect of Cooling Flow on The Operation of a Hot Rotor-Gas Foil Bearing System," ASME paper GT2012-68074

J San Andrés, L., 2012, "Damping And Inertia Coefficients for Two Open Ends Squeeze Film Dampers with a Central Groove: Measurements and Predictions," ASME paper GT2012-68212

J San Andrés, L.., Barbarie, V., Bhatthacharya, A., and Gjika, K., 2012, "On the Effect of Thermal Energy Transport to the Performance of (Semi) Floating Ring Bearing Systems for Automotive Turbochargers," ASME paper GT2012-68074

J San Andrés, L., and **Chirathadam, T.,** 2012, "A Metal Mesh Foil Bearing and a Bump-Type Foil Bearing: Comparison of Performance for Two Similar Size Gas Bearings," ASME paper GT2012-68437

2011 ASME Turbo Expo Gas Turbine Conference, Vancouver (June 2011)

San Andrés, L., 2011, "Rotordynamic Force Coefficients of Bubbly Mixture Annular Pressure Seals," ASME paper GT2011-45264

San Andrés, L., and **Chirathadam, T.,** 2011, **"**Metal Mesh Foil Bearings: Effect of Excitation Frequency on Rotordynamic Force Coefficients," ASME paper GT2011-45257

San Andrés, L.., and Delgado, A., 2011, "A Novel Bulk-Flow Model for Improved Predictions of Force Coefficients in Grooved Oil Seals Operating Eccentrically," ASME paper GT2011-45274

San Andrés, L.., and **Ryu, K**., 2011, "On the Nonlinear Dynamics of Rotor-Foil Bearing Systems: Effects of Shaft Acceleration, Mass Imbalance and Bearing Mechanical Energy Dissipation," ASME paper GT2011-45763

De Santiago, O., and San Andrés, L., 2011, "Parametric Study of Bump Foil Gas Bearings for Industrial Applications," ASME paper GT2011-46767

PUBLICATIONS OF BOOKS OR AUTHORITATIVE REFERENCES

Accepted for journal & in print (*) 2012

ASME J Eng Gas Turbines and Power

GT2012-68074	**Ryu, K.,** and San Andrés, L., 2012, "Effect of Cooling Flow on The Operation of a Hot Rotor-Gas Foil Bearing System"
GT2012-68212	San Andrés, L., 2012, "Damping And Inertia Coefficients for Two Open Ends Squeeze Film Dampers with a Central Groove: Measurements and Predictions"
GT2012-68074	San Andrés, L.., Barbarie, V., Bhatthacharya, A., and Gjika, K., 2012, "On the Effect of Thermal Energy Transport to the Performance of (Semi) Floating Ring Bearing Systems for Automotive Turbochargers"
GT2012-68437	San Andrés, L., and **Chirathadam, T.,** 2012, "A Metal Mesh Foil Bearing and a Bump-Type Foil Bearing: Comparison of Performance for Two Similar Size Gas Bearings"

Under review 2012

ASME International Mechanical Engineering Congress & Exhibition, Nov. 9-15, Houston, TX

IMECE2012-87713	San Andrés, L., 2012, " Extended finite element analysis of journal bearing forced performance to include fluid inertia force coefficients"

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