Mechanical Engineering Department
Texas A&M University

2010/2011
Research Progress Report
Tribology Group

Year XX

31st Annual
Turbomachinery Research Consortium Meeting

May 2011

Luis San Andrés
Mast-Childs Tribology Professor
Leader

http://rotorlab.tamu.edu

Tribology Group

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FOREWORD

This past year (June 2010-May 2011), Luis San Andrés spent time chasing funds for continuing the research program on gas bearings for high speed micro-turbomachinery; in particular towards the experimental verification of thrust foil gas bearings and to develop a predictive tool (to be) benchmarked by test data. NSF (National Science Foundation) rejected twice a crafted comprehensive proposal with a strong recommendation to search for industrial funding in a well established area of engineering. Other potential sponsors such as NASA and TRC members also showed no interest on the proposed work. This engineering research area is now pursued efficiently in other nations with foreign TM OEMS taking the lead on gas bearing technology.

In addition, students and Dr. San Andrés worked feverishly to satisfy the demands of a fast-paced project on testing and re-testing squeeze film dampers. Alas the sponsor leadership changed frequently and the project ended in a muddle without resources to support the graduating students. Nonetheless, the test results obtained and model developed advance significantly the state of the art in damper technology. The SFD test rig constructed is a highly engineered system for ready use to verify the forced response of SFDs operating with high static loads (off-centered) and high dynamic loads with frequencies to 400 Hz.

As per teaching, years 2010/11 are the most rewarding in Dr. San Andrés academic career. UG students taking the Junior Dynamics & Vibrations course in Fall 2010 performed better (50% more A's) than thirteen prior classes (2004-2009) taking the same class. The students showed a genuine interest in the topic and excelled in the projects and exams. In addition, in Spring 2011, Dr. San Andrés prepared and taught a new course, a technical elective without technical content. This class entitled **Practices of Modern Engineering** gives the undergraduate students the (soft) skills necessary to succeed in a global engineering world: fluent oral and written communication kills including the elevator speech; business and management practices across cultures; managing one's career and engineering one's management practices; the practice of innovation and a solid foundation on intellectual property; and how to interview and how to keep a job; how to do more with less; and, how to do things right the first time. Students' interest drove the content that included technical presentations on green engineering and sustainability as well as the 21st century Grand Challenges for Engineering. Please browse http://rotorlab.tamu.edu/me489 to know more about a course that teaches *to learn how to learn*, the lectures and student presentations, as well as sound advice from young engineers and experienced engineers who graciously donated their time and exchanged their experience with the engineering UG students.

The Turbomachinery Research Consortium (TRC) funded three projects out of four proposals submitted last May 2010. Details follow, not all projects started on September 1, 2010.

- **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 measurements and measure leakage for a labyrinth seal and a HALO™ seal
  STATUS: Measurements of leakage in labyrinth seal and HALO seal completed; no rotor spinning. Revamping of test rig in progress. Project started September 1, 2010 (2 years).
  SPONSOR : TURBOMACHINERY RESEARCH CONSORTIUM, $39,863
  Student: Alain Anderson (M.S.), James Law (U.G.)

- **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: Code for ideal rigid-pivot bearings operational. Mathematical model to include pivot stiffness shows progress. Project started September 1, 2010 (2 years).
SPONSOR : TURBOMACHINERY RESEARCH CONSORTIUM, **$34,863**
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: Project started May 2011 (1 year).
  SPONSOR : TURBOMACHINERY RESEARCH CONSORTIUM, **$34,863**
  Student: Qing Liu (Ph.D.)

Other funded/unfunded projects include:

- **Squeeze Film Damper – Identification of force coefficients from tests with high frequency & high loads**
  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 inch diameter open and sealed ends SFDs with central groove. Effect of fluid inertia dominates SFD forced response. Contract ended December 31, 2010
  SPONSOR: PRATT & WHITNEY, **$339,086**
  Students: Sanjeev Seshagiri (M.S.), Paola Mahecha (M.S.), Sarabeth Froneberger (UG)

- **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 theoretical analysis and development of computational code in progress. Project started October 1, 2010 (2 years).
  SPONSOR : HONEYWELL TURBOCHARGING TECHNOLOGIES, **$208,340**
  Student: Feng Yu (M.S.)

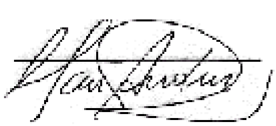
- **Computational Model for Textured Surface Gas Face Seals**
  OBJECTIVE: Develop code for prediction of leakage and forced response in novel gas face seals for steam turbines.
  STATUS: Code SpiralG under extensions for novel groove geometries..
  SPONSOR : CIATEQ A.C. (MX),
  Student: Jose Hernandez (M.S. sponsored student)

- **Gas foil bearings for high speed turbomachinery**
  OBJECTIVE: Continue to advance gas bearing technology for high temperature, hgh speed microturbomachinery applications (power < 400 kW).
  STATUS: Compare dynamic forced performance between a MMFB (metal mesh foil bearing) and first-generation bump-type foil bearing. Computational analysis of radial MMFBs in progress.
  SPONSOR : NONE. Funds from licensing software support one student
  Student: Thomas Chirathadam (Ph.D.)

In spite of the difficulties in securing significant funding, the Tribology Group students continue to excel in the quality of their research products as evidenced by the number of technical papers published. See the inset for the statistics in 2010-2011 (May).

2010-2011 papers	#
Journal (peer reviewed)	**16**
Conference (peer reviewed)	**12**
Conference (NOT peer reviewed)	2
Book Chapters	1
Accepted/awaiting publication	3

Enjoy the 31th TRC Annual Meeting. We hope to count with your continued support in 2011-2012. As per other news, do listen to some original music recordings at http://www.ies3.com/ElSanto I do have a life after all.



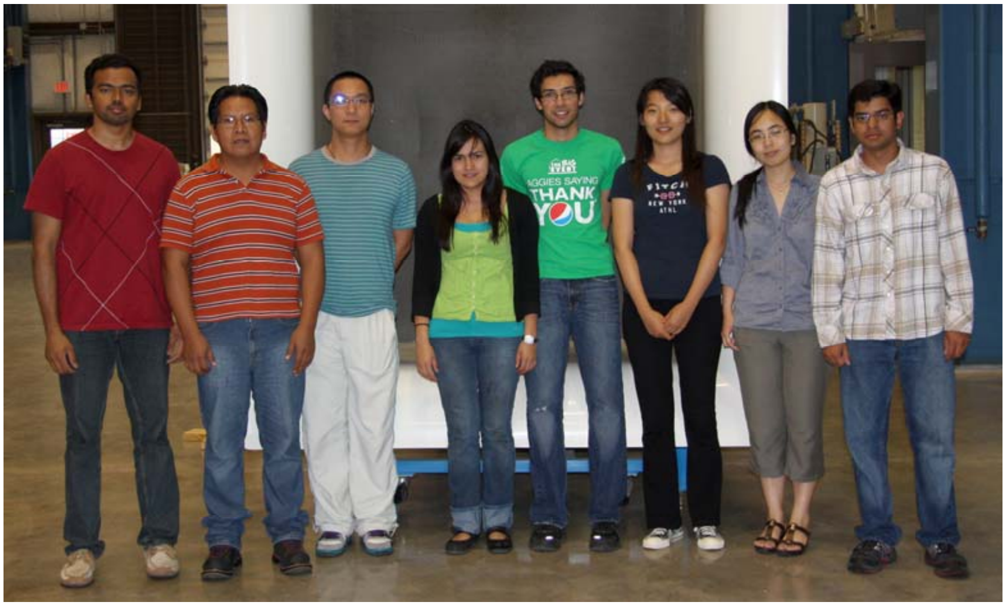
Luis San Andrés, Mast-Childs Tribology Professor

Tribology Group

Team Members 2010-2011

Name	Research Project	Degree	Graduation date
Keun Ryu Borg-Warner TCs	Bump-type Foil Bearings: Measurements of High Temperature Performance	Ph.D.	August 2011
Thomas Chirathadam	Metal Mesh and Bump-type Foil Bearings: Identification of Rotordynamic Force Coefficients	Ph.D.	December 2011
Alain Anderson+ James Law(*)	Measurement of leakage in a novel all metal non contacting annular seal at high temperatures	M.S. B.S.	May 2012 May 2011
Sanjeev Seshaghiri Paola Mahecha+ Sarabeth Froneberger(*)	SFD Test Rig & Measurements: Pratt & Whitney	M.S. M.S. B.S.	May 2011 August 2011 May 2011
Feng Yu	Turbocharger Bearing Code Development	M.S.	May 2012
YuJiao Tao+	Computational Model for Tilting Pad Journal Bearings	M.S.	May 2012
Qing Liu+	Nonlinear Dynamics of Rotor-Bearing Systems	Ph.D.	May 2013

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



Thomas Chirathadam   Feng Yu   Alain Anderson   Qing Liu

Jose Hernandez   Paola Mahecha   Yujiao Tao   Sanjeev Seshaghiri

(*) Keun Ryu not pictured. He is out in the real world making a difference!

2011 RESEARCH PROGRESS REPORTS

COMPARISON OF LEAKAGE BETWEEN A LABYRINTH SEAL AND AN ALL-METAL COMPLIANT GAS SEAL AT HIGH TEMPERATURE

TRC-Seal-XX-11

Luis San Andrés

2011 RESEARCH PROPOSALS

CONTINUATION	# years	Cost
MEASUREMENT OF LEAKAGE IN A NOVEL ALL METAL NON-CONTACTING ANNULAR SEAL AT HIGH TEMPERATURES	1	$ 35,000
COMPUTATIONAL MODEL FOR TILTING PAD JOURNAL BEARINGS	1	$ 35,558
NEW		
LINEAR-NONLINEAR FORCE COEFFICIENTS FOR SQUEEZE FILM DAMPERS	1	$37,108
METAL MESH FOIL BEARINGS: OPERATION AT HIGH TEMPERATURE	1	$38,608

PROPOSALS –SUMMARIES

MEASUREMENT OF LEAKAGE IN A NOVEL ALL METAL NON-CONTACTING ANNULAR SEAL AT HIGH TEMPERATURES (YEAR II)

Parasitic secondary flows (seals leakage) in centrifugal compressors and gas and steam turbines represent a substantial loss in efficiency and power delivery with an increase in specific fuel consumption. Labyrinth seals (LBS) 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. Presently, there are other seal types that can perform better in terms of leakage reduction and low drag power losses.

In July 2010, TRC funded a two-year program to (a) conduct non-proprietary leakage tests with a HALO™ seal and, for comparison, a three tooth labyrinth seal; and (b) to revamp the test rig for for operation at higher rotor speeds to reach a tip surface speed of 120 m/s (15 krpm), thus replicating tip speeds found in land-based power generation gas and steam turbines. The HALO™ seal [Hydrostatic Advanced Low Leakage] is an all metal compliant seal engineered to close its clearance as pressure differentials increase.

The following tasks will be completed during the second year of the research program (2011-2012):

a) Complete revamping test rig for operation at a high rotor speed (15 krpm) to reach a tip surface speed of 120 m/s.

b) Perform clearance and leakage measurements with a three tooth labyrinth seal and the HALO™ seal operating with large pressure ratios, 8 max., air inlet temperatures to 300ºC, and tip surface speeds to 120 m/s.

c) To compare the labyrinth seal measured leakage with XLLABY® predictions at high temperatures. The benchmarking is essential to trust, modify or discard current predictive models.

The research products –a reliable leakage data base and technical report (M.S. thesis)- will enable the application of state of the art sealing technology that increases system efficiency by reducing leakage and that extends maintenance intervals by eliminating wear of components

COMPUTATIONAL MODEL FOR TILTING PAD JOURNAL BEARINGS (YEAR II)

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. $XLTRC^2$ software suite includes a computational code for prediction of tilting pad bearings static operation and frequency reduced stiffness and damping force coefficients. Since 2006, Childs and students have conducted measurements of rotordynamic force coefficients for a number of industrial type tilting pad journal bearings. In general, predicted bearing stiffness and damping correlate well with the measurements for small to moderate specific loads (up to 150 psi [10 bar]). The measurements evidence the bearing stiffness force coefficients to be strongly frequency dependent, best represented with a **K-M** model. Damping coefficients are adequately represented with magnitudes not depending on frequency. In a heavily loaded condition, poor correlation of predictions to measured force coefficients is evident.

TRC funded a two-year project to enhance an existing computational tool for accurate prediction of tilting pad bearing force coefficients for heavily loaded operating conditions. The upgraded model will include pivot flexibility, typically nonlinear, for a number of pivot type configurations, with specification of sliding or rolling contact conditions. In 2011, the student working in the project read the extensive literature on experimental identification of tilting pad bearing force coefficients, understood the differences in physical behavior for the various types of pivots, and the paramount effect of pad flexibility and pivot flexibility on reducing (or increasing) TPJBs (reduced frequency) stiffness and damping force coefficients; as well as current issues on rotordynamic stability criteria for rotors supported on tilting pad bearings. The student took XLPRESDAM_TH® code, beginning modifications and enhancements towards making it into a tilting pad bearing code. Presently, the code predicts reduced frequency force coefficients for ideal tilting pad bearings, i.e., those with infinite pivot stiffness, radial and lateral. Predictions from the modified code are in agreement with those published in Someya's Bearing Handbook as well as with results obtained with XLTFPBRG® code, the tool presently available in the XLTRC^2 software suite

In the second year, the student will complete the computational program enabling TRC members to model accurately realistic tilting pad configurations. The computer code will be integrated into XLTRC^2 for ready use. A technical report detailing the model enhancements as well as comparisons to the test data of Childs et al. will be delivered at the end of the project. The GUI will be revamped for more expedite computational predictions with physically reasonable starting initial *guesses* to reduce the burden on the unseasoned user.

New

METAL MESH FOIL BEARINGS: OPERATION AT HIGH TEMPERATURES

Metal Mesh Foil Bearings (MMFBs) are simple and inexpensive gas bearings that provide low friction, long operating life, and material damping for mechanical energy dissipation into high speed rotor bearing systems. Engineered MMFBs will aid to improve system efficiency, raise power density, and lower carbon foot-print when compared to oil-lubricated bearing systems.

The main objective of the proposed work is to demonstrate the reliable operation of MMFBs at elevated temperatures (max 200°C) and their ability to survive harsh environments with an adequate thermal management. A high temperature rotor-bearing test rig constructed with NASA funds for evaluation of bump type foil bearings is available. In the rig, an electric heater cartridge inside the hollow rotor warms the rotor to high temperature (max 300°C). The tasks for 2011/12 are:

a) Construct two MMFBs fitting the existing bearing casing and shaft diameter, install the MMFBs in the test rig, align and balance the test rotor, and calibrate the high temperature instrumentation.
b) Conduct experiments with rotor OD surface temperatures to 200°C and to a top rotor speed of 50 krpm. Measure bearing temperatures as the rotor (slowly) heats up and while providing increasing cooling streams. Assess the effectiveness of the cooling flow rates on managing the bearing and rotor temperatures. Rotor speed up and coast-down measurements will show rotor lift-off and touch down speeds, and the amplitude of motion data will serve to identify system damping ratios and effective bearing stiffnesses.
c) Compare the thermal performance of the MMFBs with that recorded for generation I, bump-foil bearings.

The results of the research will characterize, both qualitatively and quantitatively, a novel (non proprietary) gas bearing technology of low cost, simple in construction, and suitable for operation at high and low temperatures.

New

LINEAR-NONLINEAR FORCE COEFFICIENTS FOR SQUEEZE FILM DAMPERS

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.

Pratt & Whitney engines sponsored a two-year test program (2008-2010) to investigate novel SFD configurations operating at typical conditions encountered in aircraft jet engines. The project provided reliable SFD forced performance data and benchmarked predictions from a new computational program. The existing test 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 strictly valid for infinitesimally small amplitude motion about an equilibrium condition. Both requirements, an equilibrium state and small whirl amplitude motions, are often violated in SFD operation. Work is proposed to:

(a) Test the short length 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 80% 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 force coefficients and experimental coefficients for smallest whirl amplitudes (5%*c*).
(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. Determine goodness of linear-nonlinear representation from the equivalence in mechanical energy dissipation with the work performed from the actual nonlinear forces (experimental and numerical).

The TAMU SFD research program is the most renown in the world. 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.

Tribology Group - Funded Research **2011**

External NEW funds (2010) $ 208,340

Principal Investigator(s)	Sponsor Project #	Amount	Project	Dates (GS support)
L. San Andrés 32525/39600/ME	HONEYWELL TURBOCHARGING TECHNOLOGIES	**$208,340**	Turbocharger Bearing Code Development	09/01/10 – 08/31/12
L. San Andrés 32513/A2850/ME	PRATT & WHITNEY	$339,086	Squeeze Film Damper – design of test rig for high frequency & high load operation	07/01/08 – 12/31/10 (2)

Internal: $109,589 (TRC)

Principal Investigator(s)	Sponsor	Amount	Project	Dates
L. San Andrés	TRC 32514/1519X5/ME	$34,863	Automated Modeling XLTRC2 RBS Transient Response	03/01/11 1 year
L. San Andrés	TRC 32514/15193B/ME	$39,863	High Temperature Low Leakage Seals	08/01/10 08/31/11
L. San Andrés	TRC 32514/15196B/ME	$34,863	Modeling of Tilting pad Bearings	08/01/10 08/31/11

Software licensing through TEES, $44,500 project 32271/84390

Licensee	Amount	Software package	Date
RAMGEN	3,500	HSeal	June 2010
Knight Hawk Eng	3,500	HSeal	June 2010
Barber Nichols	10,000	XLGFBpress	November 2010
Air Products	9,000	XLGFBpress	February 2011
FMC Technologies	3,500	HSeal	April 2011
Borg-Warner	15,000	XLGFBTH	May 2011
	44,500		

Research Expenditures Fiscal Year 2010 & 2011: ~ $ 192,469+151,347.

Source: TEES portal 05/06/2011

Tribology Group Publications 2010/2011

	2008	2009	2010	2011	Total 2010-2011
Journal (peer reviewed)	5	6	11	5	16
Conference (peer reviewed)	6	7	7	5	12
Conference (NOT peer reviewed)	2	2	2		2
Book Chapters		1	1		1
Accepted/awaiting publication				3	3

Dr. San Andrés lecture notes on *Modern Lubrication Theory* have a permanent (perpetual), stable indexed URL address at Texas A & M University Digital Libraries, http://repository.tamu.edu/handle/1969.1/93197

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

Journal publications (peer reviewed)

2011 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

2010 Gjika, K., C. Groves, L. San Andrés, and LaRue, G., 2010, "Nonlinear Dynamic Behavior of Turbocharger Rotor-Bearing Systems with Hydrodynamic Oil Film and Squeeze Film Damper in Series: Prediction and Experiment," ASME Journal of Computational and Nonlinear Dynamics, Vol. **5** (October), p. 041006-(1-8).

Delgado, A., and San Andrés, L., 2010, "A Model for Improved Prediction of Force Coefficients in Grooved Squeeze Film Dampers and Grooved Oil Seal Rings", ASME Journal of Tribology Vol. 132(July), p. **032202** (1-12)

Delgado, A., and San Andrés, L., 2010, "Identification of Force Coefficients in a Squeeze Film Damper with a Mechanical Seal: Large Contact Force," ASME Journal of Tribology, Vol. 132(July), p. **032201** (1-7)

San Andrés, L., **Chirathadam, T., Ryu, K.,** and **Kim, T.H.**, 2010, "Measurements of Drag Torque, Lift-Off Journal Speed and Temperature in a Metal Mesh Foil Bearing," ASME J. Eng. Gas Turbines Power, Vol. 132(Nov), p. **112503** (1-7)

San Andrés, L., and **Ashton, Z.,** 2010, "Comparison of Leakage Performance in Three Types of Gas Annular Seals Operating at (300ºC) High Temperature, STLE Tribology Transactions, Vol. 53(3), pp. 463

San Andrés, L., **Delgado, D.,** and **Baker, J.,** 2010, "Rotordynamic Force Coefficients of a Hybrid Brush Seal: Measurements and Predictions," ASME J. Eng. Gas Turbines Power, Vol. 132 (April), p. **042503** (ASME Paper No. GT2009-59072)

San Andrés, L., and **Kim, T.H.,** 2010, "Thermohydrodynamic Analysis of Bump Type Gas Foil Bearings:

A Model Anchored to Test Data," ASME J. Eng. Gas Turbines Power, Vol. 132 (April), p. **042504** (ASME Paper No. GT2009-59919)

Delgado, D., and San Andrés, L., 2010, "Identification of Squeeze Film Damper Force Coefficients from Multiple-Frequency, Non-Circular Journal Motions," ASME J. Eng. Gas Turbines Power, Vol. 132 (April), p. **042501** (ASME Paper No. GT2009-59175)

Kim, T. H., and San Andrés, L., 2010, "Thermohydrodynamic Model Predictions and Performance Measurements of Bump-Type Foil Bearing for Oil-Free Turboshaft Engines in Rotorcraft Propulsion Systems," ASME Journal of Tribology, Vol. 132(January), p. **011701**

San Andrés, L., **Maruyama, A.,** Gjika, K., and Xia, S., 2010, "Turbocharger Nonlinear Response with Engine-Induced Excitations: Predictions and Test Data," ASME J. Eng. Gas Turbines Power, Vol. 132(March), p. **032502** (ASME Paper No. GT2009-59108)

San Andrés, L., **Chirathadam, T. A.**, and Kim, T.H., 2010, "Measurements of Structural Stiffness and Damping Coefficients in a Metal Mesh Foil Bearing," ASME J. Eng. Gas Turbines Power, Vol. 132(March), p. **032503** (ASME Paper No. GT2009-59315)

Peer reviewed Conference publications

(J accepted for journal publication)

2011

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

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

San Andrés, L.., and Delgado, A., "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., "Parametric Study of Bump Foil Gas Bearings for Industrial Applications," ASME paper GT2011-46767

8th IFToMM International Conference on Rotordynamics, September 12-15, Seoul, Korea

2010

San Andrés, L., **and Vistamehr, A.,** 2010, **"**Nonlinear Rotordynamics of Vehicle Turbochargers: Parameters Affecting Sub Harmonic Whirl frequencies and Their Jump," Proc. of the 8th IFToMM International Conference on Rotordynamics, September 12-15, Seoul, Korea, Paper WeE3-2.

San Andrés, L., **Camero, J., Muller, S., Chirathadam, T., and Ryu, K.,** 2010, "Measurements of Drag Torque, Lift Off Speed, and Structural Parameters in a 1st Generation Floating Gas Foil Bearing", Proc. of the 8th IFToMM International Conference on Rotordynamics, September 12-15, 2010, Seoul, Korea, Paper WeD1-5.

ASME Turbo Expo 2010, June 2010, Glasgow, Scotland

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 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 paper GT2010-22983

San Andrés, L., and **Chirathadam T.A.**, "Identification of Rotordynamic Force Coefficients of a Metal Mesh Foil Bearing Using Impact Load Excitations," ASME paper GT2010-22440

Howard, S., and San Andrés, L., "A New Analysis Tool Assessment for Rotordynamic Modeling of Gas Foil Bearings," ASME paper GT2010-22508

San Andrés, L., **Niu, Y.,** and **Ryu, K,** "Dynamic Response of a Rotor-Hybrid Gas Bearing System Due To Base Induced Periodic Motions," ASME paper GT2010-22277

Conference Proceedings - Not Peer Reviewed

2010

Hung, W., San Andrés, L., and Leon, V.J., 2010, "Research Experiences for Undergraduates in Micromanufacturing," Paper AC 2010-2373, ASEE Annual Conference and Exposition, Louisville, KY, June

Howard, S., and San Andrés, L., 2010. "A New Analysis Tool Assessment for Rotordynamic Modeling of Gas Foil Bearings," NASA T/M-2010-216354.

PUBLICATIONS OF BOOKS OR AUTHORITATIVE REFERENCES

STLE Tribology Transactions: Handbook of Tribology: Chapter on Gas Lubrication (2010)

Accepted for journal & in print (*) 2011

GTP11-1077	San Andrés, L., "Rotordynamic Force Coefficients of Bubbly Mixture Annular Pressure Seals, "ASME Paper GT2011-45264
GTP11-1091	San Andrés, L., and **Chirathadam, T., "**Metal Mesh Foil Bearings: Effect of Excitation Frequency on Rotor-dynamic Force Coefficients," ASME Paper GT2011-45257
	San Andrés, L.., and Delgado, A., "A Novel Bulk-Flow Model for Improved Predictions of Force Coefficients in Grooved Oil Seals Operating Eccentrically," ASME Paper GT2011-45274

Tribology Group

Luis San Andrés, 2011

http://rotorlab.tamu.edu