MEEN 459/659 – SOUND & VIBRATION MEASUREMENTS

SYLLABUS SPRING 2019 revised Jan 25

Course Description: Credit 3. Basic acoustics, review of vibration theory, wave propagation in vibrating systems, sound radiation from vibrating systems, sound and vibration sensors and instrumentation, data acquisition systems, measurement techniques, spectral analysis, spatial FFT analysis, design of experiments with vibro-acoustic systems, and applications.

Prerequisites: MEEN 363, MATH 308.

OBJECTIVES: To review the fundaments of vibration analysis (SDOF and MDOF) as applied to lateral, torsional and axial displacements in mechanical structures, rotating in particular; to learn about measurement vibration techniques (time and frequency domain) and sensors, including calculation of uncertainty and variability for multiple I/O systems; experimental techniques for identification of system parameters using recorded data in the frequency domain; relationship between sound and vibration and calculation of sound wave propagation speed, etc. See later **OUTCOMES (page 3)**.

Class Time: T, R 8:00-9:15 am JCAIN 206 or
R 5:30-6:45 pm JCAIN 202 on selected dates (see page 2)

Instructor: Dr. Luis San Andrés, Phone 862 4744, LsanAndres@tamu.edu
Office hours: T 9:20-10:00 pm, MEOB 117**, or by scheduled appointment** (e-mail in advance).

References: **MEEN 459 Class Notes (handouts),** L. San Andrés URL
MEEN 617 Class Notes (handouts), L. San Andrés
(To be released) Lectures, tutorials and case studies published in the Turbomachinery and Pump Symposia and various professional magazines. Find web resources at end of syllabus.

Other: MEASUREMENT SYSTEMS: APPLICATION & DESIGN, Doebelin, E., 5th ed, ISBN-13: 978-0072990720
Sound Propagation: An Impedance Based Approach, Y.-H. Kim
Fundamentals of Acoustics by L. E. Kinsler, A. R. Frey, A. B. Coppens, and J. V. Sanders

COURSE OUTLINE AND GRADING: One 75' lecture on Tuesday and one 75' guest lecture on Thursday (AM or PM) when a world-renown practitioner will share his/her experiences on vibrations/sound measurements. Most guest lectures will be scheduled on Thursday afternoon, 5:30-6:45 pm.

Note: attendance to the afternoon lectures is NOT mandatory (off regular class schedule). However, you will find the guest-presentations most useful for your professional life. Title and content of guest lectures released a week earlier.

GRADED **group** homework (computational assignments) given on Tuesday and turned in two weeks later, unless otherwise noted. Two **in-class** exams (75'), and one APP challenge application! No make-up exams will be given unless the student has a TAMU official excuse, and notified the instructor **in advance**.

	Grade		
Homework	300	Assigned T or R, turned T/R (typ 2 weeks)	Group work only
First Exam	250	**Measurement of Vibrations**	TUESDAY, March 5 **8:00 am**
Second Exam	250	**Measurement of Sound**	FRIDAY, May 3 **3:00 pm**
APP challenge	250	**Use an App to quantify a sound/vibration issue**	TUESDAY, April 23 **8:00 am**
	1050	(A= 900-1000, B =800-899, C=700-799)	grading scale

Notes: April 15: Last day for all students to drop course with no penalty (Q-drop).

MEEN 459/659 – S&V MEASUREMENTS CLASS SYLLABUS Spring 2019

ME363/617 Vibration Course notes at http://rotorlab.tamu.edu/me617/default.htm

week	Instructor lectures / content or topics	All 5:30 pm lectures in JCAIN 202
	Tuesday	**Thursday**
1	**01/15 Review of basic SDOF vibrations**: basic EOM for vibration system and physical parameters (mass, stiffness, damping), natural frequency and damping ratio.	**Periodic forced response** and **uses of frequency response function** to design and troubleshoot mechanical systems
2	**01/22 Review of basic MDOF vibrations**: Modal analysis (Undamped and Damped):	Modal coordinates and orthogonality properties, mode shapes and periodic forced response.
3	**01/29 Instrumentation for vibration measurement.** Displacement, velocity and acceleration. Pros and cons including cost and accessibility. FRF of typical sensors. Proper selection of instrumentation and DAQ system.	**01/31** 5:30 pm **Dustin Pavelek,** Kelm Engineering LLC
4	**02/05 Rationale and principles of measurement** Accuracy and precision. Static & dynamic measurements. Sensor calibration. Simple uncertainty analysis (SISO)	**02/07** 5:30 pm **Joe Moreno,** Lyondell Basell
5	**02/12 DFTs and vibrations.** The discrete Fourier transform and its applications. Spectra operations, cross spectra and coherence.	**02/14** 5:30 pm **Manuel Marin,** Lyondell Basell
6	**02/19 Field identification** of physical parameters in mechanical systems using frequency domain methods	**02/21** 5:30 pm **John Kocur,** Machinery Specialist, Exxon Mobil R&E
7	**02/26** Quantification of **Uncertainty and Repeatability** in measurements for SISO and MIMO (Single or Multiple Input and Output) systems	**02/28** 5:30 pm **Yve Zhao,** Field engineer, BHP Billiton
8	**03/05 EXAM I Tuesday: March 05 in class**	**03/07** 5:30 pm **John Whalen** (retired) Bearing Specialist
9	**Spring Break March 10-15**	Lecturer to Malaysia
10	**03/19 8**:00 am **Vibrations in rotating machinery** API recommendations and limits (LogDec and stability). Measurements for Rotor Balancing and balancing of rotors. **How to balance a rotor**	**03/21** 8:00 am **Kristo Naude,** Senior Engineer, Engineering Services, NRG
11	**03/26** 8:00 am **David Ransom,** Machinery Manager, SwRI **Torsional Vibrations** Basic systems (resonances and damping ratios) and motor drive start up responses. Sensors for measurements of torque and angular displacements.	**03/28** 8:00 am **Ed Wilcox,** Chevron ETC Machinery
12	**04/02 8**:00 am, **Vykram Palant, POLYTEC.** Intro to laser vibrometry.	**04/04** 5:30 pm, **John J. Yu,** Technical Leader, Machinery Diagnostic Services, Bently Nevada, BHGE
13	**04/09 8**:00 am **Vibration of Continuum systems**. Free vibrations of strings, elastic bars, beams and plates. Properties of normal mode functions. The wave equation.	**04/11** 5:30 pm **Jeff Moore,** Rotating Machinery Manager, SwRI
14	**04/16 8**:00 am **Review of basic sound analysis** Equation for acoustic wave propagation and the meaning of wave number, wave speed, and frequency, and their relations. **Instrumentation for sound measurement.**	**04/18** 5:30 pm, **Nicolas Peton,** Global Director, Machinery Diagnostics Services, Bently Nevada, BHGE (France)
14	**04/23 8**:00 am **The future today:** The Industrial Internet of Things (IIoT) Revolution, Digital Twins, etc. **04/23 Delivery of Report/Demo on V&S APP usage**	**04/25** 8:00 am **Tae-Ho Kim,** Kookmin Univ. (S Korea)
15	**05/03 Exam II May 3: 3:00-4:00 pm**	

COURSE LEARNING OUTCOMES: At the end of this course, students should be able to:

1) Apply Newton's laws to derive equations of motion, 2D and 3D, of lumped parameter systems (SDOF and MDOF).
2) Identify the natural frequency, damped natural frequency, and damping factors for a SDOF system. Explain the effect of logarithmic decrement on the amplitude and decay speed of system response.
3) Derive the acoustic wave equation and understand plane wave propagations in air. Understand the dynamic response and wave propagation characteristics of various vibrating structures. Explain physical meaning of wave number, wave speed, and frequency and relations between these quantities.
4) Obtain the Frequency Response Function (**FRF**) for periodic excitations and explain the effects of system parameters and frequency on the amplitude of motion and phase lag. Use FRF for appropriate design considerations and reliable operation of vibrating systems.
5) Use Modal analysis to obtain the FRF of MODF systems (undamped and damped), explain the concept of mode shapes and natural frequencies, etc. Solve for free and forced motion responses of MDOF example using modal coordinates.
6) Apply spectral analysis techniques to process sound and vibration data.
7) Design and perform experiments for measuring sound and vibration data. Understand limits of vibration and effects of excessive vibration on the performance of rotating machinery. Able to explain and apply API criteria to the response of rotating machinery (lateral and torsional).
8) Write an effective report on sound and vibration measurements.
9) Gain working knowledge of vibration sensors and instrumentation utilized in rotating machinery industry. Ability to quantify measurement uncertainty and repeatability in time response measurements.
10) Gain knowledge on state of the art application for vibration and sound measurements (lasers, video, etc).
11) Use ubiquitous *cheap* sensors (in personal communication devices) to measure and track vibrations and sound.

CONTRIBUTION TO MEETING REQUIREMENTS OF ABET CRITERION 5 (CURRICULUM):

Subject	Semester Hrs	Subject	Semester Hrs	Subject	Semester Hrs
Mathematics		Engineering Science	2	General	
Basic Science		Engineering Design	1		

RELATIONSHIP OF COURSE OBJECTIVES TO ABET 2019/20 PROGRAM OUTCOMES:

https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/#GC3

	ABET Program Outcome		ABET Program Outcome
x	Ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.	x	Ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
	Ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.	x	Ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
x	Ability to communicate effectively with a range of audiences.	x	Ability to acquire and apply new knowledge as needed, using appropriate learning strategies.
x	Ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.		

See http://student-rules.tamu.edu/rule07 for official University excused absences.

Note that the course assumes you already had some basic knowledge on vibrations (MEEN 363) and have a fundamental mathematics background to solve ODEs and PDEs (MATH 308). The course will reinforce your basic knowledge and provide you with the dos' and don'ts' of measuring vibrations in mechanical systems. Dr. San Andrés is not an expert on sound (analysis and measurements) but will deliver you with some basic knowledge on the subject.

ABOUT GUEST LECTURES: During this course, you will have the privilege to learn from the best vibration practitioners in the world. The instructor invited various experts whom (not surprisingly) agreed to visit A&M to deliver presentations in the form of Case Studies: a technical presentation describing the successful implementation of established technology to solve a real-world problem

In a Case Study, the presenter presents an unique issue//problem with a specific machinery or process and walks towards the solution by producing a root failure cause analysis and detailing how various (obvious) sources were eliminated from the final outtake. The presenters will stress on the measurements section with attention to procedure. Note that, in the academic research world we stumble into problems and resolve them on the fly. In the real world, on the other hand, one must plan ahead and assess carefully risk, with operation striving for total safety and avoiding any loss in costly production, etc. The lecturer closes when explain that the solution implemented resolved the issue and sums the lessons learned.

ABOUT HOMEWORKS: assigned on Tuesday (or Thursday) and turned in two weeks later. Homework will be worked in groups of max. 6 students (min. 3 students). **Homework makes 30%** (300 points) of your total grade. There will be no excuses for missing homework assignments. Homework will be graded and returned in class the following week.

For full credit homework should be presented in a professional way, including the problem(s) statement and objective, the steps in the modeling & data analysis and procedure of solution, including a nomenclature and a sound discussion of the results obtained.

Homework material includes solving ODEs/PDEs and completing computational analyses to analyze / diagnose measurements taken in actual systems and to identify system parameters.

The instructor may make available (post) solutions to homework problems in MATHCAD. Students may work assignments using any type of computational software. However, learning MATHCAD or MATHLAB should prove beneficial in your education.

ABOUT APP CHALLENGE: As you well know, V&S measurements are at the tip of your finger by using APPS in your cell phone. A cell phone comes with a microphone and a number of accelerometers (X, Y, Z) to enable software to record/play messages and music, determining the orientation of a cell phone, counting steps while walking/exercising, and also with GPS, tracking its location, etc. Also, how about using video to identify vibration patterns (mode shapes)?

The challenge consists of finding a (free) app for S&V and applying it to quantify the vibration or sound signature of a mechanical system. For example, your group could measure sound in various environments and determine their safety according to standards, (low frequency) vibrations of a car structure and estimation of mode shapes, how (well) does a guitar/bass tuner-app work? Analyze the frequency content of a sound snippet, for example the acceleration of a turbocharged vehicle, etc.

App Group challenge makes 25% (250 points) of your final grade with delivery of a short yet concise technical report with your findings. **Due on the last day of class, April 23**. **Talk to the instructor for approval of the challenge objective and tasks (by March 19)**

The instructor will release your report to the whole class (and guests) for judging on inventiveness and practicality.

Foremost, have fun!!!

PRACTICE EXERCISES & EXAMS will be recommended as the semester progresses. There are NO past example exams as the current instructor has not taught the class before. Students' interests and prior experience (practical and academic) will be taken into account when preparing the exams. **Two in-class individual exams will make 50%** (250 x 2 points) of your final grade.

ABOUT HANDOUTS AND RELEASED MATERIAL The handouts and technical papers (tutorial and lectures) used in this course are copyrighted. By "handouts," I mean all materials generated for the course, which include but are not limited to syllabi, quizzes, exams, worked problems, in-class materials and MATHCAD codes, review sheets, and additional problem sets. The pdf material prepared by the guest lecturers is also copyrighted by the authors (and likely their companies).

Because the course material is copyrighted, you do not have the right to distribute it, unless the author expressly grants permission.

ABOUT WRITING: When developing a solution to engineering problems, and in particular when developing solutions to exam problems, students must write (in English) the complete development in full sentences, with stated definitions of parameters and description of procedures and used physical principles. **A large portion or your grade (~30%)** will be given to presentation (writing: syntax and semantics). It is NOT enough to just state formulas and the answer.

In other words, a full grade will be given for complete solutions that include written description of procedural steps to achieve task(s) and assumptions [full sentences, jargon-free], mathematical statements for calculations, and correct magnitudes of results with appropriate physical magnitudes. There will be NO partial credit for mishandling of physical units. ME graduate students should be able to gauge the order of magnitude and correct physical magnitude of the problem at hand.

ABOUT OFFICE HOURS: The purpose of office hours is to encourage individual interaction between the students and the instructor. The instructor is available to discuss not only questions related to the course, but other issues where he can help as a professional engineer, educator and researcher. Please take advantage of office hours. To utilize this time efficiently, students should prepare by organizing questions in advance.

I am willing to help you at times other than office hours without an appointment. However, just like you, I have responsibilities other than MEEN 459/659 (teach other classes, direct graduate student research, write proposals and technical papers, organize laboratories, voluntary work for ASME, etc.). I must budget certain times to meet those responsibilities. My weekly work schedule is posted outside my office. **Please do not be offended** if I am in the office but cannot meet with you.

The use of e-mail for communication with your instructor is acceptable. I usually receive three types of e-mail messages:
a) a request to schedule a meeting at other times than office hours,
b) questions related to the impending take-home quiz due (say) next day,
c) questions related to the study material for an exam.

I reply promptly to all messages (usually the same day if I am in town).

If you cannot find me in my Campus Office, please call me at 862 4744. I spend 60+ hours/week at the Turbomachinery Laboratory (corner of FM2818 and George Bush Dr). At the Turbo Lab I conduct research and manage an excellent team of engineers performing experimental and computational work serving the needs of industrial sponsors.

About plagiarism:

As commonly defined, plagiarism consists of passing off as one's own ideas, words, writings, etc., which belong to another. In accordance with this definition, you are committing plagiarism if you copy the work of another person and turn it in as your own, even if you should have the permission of that person. Plagiarism is one of the worst academic sins, for the plagiarist destroys the trust among colleagues without which knowledge and learning cannot be safely communicated. If you have any questions regarding plagiarism, please consult the latest issue of the Texas A&M University Student Rules, under the section "Scholastic Dishonesty."

The textbook, homework assignments, problem sets, lecture notes, exams and handouts (appendices) used in this course are copyrighted. Because these materials are copyrighted, you do not have the right to distribute them freely, unless the author expressly grants permission. Note that (any) material downloaded from the www may be copyrighted. In all cases acknowledge the source of your information. Furthermore, passing as your own computer assignments/projects prepared by former students is NOT acceptable and will automatically bring you into disciplinary action by TAMU.

Americans with Disabilities Act (ADA) Policy Statement

The Americans with Disabilities Act (ADA) is a federal anti-discrimination statute that provides comprehensive civil rights protection for persons with disabilities. Among other things, this legislation requires that all students with disabilities be guaranteed a learning environment that provides for reasonable accommodation of their disabilities. If you believe you have a disability requiring an accommodation, please contact the Department of Student Life, Services for Students with Disabilities, in Room B118 of the Koldus Building or call 845-1637.

Texas A&M University complies with the Americans with Disability Act. For this course, that means specifically that I will cheerfully work with identified students to provide appropriate alternative settings for tests and quizzes.

Academic Integrity Statement

Aggie Honor Code: ***"An Aggie does not lie, cheat, or steal, or tolerate those who do."***

Upon accepting admission to Texas A&M University, a student immediately assumes a commitment to uphold the Honor Code, to accept responsibility for learning and to follow the philosophy and rules of the Honor System. Students will be required to state their commitment on examinations, research papers, and other academic work. Ignorance of the rules does not exclude any member of the Texas A&M University community from the requirements or the processes of the Honor System. For additional information please visit: http://aggiehonor.tamu.edu/

On all course work, assignments, and examinations at Texas A&M University, the following Honor Pledge shall be preprinted and signed by the student:

"On my honor, as an Aggie, I have neither given nor received unauthorized aid on this academic work."

MAKE UP CLASSES : when will the instructor be absent?

During the SPRING Semester I've scheduled attendance to several technical Conferences and to attend to various Conference review meetings. I will announce the exact date of my absences at least two weeks in advance. Make up recitations for lost classes will be scheduled within a week and be conducted at night time (6:00 pm to 7:45 pm).

Jan 09	Houston, Rotordynamics & Vibrations Short Course
March 8-16	Kuala Lumpur, Asia Turbomachinery & Pump Symposium - Spring Break
April 17 (AM)	Houston, Int Pump Symposium, TAC (Papers Review Meeting)
April 27 (AM)	Houston, Turbomachinery Symposium, TAC (Papers Review Meeting)
May 14-16	College Station, Turbomachinery Research Consortium (TRC) Meeting
May 19-23	Nashville, STLE Annual Meeting

RESOURCES on the web

ME 617 LECTURE NOTES
http://rotorlab.tamu.edu/me617/default.htm

PROCEEDINGS OF THE TL/TAMU TURBOMACHINERY AND PUMP SYMPOSIA
https://turbolab.tamu.edu/proceedings/

The Vibration Institute **https://www.vi-institute.org/**

Sound and Vibration magazine **http://www.sandv.com**

Search for conference papers (O&G vibrations) **www.Rotordynamics.org**

Wikipedia **www.wikipedia.org**

Eddy current Sensors and Conditioning Monitoring
Orbit magazine **https://www.gemeasurement.com/orbit**
GE Baker Hughes **https://www.industrial.ai/solutions**
https://www.gemeasurement.com/orbit/condition-monitoring-asset-management

Turbomachinery International Magazine **https://www.turbomachinerymag.com/**

National Instruments Tool kits & DAQ conditioning monitoring solutions **http://www.ni.com**

Piezoelectric sensors **accelerometers, microphones, load cells, etc.**
https://www.pcb.com/Resources/Tech-Notes
https://www.pcb.com/Resources/Videos
https://www.pcb.com/Resources/White-Papers

Bruel & Kjaer Sensor (acoustics and vibration) **https://www.bksv.com/en/Applications**

Optical (Photo) metrology
https://trilion.com/photogrammetry/
https://trilion.com/vibration-analysis/
http://texas-surveys.com/photogrammetry.php

Laser vibrometers - fiberoptics **https://learn.polytec.com**

The Industrial Internet of Things (IIoT) and Industry 4.0
https://www.splunk.com/en_us/form/the-future-of-maintenance

IIoT : the ability of processes and machines to adapt in real time along with cognitive manufacturing solutions that transform the value chain beyond the factory walls (IBM)

Writing: **http://writingcenter.tamu.edu/c/how-to/business**