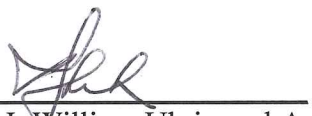
TO: The Faculty of the College of Engineering
FROM: Faculty of the School of Aeronautics and Astronautics
RE: New Graduate Course, AAE 54500 Dynamic Behavior of Materials

The faculty of the School of Aeronautics and Astronautics have approved the following new course. This action is now submitted to the Engineering Faculty with a recommendation for approval.

Course no. **AAE 54500 Dynamic Behavior of Materials**
Terms offered Fall, Lecture 3, Lab 0, Cr. 3.

Description: Materials' responses to high-rate loading are different from their quasi-static behavior. Applications of materials in structures subjected to impact loading from events such as bird strike require the understanding of dynamic material behavior. Such high-rate materials behavior is not available in standard materials handbooks or design manuals. This course introduces stress wave propagation in solids, which is the foundation to characterization and understanding of high-rate response of materials. Then, the theoretical background and working principles of high-rate experimental methods are presented to characterize the material response under high-rate loading conditions. Finally, rate-dependent material models are introduced to describe the dynamic material behavior and deformation mechanisms.

Reason: Dynamic behavior of materials is a critical aspect of materials' mechanical response to efficiently design aerospace structures against impact loading conditions such as bird strike, engine-burst containment, and crash landing. However, there are no courses at Purdue University that address this important aspect of material behavior. This course is intended to give students an overall introduction to the dynamic mechanical behavior of materials, without needing any prior materials knowledge. This course has no overlap with other courses offered at Purdue. In the previous eight times this course was offered, it has been taken by students in the following schools: AAE, CE, MSE, and ME.



Tom Shih, J. William Uhrig and Anastasia Vournas Head and Professor of Aeronautics and Astronautics
School of Aeronautics and Astronautics

Office of the Registrar
FORM 40G REV. 8/16

PURDUE UNIVERSITY
REQUEST FOR ADDITION, EXPIRATION, OR REVISION OF A GRADUATE COURSE
(50000-60000 LEVEL)

DEPARTMENT: AAE EFFECTIVE SESSION: Fall 2017

INSTRUCTIONS: Please check the items below which describe the purpose of this request.

- [x] 1. New course with supporting documents (complete proposal form)
- [ ] 2. Add existing course offered at another campus
- [ ] 3. Expiration of a course
- [ ] 4. Change in course number
- [ ] 5. Change in course title
- [ ] 6. Change in course credit/type
- [ ] 7. Change in course attributes
- [ ] 8. Change in instructional hours
- [ ] 9. Change in course description
- [ ] 10. Change in course requisites
- [ ] 11. Change in semesters offered
- [ ] 12. Transfer from one department to another

PROPOSED:		EXISTING:	
Subject Abbreviation	AAE	Subject Abbreviation	AAE
Course Number	54500	Course Number	59000

Long Title: Dynamic Behavior of Materials

Short Title: Dyn Beh of Mat

Abbreviated title will be entered by the Office of the Registrar if omitted. (30 CHARACTERS ONLY)

TERMS OFFERED (Check All That Apply): [x] Fall [ ] Spring [ ] Summer

CAMPUS(ES) INVOLVED:
- [ ] Calumet
- [ ] Cont Ed
- [ ] Ft. Wayne
- [ ] Indianapolis
- [ ] N. Central
- [ ] Tech Statewide
- [x] W. Lafayette

CREDIT TYPE
1. Fixed Credit: Cr. Hrs. 3
2. Variable Credit Range: Minimum Cr. Hrs ____ (Check One) To [ ] Or [ ] Maximum Cr. Hrs ____
3. Equivalent Credit: Yes [ ] No [x]
4. Thesis Credit: Yes [ ] No [x]

COURSE ATTRIBUTES: Check All That Apply
1. Pass/Not Pass Only [ ]
2. Satisfactory/Unsatisfactory Only [ ]
3. Repeatable [ ] Maximum Repeatable Credit: [ ]
4. Credit by Examination [ ]
5. Fees [ ] Coop [ ] Lab [ ] Rate Request — Include comment to explain fee
6. Registration Approval Type: Department [ ] Instructor [ ]
7. Variable Title [ ]
8. Honors [x]
9. Full Time Privilege [ ]
10. Off Campus Experience [ ]

Schedule Type	Minutes Per Mtg	Meetings Per Week	Weeks Offered	% of Credit Allocated
Lecture	75	2	15	100
Recitation				
Presentation				
Laboratory				
Lab Prep				
Studio				
Distance				
Clinic				
Experiential				
Research				
Ind. Study				
Pract/Observ				

Cross-Listed Courses

COURSE DESCRIPTION (INCLUDE REQUISITES/RESTRICTIONS): (Note: If description will not fit in space provided, please create a separate document and attach it to this form.)

See attached

*COURSE LEARNING OUTCOMES: (Note: If course learning outcomes will not fit in space provided, please create a separate document and attach it to this form.)

See attached

Calumet Department Head	Date	Calumet School Dean	Date	Calumet Director of Graduate Studies	Date
Fort Wayne Department Head	Date	Fort Wayne School Dean	Date	Fort Wayne Director of Graduate Studies	Date
Indianapolis Department Head	Date	Indianapolis School Dean	Date	IUPUI Associate Dean for Graduate Education	Date
North Central Department Head	Date	North Central School Dean	Date	North Central Director of Graduate Studies	Date
West Lafayette Department Head	9/6/17 Date	West Lafayette College/School Dean	Date	Date Approved by Graduate Council	Date
Graduate Area Committee Convener	Date	Graduate Dean	Date	Graduate Council Secretary	Date
				West Lafayette Registrar	Date

OFFICE OF THE REGISTRAR

Grad Form 40G must include the Graduate Council's supporting document, which is available at http://www.purdue.edu/registrar/forms/form_40_Intro.html

Course Description

Pre-requisites: senior classification or graduate status.

Materials' responses to high-rate loading are different from their quasi-static behavior. Applications of materials in structures subjected to impact loading from events such as bird strike require the understanding of dynamic material behavior. Such high-rate materials behavior is not available in standard materials handbooks or design manuals. This course introduces stress wave propagation in solids, which is the foundation to characterization and understanding of high-rate response of materials. Then, the theoretical background and working principles of high-rate experimental methods are presented to characterize the material response under high-rate loading conditions. Finally, rate-dependent material models are introduced to describe the dynamic material behavior and deformation mechanisms.

Student Learning Outcomes

Ability to express local equations of motion.

Ability to derive one dimensional wave equations in solid materials.

Ability to calculate elastic wave speeds in solids with and without constrains.

Ability to understand and calculate local stresses as an elastic wave passes through an interface.

Ability to understand and predict local stress concentrations resulted in from wave interactions.

Ability to utilize elastic waves as loading methods and as diagnostic methods.

Ability to design experiments to measure dynamic behavior of materials.

Ability to determine dynamic yield strength of ductile materials in Taylor impact tests.

Ability to determine plastic wave speeds in ductile material under intensive loading.

Ability to understand shock wave propagation in solids.

Ability to understand physics and calculate shock properties of materials.

Ability to understand physical origins of plastic waves and shock waves.

Ability to understand rate-dependent material models.

Ability to conduct a thorough search of literature on a subject of interest.

Ability to critique scientifically the content of the literature results.

Ability to understand the critical issues of the subject of interest.

Ability to identify research gaps in the subject of interest.

Ability to present effectively a summary of the literature survey.

Detailed Graduate Course Proposal for Academic Review

Note: The detailed course proposal is intended for academic review by the appropriate area committee of the Graduate Council. It supplements the Form 40G that is intended for administrative review of the Graduate School and Registrar.

To: Purdue University Graduate Council

From: Faculty Member: Weinong Wayne Chen
Department: School of Aeronautics and Astronautics
Campus: West Lafayette

Date: February 12, 2017

Subject: Proposal for New Graduate Course

Contact for information if questions arise:
Name: Wayne Chen
Phone: 41788
Email: wchen@purdue.edu
Address: ARMS 3323

Course Number: AAE54500
Course Title: Dynamic Behavior of Materials
Short Title: Dyn Beh of Mat

Course Description:

Materials' responses to high-rate loading are different from their quasi-static behavior. Applications of materials in structures subjected to impact loading from events such as bird strike require the understanding of dynamic material behavior. Such high-rate materials behavior is not available in standard materials handbooks or design manuals. This course introduces stress wave propagation in solids, which is the foundation to characterization and understanding of high-rate response of materials. Then, the theoretical background and working principles of high-rate experimental methods are presented to characterize the material response under high-rate loading conditions. Finally, rate-dependent material models are introduced to describe the dynamic material behavior and deformation mechanisms.

A. Justification for the Course

Justification of the need for the course

Dynamic behavior of materials is a critical aspect of materials' mechanical response to efficiently design aerospace structures against impact loading conditions such as bird strike, engine-burst containment, and crash landing. However, there are no courses at Purdue University that address this important

aspect of material behavior. This course is intended to give students an overall introduction to the dynamic mechanical behavior of materials, without needing any prior materials knowledge. This course has no overlap with other courses offered at Purdue. In the previous eight times this course was offered, it has been taken by students in the following schools: AAE, CE, MSE, and ME.

Justification that course will be taught at a graduate level

- The course is being offered at the 500-level to allow both graduate and undergraduate students to participate. It has been offered eight times. 20 students are enrolled in the current semester, 4 of whom are undergraduate students.
- Intermediate contents are used throughout this course, along with relevant journal papers. Basic knowledge of differential equations and advanced strength of materials is needed, which fits the backgrounds of senior undergraduate and entry-level graduate students.
- At the end of the course, the students will demonstrate learning outcomes that are indicative of graduate level concepts.

Justification of the demand for the course

- Anticipated enrollment
  - Undergraduate 5
  - Graduate 15

B. Learning Outcomes and Methods of Assessment

Learning Outcomes	Assessment Methods
Ability to express local equations of motion.	• HWs and Midterm exam
Ability to derive one dimensional wave equations in solid materials.	• HWs and Midterm exam
Ability to calculate elastic wave speeds in solids with and without constrains.	• HWs and Midterm exam
Ability to understand and calculate local stresses as an elastic wave passes through an interface.	• HWs and Midterm exam
Ability to understand and predict local stress concentrations resulted in from wave interactions.	• HWs and Midterm exam
Ability to utilize elastic waves as loading methods and as diagnostic methods.	• HWs and Midterm exam
Ability to design experiments to measure dynamic behavior of materials.	• HWs and Midterm exam
Ability to determine dynamic yield strength of ductile materials in Taylor impact tests.	• HWs and Midterm exam
Ability to determine plastic wave speeds in ductile material under intensive loading.	• HWs and Midterm exam
Ability to understand shock wave propagation in solids.	• HWs and Midterm exam
Ability to understand physics and calculate shock properties of materials.	• HWs and Midterm exam
Ability to understand physical origins of plastic waves and shock waves.	• HWs and Midterm exam
Ability to understand rate-dependent material models.	• HWs and Midterm exam
Ability to conduct a thorough search of literature on a subject of interest.	• Term project
Ability to critique scientifically the content of the literature results.	• Term project
Ability to understand the critical issues of the subject of interest.	• Term project
Ability to identify research gaps in the subject of interest.	• Term project
Ability to present effectively a summary of the literature survey.	• Term project

Final Grading Criteria

Describing the criteria that will be used to assess students and how the final grade will be determined. Add and delete rows as needed.

Assessment Methods (should match method types in the previous table)	**Weight Toward Final Course Grade**
Exams and Quizzes	25%
Homework	25%
Term project	50%

Methods of Instruction

Class Hrs/Week	**Method of Instruction**	**Contribution to Outcomes**
3	Lecture	Each class includes a lecture given by a combination of chalkboard and PowerPoint notes. Due to the expected class size of ~ 20 students, this lecture is meant to be an open discussion as students can engage with questions.
2	Independent Study	Students are assigned homework and reading journal papers each week.
0.25	Student presentation	Near the end of a semester, each student is required to give a 15-20 minute presentation on the individual term project.

C. Prerequisite(s)

- Basic mechanics of materials course, such as: AAE352, ME323, CE231 or CE270, MSE382, etc.
- Basic knowledge of differential equations.
- No prior materials science knowledge is required.

D. Course Instructor(s)

Name	Rank	School, dept., or center	Graduate Faculty or expected date
Weinong Wayne Chen	Reilly Professor	AAE/MSE	Yes

Weinong Wayne Chen received his B.S. (1982) and M.S. (1985) in Aeronautics from Beijing University of Aeronautics and Astronautics. After his Master's degree, Dr. Chen spent five years working in airplane design, with the last two years with McDonnell Douglas in Long Beach, CA, before resuming his education in 1990. He received his PhD in Aeronautics from California Institute of Technology in 1995. In August 1995, Dr. Chen started as an Assistant Professor of Aerospace and Mechanical Engineering at the University of Arizona and moved to Purdue University's School of Aeronautics and Astronautics and School of Materials Engineering in January 2005. Dr. Chen is currently Reilly Professor of Aeronautics, Astronautics and Materials Engineering, with a courtesy appointment in Mechanical Engineering. Professor Chen's research interests are in the development of innovative experimental methods to characterize dynamic behavior of materials at high rates of deformation. The research results from his group have been disseminated in the form of a book and over 170 journal articles. He is a Fellow of Society for Experimental Mechanics, Fellow of American Society for Mechanical Engineers, and Associate Fellow of American Institute of Aeronautics and Astronautics. He serves as Editorial Advisory Board member for the International Journal of Impact Engineering and Associate Editors for Experimental Mechanics and Journal of Applied Mechanics.

E. Course Schedule or Outline

I. Elastic Wave Mechanics

- **A.** 1-D Elastic Wave Equation
  - **1.** Wave equation derivation — 3 hours
  - **2.** Wave equation solutions — 3 hours
  - **3.** Wave equation solution examples — 3 hours
  - **4.** Characteristic method for wave equ. — 3 hours
- **B.** Elastic Waves in Bars
  - **1.** Hopkinson bar — 1.5 hours
  - **2.** Split Hopkinson (Kolsky) bar — 3 hours
  - **3.** Stress equilibrium in Kolsky bar — 1.5 hours
  - **4.** Pulse control in Kolsky bar — 1.5 hours
- **C.** Elastic Waves in Partially and Fully Constrained Media
  - **1.** Elastic waves in half space — 1.5 hours
  - **2.** Elastic waves in constrained plates — 1.5 hours
  - **3.** Longitudinal, shear, and surface waves — 1.5 hours

II. Plastic Wave Mechanics

- **A.** 1-D Plastic Waves
  - **1.** Plasticity in materials — 1.5 hours
  - **2.** Plastic waves in rods — 1.5 hours
- **B.** Taylor Impact Test
  - **1.** Taylor impact tests — 1.5 hours
  - **2.** Dynamic yield strength of materials — 1.5 hours

III. Shock Wave Mechanics

- **A.** 1-D Shock Waves
  - **1.** Shock relations — 1.5 hours
  - **2.** Shock profiles — 1 hour
- **B.** Equation of State
  - **1.** Equation of state of materials — 0.5 hour

IV. Rate-dependent Material Models

- **A.** Materials Models
  - **1.** Empirical models — 1 hour
  - **2.** Physics based models — 2 hours

V. Term Project Presentations

- **A.** Individual Presentations
  - **1.** In-class PowerPoint presentations — 6 hours

F. Reading List (including course text)

Primary Reading List

Meyers, M.A., 1994, Dynamic Behavior of Materials, J. Wiley, ISBN: 047158262X.

Chen, W., Song, B., 2011, Split Hopkinson (Kolsky) Bar, Springer, 978-1-14419-7981-0

Wang, L. 2007, Foundations of Stress Waves, Elsevier, ISBN: 7-118-04015-0

Secondary Reading List

Fundamentals

Y. C. Fung, Foundations of Solid Mechanics, Prentice Hall (1965)

H. Kolsky, Stress Waves in Solids, Dover (1963)

K. F. Graff, Wave Motion in Elastic Solids, Dover (1975)

Advanced

J. D. Achenbach, Wave Propagation in Elastic Solids, North Holland (1973)

A. C. Eringen and E. S. Suhubi, Elastodynamics I and II, Academic (1975)

J. Miklowitz, The Theory of Elastic Waves and Waveguides, North Holland (1977)

W. Nowacki, Dynamic Problems of Thermoelasticity, Nordhoff (1975)

Nonlinear

N. Criteascu, Dynamic Plasticity, North Holland (1967)

A. C. Pipkin, Lectures on Viscoelasticity Theory, Springer-Verlag (1972)

W. Nowacki, Stress Waves in Nonlinear Solids, Pergamon (1978)

Applied Mathematics

M. Bath, Mathematical Aspects of Seismology, Elsevier (1968)

R. Courant and D. Hilbert, Methods of Mathematical Physics-II, Interscience (1962)

G. B. Whitham, Linear and Nonlinear Waves, Wiley-Interscience (1973)

Dynamic Properties of Solids

J. A. Zukas, T. Nicholas, H. F. Swift, L. B. Greszczuk and D. R. Curan, Impact Dynamics, Krieger (1992)

G. Library Resources

Name of journal, proceedings, book, video, or other acquisition	**Already in Libraries?**
International Journal of Impact Enginering.	Yes
Journal of Dynamic Behavior of Materials	Yes
Journal of Applied Mechanics	Yes
Experimental Mechanics	Yes
Composites Part A	Yes
Engineering Fracture Mechanics	Yes
International Journal of Fracture	Yes
International Journal of Rock Mechanics and Mining Sciences	Yes
International Journal of Solids and Structures	Yes
Journal of Energetic Materials	Yes
Journal of Rock Mechanics and Geotechnical Engineering	Yes
Journal of the Acoustical Society of America	Yes
Shock Waves	Yes
Wave Motion	Yes
Journal of Composite Materials	Yes