## New Course Proposal

### Graduate: Level I

### Undergraduate: ________

Unit: School of AE  
Date: 9/23/2002

<table>
<thead>
<tr>
<th>1. Course Number</th>
<th>2. Hours:</th>
<th>Lecture</th>
<th>Lab</th>
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### 4. Descriptive Title: Combustion Dynamics

### 5. Recommended Abbreviation for Transcript: Combustion Dynamics

### 6. Catalog Description (25 words or less): Acoustic wave propagation in inhomogeneous flows, flame-acoustic wave interactions, and control of combustion driven oscillations.

### 7. Basis: L/G _____ X _____ P/F _____ X _____ Audit _____ X _____

### 8. Prerequisites: Graduate standing or approval of College.

### Corequisites:

<table>
<thead>
<tr>
<th>10. Expected Mode of Presentation:</th>
<th>% OF COURSE</th>
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### 11. Planned Frequency of Offering:  

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<tr>
<th>TERM TO BE OFFERED</th>
<th>EXPECTED ENROLLMENT</th>
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### 12. Are you requesting this course satisfy: Humanities _____ Social Science _____

### 13. Probable instructor(s): Tim Lieuwen, Ben Zinn

### 14. To replace what course(s) in the quarter system? New

### 15. Required ________ Elective ________ x ________
AE 6410 Combustion Dynamics (3-0-3)

Catalog Description: AE 6410 Combustion Dynamics. Analysis of acoustic wave propagation in inhomogeneous flows, flame-acoustic wave interactions, and control of combustion instabilities.

Text: Combustion Driven Oscillations in Industry, Abbot Putnam, Elsevier

Course Coordinator: Dr. Tim Lieuwen

Learning Objectives:

1. Teach fundamentals of wave propagation phenomenon in inhomogeneous environments, such as through ducts with variable area and temperature.

2. Teach fundamentals of unsteady flame-acoustic wave interactions, such as combustion noise and self-excited, combustion driven oscillations. Describe analytical and numerical approaches for modeling flame transfer functions.

3. Teach basic unsteady signal processing, such as Fourier transforms and autocorrelations. Discuss the measurement of unsteady pressure, heat release, and velocity.

Expected Outcomes: Students will be able to: 1) develop simplified models of combustion chamber acoustics, 2) predict stability of a combustor, 3) perform nonlinear perturbation analysis, and 4) analyze dynamic signals.

Prerequisites: Graduate level exposure to combustion.

Topics:

1. Wave propagation and generation (6 lectures): Plane waves propagation, Radial and circumferential waves, Combustion noise generation

2. Duct Acoustics (6 lectures): Longitudinal, radial, circumferential modes of oscillation, cutoff frequencies, Boundary conditions-open ends, closed ends, nozzles, Rapid expansions, flow obstructions, Mean flow effects, Temperature inhomogeneity effects

3. Combustion Dynamics - Basic Concepts (9 lectures): Instability mechanisms-feed line coupling, vortex shedding, equivalence ratio oscillations, flame area oscillations, Small perturbation (linear) analysis, Nonlinear effects, Passive control approaches

4. Combustion Dynamics - Advanced Topics (6 lectures): Sub- and supercritical bifurcations, Limit cycles, Noise and background turbulence effects

5. Modeling (9 lectures): Linear stability models, Acoustic-combustion coupling, Lumped models-Helmholtz resonators,
Well stirred reactors, Flame dynamics, Nonlinear modeling, Numerical approaches-solving differential equations, finite element methods, boundary element methods

6. Experimental methods (6 lectures): Error analysis, Acoustic measurements, Flow visualization techniques, Optical measurements

7. Active Control Approaches (3 lectures)
New Course Proposal

Graduate: Level I ___X___ Undergraduate: _______

Level II _______

Unit: School of AE Date: 9/23/2002

1. **Course Number**

2. **Hours:** Lecture Lab Recitation **Total Semester Credit**

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4. **Descriptive Title:** Turbulent Combustion

5. **Recommended Abbreviation for Transcript:** Turbulent Combustion

6. **Catalog Description (25 words or less):** Fundamentals of interaction between flow turbulence and reactive scalars. Theoretical, numerical and experimental methods. Physics of premixed, non-premixed and partially premixed turbulent combustion.

7. **Basis:** L/G _____ X ____ P/F ____ X ______ Audit ____ X ______

8. **Prerequisites:** Graduate standing or approval of College.

9. **Corequisites:**

10. **Expected Mode of Presentation:**

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11. **Planned Frequency of Offering:**

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12. **Are you requesting this course satisfy:** Humanities _____ Social Science _____

13. **Probable instructor(s):** Suresh Menon, Tim Lieuwen

14. **To replace what course(s) in the quarter system?** New

15. **Required _________ Elective _______ x _______**
AE 6412 Turbulent Combustion (3-0-3)


Course Coordinator: Dr. Suresh Menon

Learning Objectives: Introduce students to the state-of-the-art in the field of turbulent combustion. Provide familiarity and understanding of the recent advances in theoretical, numerical and experimental studies and resulting new insight into the physics of combustion when turbulence effects are very important.

Expected Outcomes: Successful students will: a) be able to work with time- and spatial-scale analysis methods for turbulent, combusting flows; b) have the tools needed to determine appropriate analysis and model approaches for various turbulent combustion regimes; and c) have an up-to-date understanding of the physics of turbulent combustion with application to practical combustion issues in real devices.

Prerequisites: Graduate level exposure to thermodynamics, combustion, and shear and turbulent flows.

Topics:
1. Turbulent Flow and Turbulent Combustion – An Overview (3 hours): Energy cascade, Kolmogorov’s similarity hypotheses, energy and dissipation spectra, coherent structures in turbulent flows, classification by non-dimensional parameters and by flow features.
2. Linear and Non-Linear Interactions (3 hours): Acoustic-Vortex-Entropy Interactions, wave reflections from boundaries, boundary conditions
3. Fundamentals of turbulent combustion (6 hours): Scale separation and high Reynolds Number independence, statistical description, computation of chemical rate
4. Theoretical and numerical models in turbulent combustion (9 hours): Moment closures for reactive scalars, eddy breakup and eddy dissipation models, PDF and conditional moment closure methods, laminar flamelet theory and models, Linear-eddy model
5. Numerical methods (3 hours): Reynolds-Averaged Navier Stokes Methods, Large-Eddy Simulations, Direct Numerical Simulations, regions of application, accuracy and limitations
6. **Experimental methods (3 hours):** Velocity Measurements, Passive and Reactive Scalar Measurements, accuracy and limitations

7. **Physics of turbulent premixed combustion (6 hours):** Regimes of premixed combustion, turbulent burning velocity, effect of equivalence ratio, Lewis and Damkohler Numbers, stretch effects, flame extinction and re-ignition, combustion instability and dynamics of lean premixed flames

8. **Physics of turbulent non-premixed combustion (6 hours):** Regimes of non-premixed combustion, Effect of equivalence ratio, Schmidt and Damkohler Numbers, molecular diffusion and turbulent mixing effects, flame extinction and stability

9. **Physics of turbulent partially premixed combustion (3 hours):** Lifted and triple flames, blow out and stability in combustors

10. **Future directions in research (3 hours)**
New Course Proposal

Graduate: Level I  X  Undergraduate: _______

Level II  ________

Unit: School of AE  Date: 9/23/2002

1. Course Number  2. Hours: Lecture  Lab  Recitation  Total Semester Credit
AE 6414  3  0  0  3

4. Descriptive Title: Multiphase Combustion

5. Recommended Abbreviation for Transcript: Multiphase Combustion


7. Basis: L/G _____ X____ P/F _____ X____ Audit ____ X____

8. Prerequisites: Graduate standing or approval of College.

Corequisites:

10. Expected Mode of Presentation: % OF COURSE
    Lecture  100
    Laboratory (Supervised)  0
    Laboratory (Unsupervised)  0
    Discussion  0
    Seminar  0
    Independent Study  0
    Library Work  0
    Demonstration  0
    Other (Specify)  0

11. Planned Frequency of Offering: TERM TO BE OFFERED  EXPECTED ENROLLMENT
    Fall  _____x____  20
    Spring  ______
    Summer  ______

12. Are you requesting this course satisfy: Humanities _____ Social Science _____

13. Probable instructor(s) Suresh Menon, Jerry Seitzman

14. To replace what course(s) in the quarter system? New

15. Required _________ Elective _______x_____


Course Coordinator: Dr. Suresh Menon

Learning Objectives: Introduce students to the issues related to flow with more than one phase and the implication to the physics due to interaction between various phases. Provide an in-depth study of the models that have been developed with a focus on practical applications. Also introduce students to the new developments in this field.

Expected Outcomes: Students will be able to: a) understand fundamental physics of multi-phase flows; b) develop approaches useful for modeling multiphase combustion flows; c) interpret results and plan measurements using common experimental methods for multiphase combustion flows.

Prerequisites: Graduate level exposure to thermodynamics, combustion, fluid dynamics and turbulent flows.

Topics:

1. **Fundamentals of the dispersed phase (3 hours):** Volume/Void Fraction, response time, Stokes Number, one-way and two-way coupling, dilute and dense flows, droplet cloud combustion

2. **Dynamics of liquid-gas flows (6 hours):** Instabilities in multiphase flows: effect of swirl and shear, liquid jet and spray breakup, droplet formation, size distribution, effect of turbulence, breakup, coalescence, shattering, and internal circulation

3. **Aerosol dynamics (3 hours):** binary nucleation, coagulation, and condensation, solid and metal combustion, nano-energetics

4. **Fluid-Particle-Wall Interactions (9 hours):** Evaporation, condensation and combustion, Drag effects, radiation and convective heat transfer, wall collisions and filming

5. **Formulation of two-phase flow equations (9 hours):** Eulerian-Lagrangian, Eulerian-Eulerian and Lagrangian-Lagrangian models, approaches for dense regime, soot and aerosol dynamic models

6. **Numerical methods (6 hours):** RANS models for spray combustion, RANS models for aerosol/soot formation, Direct and Large-Eddy simulations of sprays, aerosols
7. **Experimental methods (6 hours):** Liquid injector designs and constraints, atomization process, sampling methods, PDPA, in-situ measurements and accuracy, error analysis

8. **New areas of research (3 hours):** Examples: supercritical sprays, inception of soot, particles, nano-Al energetics
## New Course Proposal

**Graduate:** Level I  
Undergraduate: ______

**Level II**

**Unit:** School of AE  
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### 4. Descriptive Title: Combustor Fundamentals

### 5. Recommended Abbreviation for Transcript: Combustor Fundamentals

### 6. Catalog Description (25 words or less): Examination of the chemical and aerothermodynamic processes that govern gas turbine combustor performance and design. Also fuel injection, noise, emissions and testing methodologies.

### 7. Basis: L/G _____ X ____ P/F _____ X _____ Audit _____ X ______

### 8. Prerequisites: Graduate standing or approval of College.

### Corequisites:

### 10. Expected Mode of Presentation:

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### 12. Are you requesting this course satisfy: Humanities _____ Social Science _____

### 13. Probable instructor(s) Richard Gaeta, Jerry Seitzman

### 14. To replace what course(s) in the quarter system? New

### 15. Required ______ Elective ______ x ______
AE 6445 Combustor Fundamentals (3-0-3)

Catalog Description: AE 6445 Combustor Fundamentals. Examination of the chemical and aerothermodynamic processes that govern gas turbine combustor performance and design. Also fuel injection, noise, emissions and testing methodologies.

Course Coordinator: Dr. Richard Gaeta

Learning Objectives:
1. Provide necessary background to gas turbine engine combustor operation for graduate students with a propulsion interest, whether system-design, experimental, or CFD oriented.
2. Cover the elements of aerodynamic, thermodynamic, and combustion processes that govern performance and design of modern gas turbine combustors.

Expected Outcomes: Students will be able to: 1) understand and make tradeoff decisions that must occur in a successful gas turbine combustor design, and 2) apply analysis tools required to make first order predictions of the performance of a gas turbine combustor.

Prerequisites: Undergraduate level exposure to thermodynamics, fluid mechanics, compressible flow and turbine engine propulsion.

Topics:
1. Overview (3 hours): Historical Perspective, Brayton-Cycle, Basic Design Features, Component Integration
2. Review of Chemical Kinetics (4.5 hours): Classification of Flames, Flammability limits, Adiabatic flame temperature and flame speed, Stoichiometry
3. Fluid Dynamic Design Issues (6 hours): Diffuser Design, Annulus Pressure/Velocity relationships, Dilution Zone Mixing, Primary Zone Fuel/Air Mixing
4. Combustor Performance (6 hours): Efficiency, Flame stabilization, Ignition
5. Fuel Injection (4.5 hours): Atomization, Classical Jet-Sheet Breakup, Vaporizers
6. Combustor Noise (4.5 hours): Direct Noise, Instability, Control of Combustor Instability
7. Heat Transfer (6 hours): Design Issues, Film Cooling, Radiation
8. Emissions (4.5 hours): Mechanisms, Control, Design Issues
9. Testing Methodologies (3 hours)