AAE 626
Turbulence and Turbulence Modeling
Spring 2019

*(MWF 12:30–1:20, FRNY B124 [Note: B124 is in the basement; it is **not** room G124])*
(All course material will be available on Blackboard)

Instructor

Prof. Gregory A. Blaisdell
Armstrong Hall, Room 3215 (I am moving to ARMS 3227)
Phone: 765-494-1490
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Office Hours: (to be announced* (TBA))

*Please fill out the questionnaire at https://purdue.ca1.qualtrics.com/jfe/form/SV_6DnHXs6ueII6OXz after the first class and before the end of Friday, January 11. (Note: to access the questionnaire it is best to download the course syllabus from Blackboard and then click on the link in the PDF file.) Results from the survey will be used to determine office hours, and office hours will be announced during the second week of classes. Until office hours are established students may call or send email to arrange a meeting. (If the established office hours do not fit your schedule, then please call or send an email, and I will arrange to see you at some other time.)

Course Goal

To provide a sound background in the mathematics and physics of turbulence and to introduce the concepts and analytical tools needed in using and developing turbulence models and turbulence simulation methods.

Prerequisites

A graduate or senior level course in basic fluid mechanics, such as AAE 511 or ME 509. Topics covered should include derivation of the Navier-Stokes equations, potential flow, exact solutions for simple viscous flows, boundary layers and vortex dynamics. A working knowledge of vector calculus, Cartesian tensor index notation (a handout is available), and Fourier transforms. Ability to program in Matlab. Use of CFD or other software may be needed for the project depending on the topic chosen.

Text

There is no required textbook. However, I will draw material from the following two sources, among many others:

- Wilcox, D. C., *Turbulence Modeling for CFD* (3rd ed.), DCW Industries, 2006. (No longer published, since the author passed away. Used books are available for costs ranging from $99 to $5,001 – do not pay more than $99. Free PDF copies are available on the Internet; however, they violate copyright laws and should not be used.)
- Pope, Stephen B., *Turbulent Flows*, Cambridge University Press, 2000.

Wilcox's book is strong on RANS modeling. Pope's book has more material on turbulence physics and PDF methods used in computing turbulent combustion. Get whichever book best meets your needs; however, neither book is required. Other references are on reserve in the engineering library.

References

(On reserve in the engineering library)

- Hanjalic, Kemal and Launder, B. E., *Modelling turbulence in engineering and the environment: second-moment routes to closure*, Cambridge University Press, 2011.
- Durbin, P. A. and Pettersson Reif, B. A., *Statistical Theory and Modeling for Turbulent Flows*, John Wiley & Sons, 2001. (Note: the 2nd ed. Is available as an on-line resource – see below.)
- Hinze, J. O., *Turbulence* (2nd. ed.), Mc Graw Hill, 1975.

(Available as on-line resources through the Purdue library website):

(see the library policies for downloading e-books: http://guides.lib.purdue.edu/downloadingebooks)
(Note: **DO NOT** abuse access to these resources by downloading and printing copies.)

- Tennekes, H. and Lumley, J. L., *A First Course in Turbulence*, The MIT Press, 1972.
- Nieuwstadt, F. T. M., Westerweel, J. and Boersma, B. J., *Turbulence: Introduction to Theory and Applications of Turbulent Flows*, Springer, 2016.
- Bailly, Christophe and Comte-Bellot, Geneviève, *Turbulence*, 2nd ed., Springer, 2015.
- Grigoriadis, D., Geurts, B., Kuerten, H., Fröhlich, J. and Armenio, V. (eds.), *Direct and large-eddy simulation X* (10th ERCOFTAC Workshop on Direct and Large-Eddy Simulation), Springer, 2018. [Some earlier conference proceedings available also.]
- Durbin, P. A. and Pettersson Reif, B. A., *Statistical Theory and Modeling for Turbulent Flows*, 2nd ed., John Wiley & Sons, 2010.
- Garnier, E., Adams, N., and Sagaut, P., *Large eddy simulation for compressible flows*, Springer, 2009.
- Sagaut, P., *Large eddy simulation for incompressible flows : an introduction*, Springer, 2006.
- … many other on-line resources …

Grading

The grading in the course will be based upon scores on the homework, exam, and project with the following weights:

Homework	30%
Midterm Exam*	20%
Project (50%)	
Progress reports	10%
Written report	30%
Oral presentation	10%

* The midterm exam is scheduled for **Thursday March 7, 2019, 8:00-10:00 p.m., in EE 129**.

In the event of a major campus emergency, course requirements, deadlines and grading percentages are subject to changes that may be necessitated by a revised semester calendar or other circumstances. Here are ways to get information about changes in this course: Blackboard and my email address (blaisdel@purdue.edu).

Course Notes

The lecture notes will be made available on Blackboard. The notes will be given out in sections. Students are responsible for printing the course notes before lecture so they can add material to the printed notes during class. If you miss class, please get the missing material for the notes from another student. The notes contain copyrighted material and, therefore, the PDF files should not be reposted on the Internet. They are only intended for the benefit of students in this course. The same copyright restrictions apply to homework assignments and solutions.

Homework

Approximately 5-6 homework assignments will be made at various times during the first part of the semester leading up to the midterm exam. It is expected that the homework will require 10-15 hours each. There may be some smaller homework assignments after the midterm exam – I have not yet decided. The homework problems will be posted on Blackboard, and students are responsible for accessing them and turning in the solved problems on the due date. On-campus students should turn in their written homework solution in class.

[**Distance education students** should email their homework to the instructor (blaisdel@purdue.edu) by class time (12:30 p.m. ET) on the due date. The homework must be sent as a single PDF file. Handwritten work should be scanned. There are many free on-line tools available to merge PDF files. Also, figures generated in Matlab or other software can be saved in various formats, imported into a Word document and then exported as a PDF file. Please check the legibility of the PDF file before sending it. It will help me in managing the files if you include a subject line in your email with the following format:

AAE 626 PS# Last_name, First_name

where # is the number of the problem set.]

Late homework will be accepted (except for the homework due just before the midterm exam), but at reduced credit. Homework may be turned in by the beginning of the next class period after the due date for 90% credit. **No homework will be accepted after that time, without making special arrangements and then only due to unusual circumstances (e.g., severe illness, travel, etc.).** All the problems must be turned in at the same time.

The homework is to be done individually. However, you may get help from me, the TA or from other students, but the work you turn in must be your own work. The work must be legible and well organized. If you write any computer programs to solve the homework, the code listing must be included with the homework (and the code listing must be for the final working version of the program). If you have difficulty with the homework you are encouraged to come to office hours for help. I also plan to have a class discussion board for answering questions on **Piazza.com**. (Expect an email later this week inviting you to join the class discussion board.) [**Distance ed students** may call me or send questions by email. It is helpful to have a scanned copy of your draft work. It usually works best to arrange for phone calls outside of regular office hours.]

Exam

The midterm exam will be on material covered during the first part of the course (see outline below). The exam will be two hours in length (evening exam for on-campus students). It will be closed book and closed notes; however, a sheet of equations and formulas will be provided. A sample exam and the solution from the previous time the course was taught are available on Blackboard. Because we are having an evening exam University policy dictates that one class period must be dropped. We will not meet on Friday, March 8, 2019 (the Friday before spring break).

Project

Half the basis of the grade will be a term project having to do with some aspect of turbulence modeling, simulation or theory. A list of possible topics will be given out later; however, usually students propose their own topics. Project topics must be approved by me. In lieu of a final exam, students will give a short presentation of their term project. (Depending on the number of on-campus students in the course, I may consider allowing students to work on the project in teams of 2, but I have not decided yet.) For students taking the course through **distance education**, the oral presentation will be given over the telephone to the instructor.

CAPS Information

Purdue University is committed to advancing the mental health and well-being of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of support, services are available. For help, such individuals should contact Counseling and Psychological Services (CAPS) at (765)494-6995 and http://www.purdue.edu/caps/ during and after hours, on weekends and holidays, or by going to the CAPS office of the second floor of the Purdue University Student Health Center (PUSH) during business hours.

Accessibility and Accommodations

Purdue University strives to make learning experiences as accessible as possible. If you anticipate or experience physical or academic barriers based on disability, you are welcome to let me know so that we can discuss options. You are also encouraged to contact the Disability Resource Center at: ***drc@purdue.edu*** *or by phone: 765-494-1247, http://www.purdue.edu/drc/faculty/syllabus.html.*

Diversity & Inclusion

Purdue University is committed to maintaining a community that recognizes and values the inherent worth and dignity of every person; fosters tolerance, sensitivity, understanding, and mutual respect among its members; and encourages each individual to strive to reach his or her own potential. In pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The University believes that diversity among its many members strengthens the institution, stimulates creativity, promotes the exchange of ideas, and enriches campus life. Purdue's nondiscrimination policy can be found at: http://www.purdue.edu/purdue/ea_eou_statement.php.

It is expected that students will treat each other with kindness and respect at all times.

Emergency Procedures

See the attached pages.

Outline: AAE 626*

I. Background on Turbulence

A. Description of turbulence
B. Kinematics of fluid motion
C. Reynolds averaged Navier-Stokes (RANS) equations
D. Scaling of free shear flows and wall-bounded flows
E. Spectra and two-point correlations

(Midterm Exam)

II. Turbulence Modeling

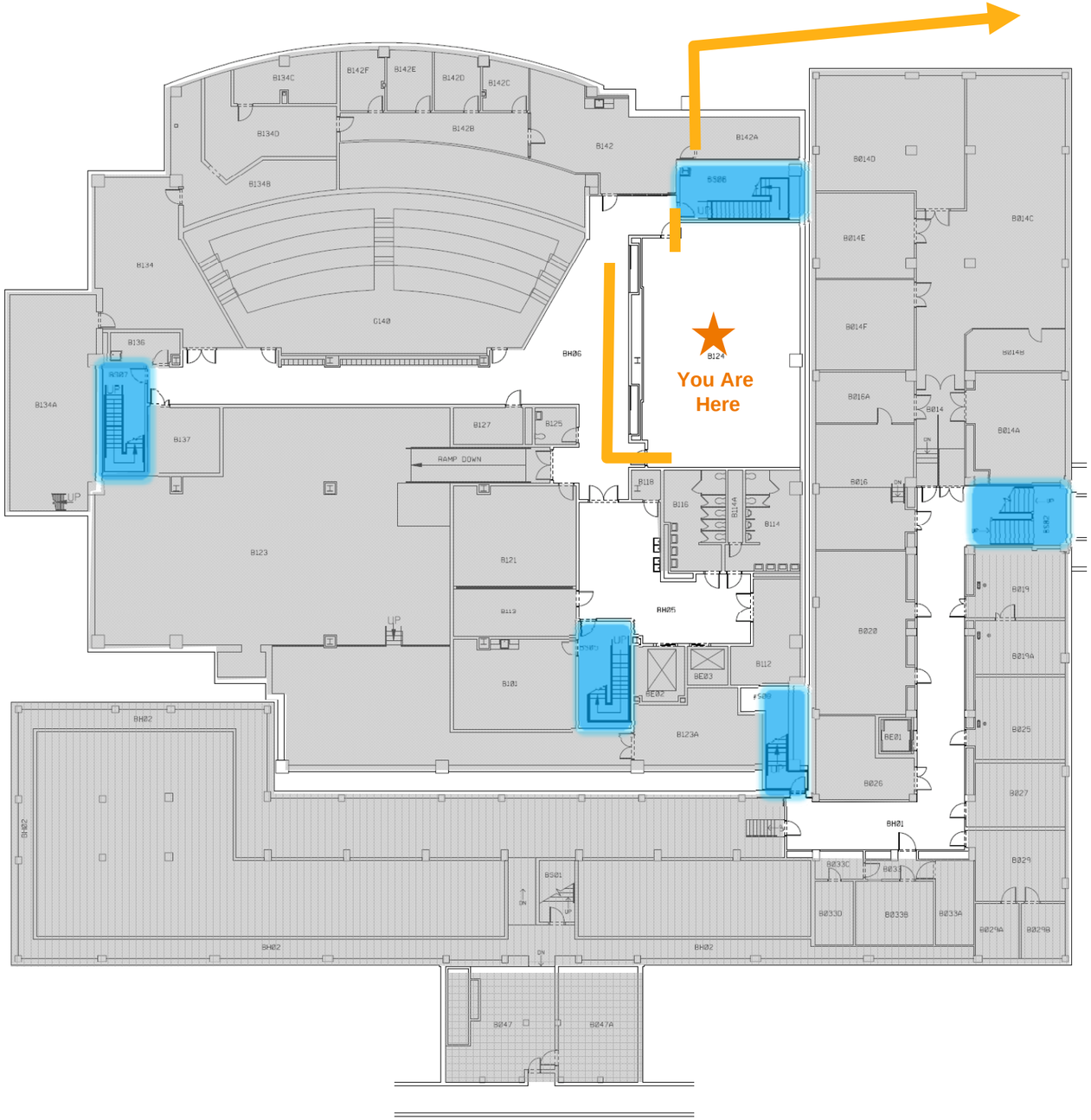
A. Hierarchy of turbulence simulations
B. Algebraic models
C. One-equation models
D. Two-equation models
E. Modeling compressible flows
F. Reynolds stress models
G. Probability density function (PDF) methods (overview only)
H. Direct numerical simulation (DNS)
I. Large-eddy simulation (LES)
J. Detached Eddy Simulation (DES)/Hybrid RANS-LES approaches

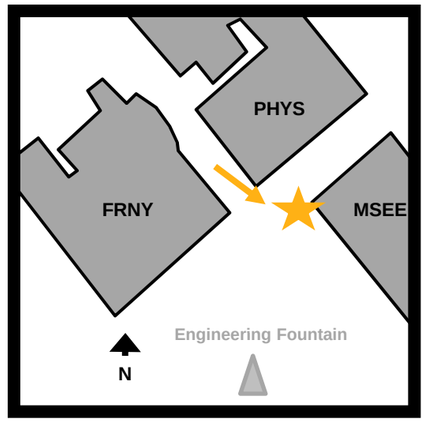
* Note: this outline is approximate and may be changed

FRNY B124

Updated: Fall 2010

Evacuation and Shelter-In-Place Procedures





Emergency Assembly Area

In case of Fire:

Calmly follow the solid gold path — to the closest **stairwell**, take it to the GROUND FLOOR and exit the building, assemble 100ft from the NORTHEAST end of the building. (In case of inclement weather congregate in the MSEE Atrium)

In case of fire, elevators will not operate.

In case of Shelter-in-Place-Weather-Related Emergencies:

Calmly remain in B124

In case of Violence:

If incident is occurring in your building, call 911.
If possible, seek shelter in a lockable or securable room, preferably without windows.

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Evacuation Procedures

- You are in a facility used for research; it is possible that the evacuation horn will sound.
- This is a very loud INSIDE alarm.
- Please walk calmly out of the building and gather outside in the Engineering Mall near MSEE. (In case of inclement weather, congregate in MSEE atrium.)
- Stay in the mall area until a police officer gives the all clear.
- It is extremely dangerous to enter a building in the middle of an emergency.
- It is the responsibility of the faculty and staff to execute this emergency plan upon hearing the evacuation siren.

All Hazards Emergency Warning Sirens

- A weather emergency, such as a tornado, will activate the "shelter in place" siren.
- This is a less audible OUTSIDE, area-wide siren.
- Please seek shelter in the basement area.

EMERGENCY PREPAREDNESS – A MESSAGE FROM PURDUE

To report an emergency, call 911. To obtain updates regarding an ongoing emergency, sign up for Purdue Alert text messages, view www.purdue.edu/ea.

There are nearly 300 Emergency Telephones outdoors across campus and in parking garages that connect directly to the PUPD. If you feel threatened or need help, push the button and you will be connected immediately.

If we hear a fire alarm during class we will immediately suspend class, evacuate the building, and proceed outdoors. Do not use the elevator.

If we are notified during class of a Shelter in Place requirement for a tornado warning, we will suspend class and shelter in [the basement].

If we are notified during class of a Shelter in Place requirement for a hazardous materials release, or a civil disturbance, including a shooting or other use of weapons, we will suspend class and shelter in the classroom, shutting the door and turning off the lights.

Please review the Emergency Preparedness website for additional information.
http://www.purdue.edu/ehps/emergency_preparedness/index.html