**North Dakota State University**
**Department of Mechanical Engineering**
**ME 478/678 – Advanced Flow Diagnostics**
**(3 credit)**
Syllabus/subject to change or modification
2021 Fall Semester
T TH 11 AM – 12:15 AM

**Instructor:** Dr. Jordi Estevadeordal
Dolve 101E
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email: jordi.estevadeordal@ndsu.edu

**Prerequisites:** ME 352 and admission to professional program

**Classroom :** Dolve 118

**Office Hours:** T, TH 12:15PM-1:45PM or by appointment

**Course Description:**
Introduction and review of fundamentals of advanced thermal and fluid measurement techniques for engineering applications including advanced laser and optical diagnostics, high speed imaging, infrared thermography, fiber optics, fluorescence, etc.

**Text:**
None required. Manuals, review articles from literature, and excerpts from various textbooks will be optional:

- "Particle Image Velocimetry," Raffel, M., Willert, C.E., Wereley, S., Kompenhans., Springer 2007
- "Tomographic PIV," Scarano, F., Meas. Sci. and Tech.24 , 2013
- "Pressure and Temperature Sensitive Paints," Liu, T., Sullivan, J.P., Springer 2005
- "Schlieren and Shadowgraph Techniques," Settles, G.S., Springer 2001
- "Particle Shadow Velocimetry," Estevadeordal, J., Goss, L., AIAA 2005-37, 2005
- "Laser Rayleigh Scattering," Miles, R.B., Lempert, W.R., Forkey, J.N., Meas. Sci. Tech., 12, 2001

**Course Goals:**
The course will introduce and provide a theoretical basis and hands-on experience in several advanced diagnostic techniques and instruments typically used in engineering research and industry for advanced thermal and fluid flow property measurements of velocity, pressure, temperature, density, etc. The techniques include particle image velocimetry (PIV), stereoscopic and tomographic PIV, pressure and temperature sensitive paints (PSP/TSP), shadowgraph and Schlieren imaging, filtered and interferometric Rayleigh scattering (FRS, IRS), laser Doppler velocimetry (LDV), laser induced fluorescence (LIF), particle shadow velocimetry (PSV), infrared thermography, thermal phosphorescence, surface oil visualization, holography, etc.

**Anticipated Course Outcomes and Affected Program Outcomes:**
The anticipated Course Outcomes are listed below along with the affected Mechanical Engineering program outcomes. At the conclusion of ME 478/678, students with a passing grade will be able to:

1. Identify fundamental laws and principles of thermodynamics, fluid mechanics, and heat transfer and apply them in specific experimental sets. (1, 2, 6)

2. Explain the basis of advanced techniques for thermal and fluid flow property measurements (1, 2, 6, 7)
3. Use the training and hands-on experience for state-of-the-art equipment operations such as lasers, fast cameras, LED, Infrared technology, etc. (1, 2, 3, 6, 7)
4. Analyze and report experimental results. Compare data with theoretical models. (1, 2, 3, 4, 5, 6, 7)
5. Apply communication skills both written and oral to technical subjects at professional levels.(1, 2, 3, 4, 5, 6, 7)

**Assessment:**

Homework, Quizzes, Midterm, Final Examination, Class Participation, and Laboratory Reports and Presentations will be used for assessment for the given material during classes and Laboratory sessions. The format of your solutions should be in acceptable engineering form. Specifics related to Covid-19 are provided in the following sections for reference and information.

(a) Homework Assignments, Class participation:

Homework assignments will be posted in Blackboard with instructions. Homework assignments will be due typically in a week after assignment in blackboard. Late papers will not be accepted without a valid excuse. Problems should be completed in acceptable engineering form including the given assumptions, the questions statements, and the drawings labeled (if applicable) of the system being considered or will not be graded.

Blackboard will be used for assignment submission (and grading) for all students. You will need to submit your work electronically via the provided Blackboard assignment links. For full grade note:

i. Method of submission is electronically online via Blackboard.
ii. Each assignment has to be submitted as a single file including all questions/answers.

If you are sick, do not come to class or campus. Instead notify the course instructors as soon as practical, so that accommodations can be made. Class participation by attendance and interactive participation will be counted towards the total homework grade.

(b) Quizzes and Exams:

During the semester there will be quizzes and/or 50-minute exams. The two-hour final exam will be given on the date and time specified by the University Finals Schedule.

(c) Laboratory experiments:

The various topics covered in the classes will have hands-on experience where team of students will set up experiments, learn state-of-the-art instrumentation, and perform advanced flow measurements under instructors guidance. The experiments will be performed in the Advanced Flow Diagnostics Laboratory in Dolve 131.

(d) Design Project – Graduate Students (ME 678):

Graduate students will be required to work on an open-ended design project based on the student literature survey in one of the advanced flow diagnostic techniques. This project will involve the application of concepts learned in the class and laboratories.

Students who fall ill or need to quarantine, or who know they will be missing class, exam, labs, etc. for a valid reason (e.g. family emergency) are encouraged to notify the instructor by phone or e-mail prior to the class, if at all possible. Students missing exam without a valid excuse will receive a grade of zero for that exam.

**Grading Policy:**

The grades for this course will be determined as follows:

| **ME 478 (undergraduate):** | | **ME 678 (graduate):** | |
|---|---|---|---|
| HW, Class Participation | 25% | HW, Class Participation | 20% |
| Quizzes and Midterms | 25% | Quizzes and Midterms | 20% |
| Laboratories (report/presentation) | 25% | Laboratories (report/presentation) | 20% |
| Final Exam | 25% | Final Exam | 20% |
| | | Design Project | 20% |

Final course grades will assigned according to the following scale:

| | | | |
|---|---|---|---|
| A | 90% or greater | D | 60% to less than 70% |
| B | 80% to less than 90% | F | less than 60% |
| C | 70% to less than 80% | | |

**Communication**

- *The primary method by which course-related information will be communicated is during class. Reminders, notification of any schedule or assignment changes will be communicated through NDSU email and posted on Blackboard announcements page. Your NDSU email address is the official route for information.*
- *Office Hours: You may meet with me in person during office hours (please remember to wear a face covering and practice social distancing), by appointment, or virtually using the Blackboard Collaborate Virtual Classroom or Zoom. Casual email and virtual requests are welcome.*

**Health and Safety Expectations**

Information and resources on COVID-19 and NDSU's response can be found in the website: *https://www.ndsu.edu/police_safety/covid_19_preparedness_and_response/* .

Currently (or at the time of writing this syllabus or as of August 9, 2021), NDSU is strongly recommending that all people wear masks in indoor spaces when social distancing cannot be maintained. Further, faculty may require masks to be worn in their classes at their discretion. In case of any changes, you will be notified and this syllabus will be updated. Consistent with NDSU's recommendations, **in this class all participants, including those who are fully vaccinated, are required to wear a face covering**. If you fail to properly wear a face covering, you will not be admitted to the classroom. Given the changing conditions associated with the pandemic, this class' faculty member has reserved the right to modify the mask status of the class during the semester. The following will be used as needed: referral to Dean of Students Office or administrative removal from class.

- Students who cannot wear a face covering due to a medical condition or disability, or who are unable to remove a mask without assistance may seek an accommodation through the Disability Services (701-231-8463; https://www.ndsu.edu/disabilityservices/).
- In accordance with NDSU Policy 601, failure to comply with instructions, including the mask requirement, may be handled according to the Code of Student Conduct resolution process and may result in disciplinary sanctions.

**Attendance Expectations**

For class attendance refer to NDSU Policy 333:

- *Students are expected to attend every class and remain in class for the duration of the session when it is safe to do so in accordance with NDSU guidance regarding COVID-19.*
- *While the late participation policy for this course is outlined below, please note that I will be flexible regarding deadlines for students who are experiencing illness or other challenges*

*related to COVID-19. Please contact me as early as possible if you think you may not be able to complete an assignment or participate in the course due to illness.*

- *Do not come to class if you are sick or if you have been exposed to individuals who tested positive for COVID-19 and/or you have been notified to self-quarantine due to exposure. Notify the instructor by phone or e-mail you will be absent.*

**Copyright of Course Materials**

Refer to NDSU Policy 190 on Intellectual property:

- *In this course recording the lectures is prohibited with your own personal devices (without prior express approval from the instructor).*
- *In this course recording the lectures for anything other than personal use is prohibited.*

**Additional Resources for Students**

You are encouraged to use support resources:

- *As a member of the NDSU community, resources are available for you should you need help in dealing with adverse reactions to things happening in the world today. A variety of resources are listed below:*

For students on campus and remotely (telehealth):
Counseling Services: 701-231-7671; https://www.ndsu.edu/counseling/
Disability Services: 701-231-8463; https://www.ndsu.edu/disabilityservices/
Student Health Service: 701-231-7331; https://www.ndsu.edu/studenthealthservice/
Dean of Students Office: 701-231-7701; https://www.ndsu.edu/deanofstudents/

In a crisis or emergency situation:
Call University Police: 701-231-8998
Call 9-1-1
Go to a Hospital Emergency Room
Go to Prairie St. Johns for a Needs Assessment: 701-476-7216 (510 4th St. S.)
Call the FirstLink Help Line: 1-800-273- TALK (8255) or 2-1-1
Call Rape and Abuse Crisis Center: 701-293-7273

**Additional Information:**

1. Course assignments, calendar, announcements, etc. will be posted on Blackboard on a regular basis. You will need to login and check https://bb.ndsu.nodak.edu/ for announcements and online assignments.

2. The academic community is operated on the basis of honesty, integrity, and fair play. NDSU Policy 335: Code of Academic Responsibility and Conduct applies to cases in which cheating, plagiarism, or other academic misconduct have occurred in an instructional context. Students found guilty of academic misconduct are subject to penalties, up to and possibly including suspension and/or expulsion. Student academic misconduct records are maintained by the Office of Registration and Records. Informational resources about academic honesty for students and instructional staff members can be found at www.ndsu.edu/academichonesty . All work in this course must be completed in a manner consistent with NDSU University Senate Policy, Section 335: Code of Academic Responsibility and Conduct

   (https://www.ndsu.edu/fileadmin/policy/335.pdf ) and the CoE Honor System

   (https://www.ndsu.edu/coe/undergraduate_students/honor_code/ ).

3. Any students with disabilities or other special needs, who need special accommodations in this course are invited to share these concerns or requests with the instructor and contact the Disability Services Office (https://www.ndsu.edu/disabilityservices/ ) as soon as possible.
4. Veterans and student service members wih special circumstances or who are activated are encouraged to notify the instructor as soon as possible and are encouraged to provide Activation Orders.

***Tentative List of Subjects:***

| Lecture/Lab Hours | TOPIC |
|---|---|
| 6 | 1. Hot Wire Anemometry |
| 6 | 2. Laser Doppler Velocimetry (LDV) |
| 5 | 3. Particle Seeding |
| 9 | 4. Particle Image velocimetry (PIV) |
| 6 | 5. Three dimensional (3D) stereoscopic and tomographic PIV |
| 6 | 6. Particle Shadow Velocimetry (PSV) |
| 9 | 7. Pressure and Temperature Sensitive Paints (PSP/TSP) |
| 5 | 8. Filtered and Interferometric Rayleigh Scattering (FRS/IRS) |
| 6 | 9. Shadowgraph and Schlieren Imaging |
| 6 | 10. Infrared Thermography (IRT) |
| 6 | 11. Other topics: Holography, surface oil visualization, etc |

Note important dates : https://www.ndsu.edu/registrar/dates/2021/

**Tentative Subject Content Details:**

1. **Pitot Tubes and Hot Wire Anemometry and Laser Doppler Velocimetry (LDV)**
   Review of Pitot tubes and introduction to hot wire and laser Doppler anemometry measurement techniques for point-wise measurements of velocity. Relationship between hot-wire cooling by forced convection and laser Doppler shift with flow velocity. Calibration and hands-on instruction in jet and wind tunnel models.

2. **Particle Image Velocimetry (PIV)**
   Introduction to the fundamentals of this planar imaging technique for flow velocity mapping. System design for optical path, laser planar illumination, camera setup, synchronization electronics, particle Mie scattering and seeding system, correlation algorithms, calibration, and data acquisition and processing software for velocity vectors. High speed (time resolved) options. Laser training and hands on instruction for jet, sprays, and wind tunnel race car and airfoil model experiments. Laser delivery and imaging with fiber optics technology.

3. **Three-dimensional (3D) Stereoscopic/Tomographic PIV**
   Extension of the planar PIV technique to three-dimensions (3D) for three-components of velocity. Volumetric illumination and multiple camera setup, calibration, and processing software. Laboratory testing on same models as planar PIV.

4. **Particle Shadow Velocimetry (PSV)**
   Variant of the PIV technique based on LED illumination and imaging of particle shadow instead of the laser light scattering. Advantages include near surface measurements, high-repetition data rates, and commercial camera capability, and disadvantages include small field of view. Lab includes velocity and particle size measurements in humidifiers, multiphase flows, spray, bubble and drop flows.

5. **Pressure and Temperature Sensitive Paints**
   Introduction to fluorescent paints and their use for surface pressure and temperature measurements in aerodynamics and aerospace models. A brief description of the chemistry processes will be given followed by a hands on instructional methodology explaining how to perform spray painting, calibration, set up of illumination and camera, and data processing software. Laboratory testing will be performed on impinging jets and the same wind tunnel models as planar PIV.

6. **Filtered and Interferometric Rayleigh Scattering**
   Introduction to the use of small particle and molecular Rayleigh light scattering methods and algorithms for flow property measurements of velocity, density, temperature, etc. Laser testing in various basic hot/cold gas jets, sprays, and flames.

7. **Shadowgraph and Schlieren Imaging**
   Introduction to the imaging techniques shadowgraphy and Schlieren that capture flow density variations, shock structures, etc. Setup of optical path with mirrors, LED illumination, and camera. Lab testing in hot gas mixing, compressible flow, shocks, and supersonic flows.

8. **Infrared Thermography**
   Review of infrared techniques that are used to measure temperature in surfaces and gases under various temperature ranges. Review of heat radiation laws and their applications. Multi-wavelength algorithms. Review of applications including flame and combustion product temperature measurement and methods for engine testing including IR borescope probe and fiber optic design such as those used for turbine engine blade health monitoring.

9. **Other topics: surface oil visualization, holography, etc**
   Brief introduction and review of other state-of-the-art techniques including surface flow visualization using oil and shear stress sensors, laser induced fluorescence for combustion, thermographic phosphors for high temperature flows, and other 3D techniques including holographic and plenoptic.

# North Dakota State University
## Department of Mechanical Engineering

### Student Outcomes

The program must have documented student outcomes that support the program educational objectives. Attainment of these outcomes prepares graduates to enter the professional practice of engineering. Student outcomes are outcomes (1) through (7), plus any additional outcomes that may be articulated by the program.

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an 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
3. an ability to communicate effectively with a range of audiences
4. an 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
5. an 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
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.