Last Revised, January 3, 2024

General Information for A&AE 519
Hypersonic Aerothermodynamics
Prof. Steve Schneider Spring 2024

Catalog Description of Course:
A&AE 519, Hypersonic Aerothermodynamics, 3 credits. Prerequisites: A&AE 334 or equivalent, and MA 303 or 304.

Aerodynamics of satellites and planetary reentry. Continuum hypersonic flow. Inviscid and viscous effects, boundary layers, and heat transfer. Shock and boundary-layer interactions. Equilibrium flow of high-temperature reacting gases. Nonequilibrium effects. Kinetic theory and rarefied flows. Direct Simulation Monte Carlo techniques.

Class Hours: MWF 11:30-12:20 in ARMS 1109. Also EPE online. Schneider expects to be on travel at several hypersonics meetings, including AIAA SciTech during 7-12 January 2024. Robert Velte is to hold an initial class on Monday 8 Jan. 2024 to review the course syllabus and operations, discuss the first problem set, and answer any questions. On Wed. 10 Jan. and Friday 12 Jan. the TA's may be available to answer questions about the class and the homework. However, the first regular lecture is to be on Wed. 17 Jan., after the M.L. King holiday. Schneider may also be on travel in New Mexico during 6-11 Feb., working at Holloman AFB. When Schneider is on travel, the TA's may give some of the lectures that consist of blackboard derivations from notes. Lectures will be cancelled or made up as needed, with details to be arranged later. Two 2-hour evening exams are to be scheduled, each requiring cancellation of two class periods, during times when Prof. Schneider is on travel. The class will be informed via email.

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Armstrong Hall Room 3216, 49-45254
Campus Office Hours: TBD, ARMS 3216
Otherwise, email, call, or visit lab, or meet me before or after class.

T.A.'s: Robert Velte, `rvelte@purdue.edu`, 1/4-time. Jie Tao, `tao7@purdue.edu`, 1/4 time. In addition, we have a grader, Andy Bai.

Solution sets will be handed out, and homework will be graded on a 1-10 scale. The TA's are also to hold office hours to help answer questions - should be these be in-person or via Teams?

Grading: Problem sets, 25%. Two (evening) midterm exams: 25% each. Final exam, 25%. Please note that many problem sets will involve the use of existing FORTRAN codes, and thus require the students to develop an introductory understanding of that programming language. A project may be substituted for the final exam on student request, with topics to be approved by the instructor.

Text: J.D. Anderson, *Hypersonic and High-Temperature Gas Dynamics*, 3rd edition, AIAA, 2019. A well-respected recent text. Available to AIAA members at a discount. For the midterm exams, you will need a bound paper copy from the publisher.

Some References:

1. John J. Bertin, *Hypersonic Aerothermodynamics*, AIAA, Washington DC, 1994. An experimentalist's perspective.

2. G.A. Bird, *Molecular Gas Dynamics and the Direct Simulation of Gas Flows*, Clarendon Press, Oxford, 1994. Contains theory, examples, and programs for rarefied gasdynamics (for high-altitude flows). The seminal researcher in the field, now retired. For a more recent treatment, see Boyd and Schwartzentruber, *Nonequilibrium Gas Dynamics and Molecular Simulation*, Cambridge U. Press, 2017.

3. Wallace D. Hayes and Ronald F. Probstein, *Hypersonic Flow Theory*, Academic Press, New York, 1959. Theoretical but classic. Includes some viscous flow, and a nice description of various similarity solutions. See also *Hypersonic Inviscid Flow*, same authors, Dover, 2004, an affordable reprint of the 1966 update of the inviscid-flow portion.

4. Ernst Hirschel, *Basics of Aerothermodynamics*, vol. 204 in Progress in Astronautics and Aeronautics, AIAA, Reston, Virginia, 2004. Revised second edition, Springer, 2015. Also E. Hirschel and C. Weiland, *Selected Aerothermodynamics Design Problems of Hypersonic Flight Vehicles*, Springer-Verlag, Berlin, 2009.

5. Charles Kittel and Herbert Kroemer, *Thermal Physics*, W.H. Freeman, San Francisco, 1980. A classic undergraduate text on statistical mechanics and thermodynamics.

6. Chul Park, *Nonequilibrium Hypersonic Aerothermodynamics*, Wiley-Interscience, New York, 1990. Or, more recently, Eswar Josyula et al., *Hypersonic Nonequilibrium Flows: Fundamentals and Recent Advances*, AIAA Progress in Astronautics and Aeronautics, v. 247, 2015.

7. Walter Vincenti and Charles Kruger, *Introduction to Physical Gas Dynamics*, Wiley, New York, 1965. A classic text on high-temperature and non-equilibrium gas flows.

Scope: The text and references are well-respected books that present the relevant technical background. A thorough understanding of all of this material is far beyond the scope of this course. In addition, some supersonic and low-speed viscous-flow methods must be covered, to provide sufficient preparation. Thus, this course can only serve as an introduction. The fundamental physical phenomena will be introduced, along with some of the methods used for analysis. A few selected areas will be covered in some depth. The course is intended to prepare the student to carry out further studies of particular topics as needed.

Delivery Modes: About 3/5 of the course involves blackboard lectures describing analytical derivations for relatively simple topics that can be understood in much more detail. PDF's of the instructor's notes are available on the course website.

About 2/5 of the course involves lectures from slides that describe more complex phenomena. PDF's of these slides are also available on the course website.

Digital audio recordings of all lectures are to be provided. There will be no video recordings.

Outline:
The following lists topics in the order in which they are to be covered. The relevant sections of the various references are cited.

1. **Introduction:** Hypersonic flow phenomena. Characteristics of planetary atmospheres. Anderson Chap. 1, Bertin Chap. 1, papers.

2. **Inviscid Hypersonic Flow:** Hypersonic shock approximations. Local surface inclination methods. Other approximate methods. Survey of exact methods. Anderson Chap. 2-5.

3. **Viscous Hypersonic Flow:** Self-similar boundary layer theory. Heat transfer. Shock and boundary-layer interactions. Survey of approximate and exact methods. Anderson Chap. 6-8, Bertin Chap. 7, 9, and 10.

4. **Introduction to Physical Chemistry of Gases:** Thermodynamics of reacting gases. Statistical mechanics and kinetic theory. Anderson Chap. 9-12, Vincenti and Kruger Chap. 1-5 + 9, Bird Chap. 1-6. Time constraints will allow us to provide only a very brief overview. The chemistry of reacting gases is covered in some depth in AAE439 and AAE539, in Prof. Poggie's Nonequilibrium Hypersonic Flow course, and in ME501.

5. **High-Enthalpy Gasdynamics:** Hypersonic flows with chemical reaction effects. Equilibrium flow. Stagnation point heating. Anderson Chap. 13-18, Bertin (various sections), Vincenti and Kruger Chap. 6-8 and 10-12. This is a large and complex topic. Here, only equilibrium flow will be covered in any depth. The thermodynamics of equilibrium air will be presented without derivation and used to discuss stagnation point flow. This section will provide only an overview. Take Poggie's course to cover more detail.

6. **Rarefied Gasdynamics:** Collisionless flows. The newtonian free-molecular approximation. Direct Simulation Monte Carlo techniques. Application to high-altitude aerodynamics and the gasdynamics of satellite thrusters. Bird Chap. 7-16. Beginning in 2007, this section has been reduced to a lecture or two. Persons interested in rarefied flows should take Prof. Alexeenko's course.