Georgia Institute of Technology
School of Aerospace Engineering

Fall 2026 — Dr. W. M. Haddad
M W 12:30 – 1:50 pm — Office: Knight 415-1
Room: Clough Commons 423 — email: wm.haddad@aerospace.gatech.edu

AE 6530 – A/Q: Multivariable Linear Systems and Control

Course Description:

This course will develop theoretical concepts and techniques for analyzing and designing feedback control laws for multivariable linear dynamical systems.

Course Objectives:

To provide students with an advanced treatment of multivariable linear-quadratic optimal control as applied to aerospace systems. Specifically:

- Model physical systems using linear, time-invariant (LTI) ordinary differential equations with multiple states, inputs, and outputs (MIMO systems).
- Solve linear ordinary differential equations in the time-domain using the matrix exponential, state transition operator, and Lagrange's equation.
- Master linear algebra concepts pertaining to the analysis and control synthesis of MIMO LTI systems.
- Design state-feedback stabilizing controllers for MIMO LTI systems.
- Develop controllability observability tests for MIMO LTI systems.
- Address exogenous system disturbances and measurement noise and develop design techniques to mitigate their effects.
- Design observers and estimators to reconstruct the state of a system given a set of noisy measurements.
- Use optimal control theory to design optimal feedback controllers and state estimators for LTI systems.
- Master the theoretical properties and solution techniques for matrix equations (e.g., Lyapunov, Sylvester, and Riccati equations).
- Combine optimal state estimators (i.e., Kalman filter) with optimal state feedback controllers (i.e., linear-quadratic regulators) to control MIMO systems.
- Apply these control and estimation techniques to a wide variety of engineering systems.

Topics:

An Introduction to Matrix Theory

- Matrix Operations
- Matrix Decompositions (Jordan, Schur, Singular Value)
- Nonnegative Definite and Positive Definite Matrices
- Matrix Norms, Generalized Inverses

- Kronecker Matrix Calculus

Linear Systems Theory
- The Matrix Exponential
- State-Space Models
- Lyapunov Stability Theory
- The Lyapunov Equation
- Controllability, Stabilizability, Observability, Detectability
- Transfer Function Models
- Realization Theory
- Harmonic Steady-State Response
- System Interconnections
- Matrix Differentials and Optimization Theory

H_2 System Norm
- H_2 Norm of Asymptotically Stable Transfer Functions
- L_2 Norm of the Impulse Response Function
- L_2 Norm of the Free Response
- Mean-Square Stochastic Response
- Standard Control Problem
- Specializations of the Standard Problem
- PI Control, Model Following

Static Feedback Control
- Static Full-State-Feedback Control
- Linear-Quadratic Regulation (LQR)
- Full-State Feedback and Integral-Error Feedback
- Static Output-Feedback Control

Analysis of the Riccati Equation
- The Riccati Equation for Full-State-Feedback Control
- The Stabilizing Solution of the Riccati Equation
- The Maximal Solution of the Riccati Equation
- Positive Semidefinite and Positive Definite Solutions of the Riccati Equation

State Estimators
- Observers and State Estimators Without Noise
- Linear-Quadratic Estimation (LQE) and the Kalman Filter
- Analysis of the LQE Riccati Equation

Dynamic Feedback Control
- Observer-Based Compensation
- Linear-Quadratic Gaussian (LQG) Control
- Integral-Error Feedback and Internal Model Control
- Applications of LQG Control

Frequency Domain Concepts
- Frequency Domain Properties of the LQR and LQG Problems

- The Return Difference Equality
- Guarantees of Phase and Gain Margins of the LQR and the LQG Problems

Office Hours:

By appointment. The GTA will hold weekly office hours.

Prerequisites:
- A course in classical control theory.
- A course in linear systems, state space models, and matrix theory.

Computers:

Several assignments will require computations using MATLAB and the Control System Toolbox.

Grading Policy:

There will be five homework assignments, a midterm exam, and a final exam for this course. The midterm and final exams will be closed book and closed notes.

- Homework/Projects 50% of grade
- Midterm Exam 20% of grade
- Final Exam or Project 30% of grade

Attendance Policy:

Classroom attendance is mandatory.

Academic Integrity and Code of Conduct:

See Academic Honor Code and Student Code of Conduct.

Homework/Project Requirements (Start each assignment as soon as it is posted)**:**

- Restate each problem before beginning to solve it.
- Write on only one side of each sheet of paper.
- Start each new problem on a new sheet of paper.
- All homework must be scanned and submitted through Canvas.
- Your uploaded homework file must be exactly **one** PDF file.
- Label your PDF file as “YourName_AE6530_FA_26_HW1”.
- Homework must be neat and professional in appearance. Messy homework will not be graded. No cross-outs of any kind may appear anywhere.
- Late homework will not be accepted.

Honor Code Rules for Homework in this Course:

- Conceptual collaboration is allowed. This means that you may discuss problems with other students.

- However, all substantive work---calculations, derivations, and all written work must be your own.
- Very similar homework solutions will be referred to the Honor Council for investigation and adjudication.
- The use of solutions from prior semesters or any other source (such as web resources) is strictly not allowed and will represent a breach of the honor code rules for this course.
- The use of artificial intelligence (AI) tools is strictly prohibited.

Required Course Material:

J. B. Hoagg, W. M. Haddad, and D. S. Bernstein, *Linear-Quadratic Control: Theory and Methods for Continuous-Time Systems*. Cambridge, U.K.: Cambridge University Press, preprint. (Preprint will be provided through Canvas.)

Multivariable Control-System Synthesis: The Fixed-Structure Approach. W. M. Haddad and D. S. Bernstein, notes. (Notes will be provided through Canvas.)

Additional Criteria for Successful Completion of the Course:

A willingness to work hard.

Disability Services:

Students with learning needs that require special accommodation contact the Office of Disability Services at (404) 894-2563.

Additional References:

H. Kwakernaak and R. Sivan, *Linear Optimal Control Systems*, Wiley, New York, 1972.

T. Kailath, *Linear Systems*, Prentice Hall, Englewood Cliffs, NJ, 1980.

B. A. Francis, *A Course in H_∞ Control Theory, Springer-Verlag, New York,* 1987.

B. D. O. Anderson and J. B. Moore, *Optimal Control-Linear Quadratic Methods*, Prentice Hall, Englewood Cliffs, NH, 1990.

S. P. Boyd and G. H. Barratt, *Control System Design-Limits to Performance*, Prentice Hall, Englewood Cliffs, NJ, 1990.

W. L. Brogan, *Modern Control Theory*, Prentice Hall, 1991.

J. C. Doyle, B. A. Francis, and A. Tannenbaum, *Feedback Control Theory*, MacMillan Publishing Co., 1991.

K. Zhou, J. C. Doyle, and K. Glover, *Robust and Optimal Control,* Prentice Hall, New Jersey, 1996.