Georgia Institute of Technology
Daniel Guggenheim School of
Aerospace Engineering

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AE 6580: Aerospace Nonlinear Control

Topics:

Dynamical Systems and Differential Equations
- System Equilibria
- Nonlinear Differential Equations
- Dynamical Systems, Flows, and Vector Fields
- Existence and Uniqueness of Solutions
- Continuous Dependence on System Initial Conditions and Parameters
- Continuity, Uniform Continuity, and Lipschitz Continuity
- Limit Points, Limit Sets, and Attractors

Nonlinear Second-Order Dynamical Systems
- Vector Fields, Flows, Phase Portraits
- Nodes, Saddles, Foci, and Centers
- Isocline Method and Linearization
- Periodic Orbits and Limit Cycles
- Poincare, Bendixon, and Poincare-Bendixon Theorems

Stability Theory for Nonlinear Dynamical Systems
- Lyapunov Stability, Asymptotic Stability, Exponential Stability
- Lyapunov Stability Theorems
- Lyapunov Function Constructions
- Krasovskii's Method, Variable Gradient Method, Zubov's Method
- Stability of Linear Systems and Lyapunov's Linearization Method
- Invariance Principal
- Invariant Set Stability Theorems
- Converse Lyapunov Theorems
- Instability Theorems
- Partial Stability
- Stability Theory for Time-Varying Systems
- Lagrange Stability, Boundedness, and Ultimate Boundedness
- Poincare Maps and Stability of Periodic Orbits

Dissipativity Theory for Nonlinear Dynamical Systems
- Dissipativity and Exponential Dissipativity
- Lagrangian and Hamiltonian Dynamical Systems
- Passivity and Nonexpansivity
- Storage Functions, Supply Rates, Available Storage, Required Supply
- Kalman-Yakvbovich-Popov Conditions

- Positive Real and Bounded Real Dynamical Systems

Absolute Stability Theory
- The Lure Problem
- Positivity Theorem, Circle Theorem, Popov Theorem
- Stability of Feedback Intercorrections
- Small Gain and Positivity Theorems
- Connections to Robust Control

Input-Output Stability
- Lp Spaces and Extended Lp Spaces
- Causality
- Lp Stability and the Small Gain Theorem
- Connections to Nonexpansivity
- Input-to-State Stability
- Applications to Linear Systems

Nonlinear Control
- Energy-Based Feedback Control
- Control Lyapunov Functions
- Hamilton-Jacobi-Bellman Equation
- Optimal Nonlinear Feedback Control
- Stability Margins of Nonlinear Regulators
- Nonlinear Disturbance Rejection Control
- Hamilton-Jacobi-Isaacs Equation
- Feedback Linearization, Zero Dynamics, and Minimum Phase Systems
- Backstepping Control
- Adaptive Control

Course Objective: To provide students with an advanced treatment of nonlinear dynamical systems and control as applied to aerospace systems.

Office Hours: M 3:30-4:30 pm.

Prerequisites:
1) A course in classical control theory.
2) A course in linear systems, state space models and matrix theory.
3) A willingness to work hard.

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

Course Structure:

• Homework/Projects	50% of grade
• Midterm Exam	20% of grade
• Final Exam	30% of grade

Homework/Project Requirements:

- 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.
- Staple sheets together.
- Hand in *original*; keep a copy for yourself.
- "Neatness counts for points."

Textbook: W. M. Haddad and V. Chellaboina, *Nonlinear Dynamical Systems and Control: A Lyapunov-Based Approach,* Princeton University Press, 2008.

An updated list of errata and addenda to the book can be found under "Textbooks and Monographs" at: http://haddad.gatech.edu.

Additional Nonlinear Systems and Nonlinear Control Books

Major Texts:

H. K. Khalil, *Nonlinear Systems*, Third Edition, Prentice Hall, 2002.

M. Vidyasagar, *Nonlinear Systems Analysis*, Second Edition, Prentice Hall, 1993.

S. Sastry, *Nonlinear Systems: Analysis, Stability, and Control*, Springer, 1999.

There are numerous texts on ODEs. One is

J. K. Hale, *Ordinary Differential Equations*, Wiley-Interscience, 1969.

ODEs with discontinuous dynamics are considered in

A. F. Filippov, *Differential Equations with Discontinuous Righthand Sides*, Kluwer, 1988.

Some books devoted to stability theory:

W. Hahn, *Theory and Application of Lyapunov's Direct Method*, Prentice Hall, 1963.

K. S. Narendra and J. H. Taylor, *Frequency Domain Criteria for Absolute Stability*, Academic Press, 1973.

C. A. Desoer and M. Vidyasagar, *Feedback Systems: Input-Output Properties*, Academic Press, 1975.

P. Habets, N. Rouche, and M. Laloy, *Stability Theory by Lyapunov's Direct Method*, Springer, 1977.

V. I. Vorotnikov, *Partial Stability and Control*, Birkhauser, 1998.

Some more specialized texts:

A. Gelb and W. van der Velde, *Multiple Input Describing Functions and Nonlinear Systems Design*, McGraw Hill, 1968.

D. Atherton, *Nonlinear Control Engineering*, Van Nostrand Reinhold, 1975.

W. J. Rugh, *Nonlinear System Theory: The Volterra/Wiener Approach*, Johns Hopkins University Press, 1981.

E. P. Ryan, *Optimal Relay and Saturating Control System Synthesis*, Peter Peregrinus, 1982.

Y. Z. Tsypkin, *Relay Control Systems*, Cambridge University Press, 1984.

S. P. Banks, *Mathematical Theories of Nonlinear Systems*, Prentice Hall, 1988.

A. Isidori, *Nonlinear Control Systems*, 1989.

H. Nijmeijer and A. van der Schaft, *Nonlinear Dynamical Control Systems*, Springer, 1990.

J. B. Roberts and P.D. Spanos, *Random Vibration and Statistical Linearization*, Wiley, 1990.

J. J. E. Slotine and W. Li, *Applied Nonlinear Control*, Prentice Hall, 1991.

W. R. Kolk and R. A. Lerman, *Nonlinear System Dynamics*, Van Nostrand Reinhold, 1992.

R. M. Murray, Z. Li, and S. S. Sastry, *A Mathematical Introduction to Robotic Manipulation*, CRC, 1994.

R. Marino and P. Tomei, *Nonlinear Control Design*, Prentice Hall, 1995.

M. Krstic, I. Kanellakopoulos, and P. Kokotovic, *Nonlinear and Adaptive Control Design*, Wiley, 1995.

V. Jurdjevic, *Geometric Control Theory*, Cambridge University Press, 1997.

Z. Qu, *Robust Control of Nonlinear Uncertain Systems*, Wiley, 1998.

A. Isidori, *Nonlinear Control Systems II*, Springer, 1999.