Nonlinear and Adaptive Control Techniques for Advanced Aerospace Systems

Synopsis: The course aims at introducing methodologies for synthesis of nonlinear and adaptive controllers for advanced highly maneuverable aircraft. The lectures will focus on control of fixed-wing aircraft, but extensions to other types of vehicles (e.g., tail-sitter aircraft) may be considered if time permits. Examples concerning the design of reconfigurable and fault-tolerant controllers for conceptual hypersonic vehicles and over-actuated subsonic aircraft will be presented. Specific methodological tools will be introduced in support of the proposed solutions.

Topics:

1. **Control-Oriented Aircraft Modeling.** Equations of motion. Aerodynamics forces and moments. Stability-axes and body-axes parameterization. Attitude parameterizations: angle-axis, Euler angles and modified Rodrigues parameters. Control effectiveness. Under-actuation vs. over-actuation.
2. **Flight Control Problem Formulation.** Systems decomposition: airspeed dynamics, attitude dynamics, longitudinal dynamics, lateral dynamics. Model inversion for over-actuated aircraft. **Tools:** Right-inversion, zero-dynamics.
3. **Airspeed Control.** Adaptive airspeed control. Anti-windup redesign. **Tools:** Elementary adaptive control theory, Lyapunov stability, invariance theorems.
4. **Attitude Control.** Adaptive attitude control. Anti-windup redesign. **Tools:** Elementary adaptive control theory, passivity-based control, back-stepping control.
5. **Internal Dynamics.** Robust control of the lateral dynamics. Adaptive/robust control of the vertical dynamics. **Tools:** Input-to-state stability, gain assignment.
6. **Stability Analysis. Tools:** Small-gain theorem for (locally) input-to-state stable systems.
7. **Reconfigurable Control.** Strong input redundancy and weak input redundancy. Gradient-based dynamic control allocation. **Tools:** Elementary geometric theory of nonlinear control systems.
8. **Constrained Control (if time permits).** Adaptive airspeed reference management. Enforcing constraints on angle of attack. **Tools:** Lyapunov redesign.
9. **Examples.** Reconfigurable adaptive control of a hypersonic vehicle model. Fault-tolerant control of an over-actuated subsonic aircraft. Flight test results on a scaled model.

References:

1. Notes (available to registered students).
2. Stevens, B. L., Lewis, F. L., & Johnson, E. N. (2016). Aircraft Control and Simulation (Third Edition). John Wiley & Sons.
3. Isidori, A., Marconi, L., & Serrani, A. (2003). Robust Autonomous Guidance: An Internal Model Approach. Springer Science & Business Media. Appendix A-C (available to registered students).

Course Prerequisites: A beginning graduate-level course in nonlinear systems theory is required. Exposure to adaptive control theory is desirable but not essential. Familiarity with the basic concepts of Lyapunov stability theory is highly desirable.

Examination and Grading: Grading will be based on a take-home final exam or project.

Tentative Course Schedule:

1. **Monday, July 3 (Morning):** Control-oriented Aircraft Modeling.
2. **Monday, July 3 (Afternoon):** Flight Control Problem Formulation. Airspeed Control.
3. **Tuesday, July 4 (Morning):** Attitude Control. Internal Dynamics.
4. **Tuesday, July 4 (Afternoon):** Stability Analysis. Reconfigurable Control.
5. **Wednesday, July 5 (Morning):** Constrained Control. Examples