Flight Dynamics, Simulation and Control with MATLAB and Simulink

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The goal of this course is to teach:

- tensor flight dynamics,
- flight simulation, and
- robust and adaptive multivariable linear and nonlinear flight control systems design

for the efficient construction and execution of six-degree-of-freedom (6-DoF) simulations of air vehicles, such as aircraft and missiles, in MATLAB and Simulink, including automated stability, robustness and performance analyses.

The course is intended for engineers and scientists involved in the modeling, simulation, design, and analysis of complex interdisciplinary flight control systems. Attendees are expected to have a basic understanding of control systems (frequency-domain and state-space methods) and also be familiar with the MATLAB and Simulink modeling and simulation environment.

The first day of the course shall be devoted to flight dynamics and simulation, studying the rigid-body equations of motion for a round and rotating Earth, in tensor form (invariant under coordinate transformations); the simplified, more familiar, stationary and flat Earth equations of motion shall also be considered. These tensor equations will be resolved in a convenient coordinate system using matrices, for MATLAB and Simulink implementation. Important modeling and simulation aspects of air-vehicle aerodynamics, propulsion system, flight controls, actuation, feedback sensors, Earth and gravity, and the atmosphere (atmospheric properties and atmospheric disturbances, such as turbulence) shall also be addressed, which are the bare necessities of 6-DoF simulations (also required for robustness and performance analyses of flight control systems during the second day of the course). All demonstrations will be based on a conceptually designed hypothetical, yet realistic, full operational envelope 6-DoF benchmark problem, which is constructed in MATLAB and Simulink environment using the latest version, and posed as a research and educational challenge for flight control systems design. The required open-source simulation tool and datasets, covering all aerodynamic, propulsive, and mass-inertia properties of the airframe for full nonlinear and coupled 6-DoF equations of motion of rigid-body flight dynamics, will be distributed to all participants of the course as additional resources in order to create the necessary platform for testing controller performance and robustness under demanding requirements and conditions.

The second day of the course covers detailed robust and adaptive flight control systems design using multivariable linear optimal control and nonlinear control methods (state-dependent Riccati equation control, sliding mode control, model reference adaptive control, and combinations of these) frequently used in the aerospace industry, and involves 17 years of first instructor's experience (12 of which have been in the aerospace/defense industry) and more than 30 years of second instructor's experience. Upon completion of this intense course, attendees will be able to model, simulate, control and analyze flight control systems in 6-DoF using MATLAB and Simulink.

Course notes and additional resources will be distributed to all participants on the first day of the course. These materials are for participants only and are not available for sale or unauthorized distribution.

SCHEDULE: July 8, 2017

FLIGHT DYNAMICS & SIMULATION

09:00 – 09:45 : **Tensors, Frames and Coordinate Systems**

- Definitions
- Notations and Conventions
- Reference Frames and Coordinate Systems (*Earth, Vehicle, Wind, Flight Path, Propulsion*)
- Kinematic Relationships (*Orientation Angles, Coordinate Transformations, Angular Velocities, Angular Rates*)

09:45 – 11:00 : **Tensor Flight Dynamics**

- Translational Motion
- Rotational Motion
- Forces and Moments

11:00 – 11:30 : **Aerodynamics**

- Aerodynamic Definitions
- Aerodynamic Coefficients (*Component Buildup, Functional Dependency, Uncertainty Modeling*)
- Computational Aerodynamic Data (*Aerodynamic Database*) for Simulations

11:30 – 12:30 : **6-DoF Benchmark Case Study**

- System Requirements (*Tactical, Operational, and Flight Controls*)
- Configuration Geometry
- Mass-Inertia Properties
- Propulsive Characteristics
- Aerodynamic Characteristics (*Aerodynamic Stability, Maneuverability, and Trim Analysis*)

14:00 – 14:45 : **Earth and Gravity**

- Geodesy
- WGS84 Oblate Spheroid Earth
- Gravity (*Zonal Harmonics Gravity, Ellipsoidal Gravity, Standard Gravity*)

14:45 – 15:30 : **Atmosphere**

- Atmospheric Properties (*Atmospheres Layers, Standard and Nonstandard Atmospheres*)
- Atmospheric Disturbances (*Wind, Gust, Turbulence, and Wind Shear*)

15:30 – 16:15 : **Flight Controls**

- Actual & Virtual Aerodynamic Control Surfaces
- Control-Surface Sign Conventions
- Control Allocations (Blending Logic)
- Thrust Vectoring
- Control Actuation
- Feedback Sensors

16:15 – 17:00 : **Derivation of the Equations of Motion for Flight Control Systems Design & Analyses**

- Nonlinear Airspeed and Incidence/Wind-Angle Dynamics
- Nonlinear Body-Rate and Body-Acceleration Dynamics
- Nonlinear Bank-Angle and Flight-Path-Angle Dynamics
- Linear-Parameter-Varying Models

17:00 – 17:30 : **6-DoF Benchmark Case Study & Wrap-Up**

- Earth and Gravity
- Atmosphere
- Flight Controls

SCHEDULE: July 9, 2017

FLIGHT CONTROL SYSTEMS DESIGN

09:00 – 10:00 : **Multivariable Robust and Optimal Control Design**

- Robust Linear-Quadratic Integral Servomechanism
- Frequency-Domain Performance and Robustness Specifications
- Weighting Parameter Selection
- Gain Scheduling for Flight Control Systems

10:00 – 10:30 : **State-Dependent Riccati Equation (SDRE) Control Design**

- State-Dependent Coefficient (SDC) Parameterization
- SDRE Controller (Regulation and Integral Servomechanism): Structure and Conditions
- SDRE Design Parameters
- SDRE Inner-Outer Loop Design for Flight Control Systems

10:30 – 11:30 : **Sliding Mode Control Design (SMC)**

- Sliding Surface and Sliding Mode
- Switching Control to Ensure Sliding Mode
- Robustness of Sliding Mode to Disturbances and/or Uncertainties
- Chattering Phenomena and Chattering Reduction

11:30 – 12:30 : **Model Reference Adaptive Control Design (MRAC)**

- MRAC Scheme
- Assumptions for MRAC Design
- Adaptation Rule Design

14:00 – 15:30 : **Combined Control Design Methods**

- LQR + MRAC Flight Control Systems Design
- SDRE + MRAC Flight Control Systems Design
- SDRE + SMC Flight Control Systems Design
- SMC + MRAC Flight Control Systems Design

15:30 – 17:30 : **6-DoF Benchmark Case Study & Wrap-Up**

- Test Cases
- Feedback (Sensor) Delay Analysis
- Aerodynamic Uncertainty Analysis

BIOGRAPHIES

Tayfun Çimen is an Engineering Scientist in flight control systems. He received a B.Eng. with first-class honors in computer systems engineering in 2000 and a Ph.D. in systems and control theory in 2003, both from the Department of Automatic Control and Systems Engineering at the University of Sheffield, where he continued his postdoctoral research in nonlinear systems and control until the end of 2004. In 2005, he became a Naval Reserve Officer at the Turkish Naval Research Center Command. Later that year, he joined ROKETSAN Missiles, Inc., and for over a decade he was actively involved in the design, development, and performance evaluation of air-defense missile systems, with emphases on modeling and simulation aspects as well as application of modern (linear and nonlinear) control methodologies to multivariable flight control problems. He is currently with Turkish Aerospace Industries, Inc., working as a flight control systems engineer on the Turkish fighter aircraft development program. He is a member of the Turkish National Committee of Automatic Control (TOK), which is the National Member Organization of the International Federation of Automatic Control (IFAC), and he serves on several IFAC technical committees. He is an Associate Professor of engineering sciences, awarded by the Inter-University Board of Turkey in 2010. His research interests include dynamics and simulation of systems, nonlinear systems and control theory, applied nonlinear control, and practical applications involving complex dynamical engineering systems. He is a Senior Member of the IEEE and a Senior Member of the AIAA.

Metin U. Salamci received his Ph.D. degree from the Mechanical Engineering Department at Middle East Technical University, Ankara, Turkey in 1999. He worked for the Turkish Prime Ministry between 1987 and 2003 as an expert and head of department in various divisions. He moved to academia in 2003 and, since then, he has been working for Gazi University, Ankara, Turkey in the Department of Mechanical Engineering as a Professor. He served as the Dean of Faculty of Engineering between 2013 and 2016. His main research activities are in the areas of nonlinear dynamical systems and their control including cancer dynamics, personalized drug administration and flight control. He has supervised more than 30 theses; most of them are in the fields of controller design and synthesis using "State Dependent Riccati Equation based Controllers", "Sliding Mode Control", "Model Reference Adaptive Control" and "Optimal Control" for nonlinear dynamical systems. Recently, he works in collaboration with medical doctors to develop personalized drug administration and delivery systems. In addition to biomedical systems and their control, he also designs and implements controllers for flight dynamics in Lab environment using small UAVs.