CONSIDERATIONS FOR GRADUATE COURSES IN FLIGHT DYNAMICS, STABILITY, AND CONTROL

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Abstract
This paper proposes topics for a graduate level course in flight dynamics, stability, and control. Seven specific topics and some math pre/co-requisites are suggested.

Introduction
The practicing flight dynamicist requires intensive training in several branches of engineering science, and a broad outlook insofar as the practical ramifications of his work are concerned. A previous paper proposed topics and a methodology for teaching an undergraduate course in flight dynamics, stability, and control [1].

This paper proposes several topics which the author believes are relevant for a graduate level understanding of flight dynamics, stability, and control. The recommendations stem from the author’s experiences in industry and academia, and are not intended to be all-encompassing and all-inclusive. The author does not provide prerequisite topics for an undergraduate course as these courses tend to be well standardized. It is also acknowledged that some of the topics below might already be included in existing undergraduate courses. Finally, the topics below are not ranked in order of importance.

Topics

DYNAMICS
The emphasis here is on nonlinear dynamics, since it is assumed that the prerequisite undergraduate course primarily uses linearized equations of motion and related analyses, and because many problems of interest are highly nonlinear in nature (high alpha [2], fighter agility [3-6], etc.). Besides Newton’s 2nd Law, deriving equations of motion using the Lagrangian method and D’Alembert’s principle are very useful in aerospace applications. The latter is especially useful for multi-body systems with constraints. Presentation of how to derive equations of motion for arbitrary centers of mass (as is often done in spacecraft applications) is strongly recommended. The nonlinear approach necessarily requires Lyapunov and phase-plane methods to analyze stability. Numerical methods are required to analyze the stability of nonlinear systems which do not apply to Lyapunov analysis.

REFERENCE FRAMES AND COORDINATE TRANSFORMATIONS
Extension of the equations of motion to multi-body systems naturally leads to multiple reference frames. This in turn requires knowledge of and familiarity with relative velocities and accelerations. In terms of coordinate transformations, it is strongly recommended that students be introduced to quaternions.
MODAL ANALYSIS
Undergraduate courses usually focus on eigenvalues, eigenvectors, and mode shapes. The modal analysis proposed here is modal superposition. Reference 7 demonstrates how to construct and interpret linear models in terms of a modal vector, not a state vector. This allows one to see the effect each control input has on specific modes, not just the states.

ELASTIC EFFECTS
The effect of body bending, or structural flexibility. Airframe flexure causes additional aerodynamic loads which in turn cause additional flexure. Interactions occur between the elastic modes and the flight control system since it senses both the rigid body motions and the elastic motions. Topics include methods for determining the natural frequencies and modes shapes of the body bending modes [8, 9], and methods to account for fuel slosh [10].

ATMOSPHERIC EFFECTS
The effects of gusts and turbulence on the airframe and the resulting effect on flying qualities. For gusts this means deriving transfer functions which relate airframe outputs to various gust inputs, such as the response of angle-of-attack to a vertical gust input. Also the response of the aircraft to random-type inputs. These would consist of atmospheric turbulence, terrain elevation, and noisy sensors. Aircraft flying in turbulence can be subjected to excessive g-loads. Flutter, the condition essentially characterized by structural damping going to zero due to atmospheric excitation, is another consideration. What is required in all of these situations are exposure to analytical methods for predicting the performance of the system to random inputs. To do this the theory of random processes is required.

SPINNING ROTORS AND MASS IMBALANCE
This means studying angular momentum in-depth and in three dimensions, leading to gyroscopic effects due to spinning rotors such as props and turbines, and the effects of rotating mass imbalance which lead to vibrations at high angular velocities. The effects of asymmetric mass distributions due to hung-up stores or airframe damage are also to be considered.

COUPLING
The familiar cross-coupling in aircraft is due to an imbalance in the magnitudes of the inertia terms in the rotational equations of motion, and can be induced by perturbations in any of the body-axis angular rates. The specific phenomenon of roll coupling is an important subset. A method to analyze and define specific boundaries in terms of aircraft parameters is presented in Reference [8].

MATH
The requisite mathematical tools for the topics described above include linear algebra; bifurcation methods; phase-plane analysis; numerical methods; and random processes.

Summary
Topics and considerations for a graduate course in flight dynamics, stability, and control are proposed. Seven specific factors and math pre/co-requisites relevant to a graduate level command of the subject have been identified. The relative importance of these factors is subject to personal preference and interpretation and is therefore left up to the reader.

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References


