Engineering Faculty Document No.: 5-04
Date: January 25, 2005

TO: Faculty of Schools of Engineering
FROM: Faculty of the School of Aeronautics and Astronautics
SUBJECT: New Graduate Course

The Faculty of the School of Aeronautics and Astronautics has approved the new course listed below. This action is now submitted to the Engineering Faculty with a recommendation for approval.

AAE 575 Introduction to Satellite Navigation and Positioning
Sem. 1, Class 3, cr. 3.
Prerequisite: AAE 301, ECE301, ME365 or equivalent.

Course Description:
Introduction to radio-navigation techniques using the Global Navigation Satellite System (GNSS); GNSS signal structures; satellite search and acquisition; satellite tracking; coordinate systems and time; observations; atmospheric effects; and position-velocity-time (PVT) solutions.

Reason:
Over the last decade there has been substantial growth in the use of GNSS technology in a variety of fields. Many commercial, scientific, and defense applications are being developed. The technical background required for research or development in these areas spans several traditional fields, including communications, controls, orbit mechanics, space and atmospheric physics, geodesy and estimation. This course introduces students to the integration of these different areas into one, operational system. This course was taught as AAE590G for four terms in Fall 01, 02, 03 and 04, with enrollments of between 12 and 23 students each term. A substantial portion of past classes were students outside of AAE (primarily from Civil Engineering, but also a few from ECE or EAS).

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Thomas N. Farris, Professor and Head
School of Aeronautics and Astronautics

AAE 575 Introduction to Satellite Navigation and Positioning

- **Course Instructor:** Professor James L. Garrison

- **Course Description:**

This course is an introduction to radio-navigation techniques using the Global Navigation Satellite System (GNSS). The course material will be based upon the Global Positioning System (GPS) operated by the United States. The course content, however, will be general enough to apply to other GNSS which may become available. The objective of this course is to prepare students for future study and research in the applications of satellite navigation. The structure of the course takes a "bottom up" approach, starting from the basic signal properties and working up to the generation of observations and the formulation of a navigation solution for the receiver position. The subjects covered are; GNSS signal structures; satellite search and acquisition; satellite tracking; coordinate systems and time; observations; atmospheric effects; and position-velocity-time (PVT) solutions. The audiences for this course are beginning graduate students, or advanced undergraduates in any School of Engineering, Physics, or in Earth and Atmospheric Sciences.

- **Course outline:**

1. **Introduction and Overview** High-level description of Global Navigation Satellite Systems (GNSS). Space, control and user segments. Outline of the remainder of the course. [2 hours]
2. **Background Material: Signals and Systems** Energy and power signals. Linear systems, impulse response and the frequency response function. The Fourier transform and the frequency domain. Sampling, the Nyquist frequency, and the discrete Fourier transform (DFT). [3 hours]
3. **GNSS Signal Structure** Introduction to spread spectrum systems. Non-return to zero (NRZ) signals and binary phase shift keyed (BPSK) modulation. Pseudorandom noise (PRN) code generation. Auto- and crosscorrelation properties of PRN codes. Structure of the data message. The Doppler effect. [6 hours]
4. **Background Material: Random Variables** Probability density and distributions. Expected value and moments. Normal random variables. Stochastic processes. Auto- and cross correlation. Covariance matrices. Power spectrum. [3 hours]
5. **Link Budget** Summary of link budget for satellite communications. Use of dB in calculations. Space loss, antenna gain and effective area. Thermal noise and equivalent noise temperature. Carrier to noise ratio (C/N0). Polarization. Spectrum allocation. Typical numerical values for GNSS satellites. [1 hour]
6. **Satellite Search and Acquisition** Downconverison. Coherent integration vs. incoherent averaging. Inphase and quadrature signals. The ambiguity function. Satellite search algorithms, acquisition tests and thresholds. Influence of C/N0. Probability of detection and probability of false alarm. [6 hours]
7. **Atmospheric Effects** Electromagnetic wave propagation, wave number, phase velocity and group velocity. The ionosphere and troposphere. Total Electron Content (TEC) and dual frequency measurements. Obliquity factor. The Klobuchar model. Wet

and dry tropospheric delay. The Hopfield and Sasstamoinen models. Mapping functions. [4 hours]

8. **Satellite Tracking** Review of linear controls. Discriminators. The delay lock loop (DLL). Jitter and dynamic tracking errors and the influence of loop bandwidth, early-late separation, and integration time. Tracking threshold and loss of lock. Frequency and phase lock loops. [4 hours]
9. **Raw GPS Observations** Pseudorange, Doppler frequency and carrier phase. Carrier aiding of code tracking. Code-carrier divergence. [2 hours]
10. **Reference Frames and Time** Conventional Terrestrial Reference System (CTRS), Conventional Inertial Reference System (CIRS), Geodetic coordinates, WGS-84 and regional ellipsoids. Time standards: UTC, GMT, and GPS time. [3 hours]
11. **Background Material: Orbit Mechanics** Newton's Second Law and Law of Universal Gravity. Two-body orbits, and classical (Keplerian) orbit elements. Mean and osculating elements. [1 hour]
12. **Satellite Orbits and the Data message** Structure of the data message. Generation of satellite position from the broadcast almanac and ephemeredes. Precise ephemerides from the National Geodetic Survey (NGS) [3 hours]
13. **Navigation solutions** Correction of pseudoranges for clock biases, relativity, and propagation time. Position-Velocity-Time (PVT) solution using least squares estimation. Dilution of precision (DOP). Introduction to the use of Kalman filters to improve PVT estimates.[6 hours]
14. **Current Issues** [1 hour]

- **Text:** *Global Positioning Systems: Signals, Measurements and Performance,* Pratrap Misra and Per Enge, Ganga-Jamuna Press, 2001. An extensive set of slides, used for each of the lectures is used, and hard copies are available. A document summarizing the relevant topics from signals and systems, controls, random variables, and orbit mechanics is also provided for background material.