ORGANIZATIONS THAT HAVE HOSTED COURSE:

- Raytheon Missile Systems
- Lockheed Martin Space Systems Company, Astronautics Operations
- Sandia National Laboratories
- Redstone Arsenal

FOR DETAILED INFORMATION ABOUT SCHEDULING, OR OTHER QUESTIONS:

Call or E-mail Kelly Roscoe at:

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ASA

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ADVANCED STRAPDOWN INERTIAL NAVIGATION ANALYTICS COURSE

BY

APPLIED STRAPDOWN ANALYTICS, LLC

LENGTH: **4 Days**
LOCATION: **On-Site (at Hosting Organization)**

COURSE DESCRIPTION:

The Advanced Strapdown Inertial Navigation Analytics Course is a detailed presentation on the analytical aspects of strapdown inertial navigation systems. It covers the analytics associated with strapdown inertial navigation software resident in the navigation computer, system testing software, and performance analysis of strapdown inertial navigation systems. The course is mathematically rigorous, and includes 21 course problems that are completed during class throughout the week.

COURSE MATERIALS:

The course material provided to each attendee consists of three books (listed below) plus handouts of Course Problems and Solutions.

- **Advanced Strapdown Inertial Navigation Analytics**
  395 page volume containing copies of the course overhead slides.

- ***Strapdown Analytics* Textbook**
  by Paul G. Savage

  Part 1: 881 page volume used to develop Course Slides 1-229.
  Part 2: 833 page volume used to develop Course Slides 230-395.

WHO SHOULD ATTEND:

The course is designed for analytically inclined engineers, scientists, or recent college graduates who are or will be involved in strapdown inertial navigation system software design, testing, or performance analysis. No previous experience in navigation is required, but attendees should be versed in vector calculus, differential equations, and linear algebra.

PROFILE OF INSTRUCTOR:

Kelly M. Roscoe is the owner of Applied Strapdown Analytics, LLC (ASA), a company she founded in 1999 to provide engineering consulting, software design, and educational services for strapdown inertial navigation systems. At ASA, Ms. Roscoe was the proofreader of the course textbook *Strapdown Analytics*, a two volume publication written by her father, Paul G. Savage. Proofreading included re-deriving all equations in the book and providing comments to the author regarding equation derivation methods.

Ms. Roscoe's previous experience includes employment at Minnesota Mining & Manufacturing (3M) as a product development team leader for multilayered optical film programs and at Rockwell International at the Strategic Defense Center as a systems design/test engineer for the Kinetic Energy Anti-Satellite Weapon System (KE ASAT) program.

Ms. Roscoe received her B.S. and M.S. degrees (1991) in Electrical Engineering from the Massachusetts Institute of Technology (MIT). Her M.S. was earned through MIT's Electrical Engineering Internship Program where she worked and developed her Masters Thesis at The Charles Stark Draper Laboratory. Ms. Roscoe is a member of Tau Beta Pi and Eta Kappa Nu Honor Societies and an inventor on U.S. Patent 6,208,466; Multilayer Reflector with Selective Transmission (Assignee —3M Innovative Properties Company). She has also been published in the AIAA *Journal of Guidance, Control, and Dynamics*.

COURSE OUTLINE

FIRST DAY

- Introduction to Strapdown Inertial Navigation
- Mathematical Concepts/Terminology
  - Develop Equations for Direction Cosine Matrix (DCM), Rotation Vector, Euler Angles, Quaternions
  - Generate Attitude Parameter Rate Equations
  - Develop DCM and Vector Error Characteristic Equations
- Earth Related Navigation Parameters
  - Construct Key Parameter Equations (Distance Vector, Unit Normal, Curvature, Transport Rate, Gravity)
- Generate Continuous Form Strapdown Inertial Navigation Equations
  - Derive Attitude, Acceleration Transformation, Velocity, and Position Equations
  - Vertical Channel Control/Designing Control Gains
  - Navigation Coordinate Frame Options/Geometries
- Develop Digital Integration Algorithms
  - Attitude Updating (Coning Algorithm Derivation)
  - Acceleration Transformation/Velocity Updating (Derive Gravity/Coriolis Increment and Sculling Term Algorithms)
  - Position Updating (Scrolling Algorithm Derivation)

SECOND DAY

- Sensor Compensation Algorithms
  - Generate Angular Rate Sensor Compensation Algorithms (Scale Factor, Bias, Quantization, Misalignment Errors)
  - Generate Accelerometer Compensation Algorithms (Scale Factor, Bias, Quantization, Misalignment, Size Effect, Anisoinertia Errors)
- Strapdown Algorithm Validation
  - Specialized and General Simulator Examples
- Quasi-Stationary Initialization
  - Determining Attitude/Velocity/Position
- Sensor Assembly Jitter
  - How to Measure/Remove
- Vibration Effects Analysis
  - Determine INS Performance Under Sinusoidal and Random Vibration Input
  - Methods for Modeling Sensor Assembly Response to System Level Vibration
  - Vibration Effects Simulation Program Example

THIRD DAY

- Derive Strapdown Inertial Navigation Error Equations
  - Define Attitude, Velocity, Position Error Parameters and Develop Error Parameter Rate Equations for Three Navigation Equation Sets (Earth Fixed Coordinates, Locally Level Navigation Frame Coordinates, Non-rotating Inertial Coordinates)
  - Modeling Inertial Sensor Error Terms

THIRD DAY (CONT.)

- Solutions to Error Equations
  - Generate Closed Form Analytical Solutions Under the Following Conditions (Constant Attitude or Rotating Attitude with Constant Sensor Errors, Circular Trajectory at Constant Angular Rate, Constant Attitude with Random Sensor Output Noise)
  - Determine Solutions With and Without Vertical Control
  - Scale Factor/Misalignment Effects
- Quasi-Stationary Initialization Error Equations and Solutions
  - Derive Initialization Error Equations
  - Determine Closed Form Analytical Solutions Under Following Conditions (Constant Inertial Sensor Error, Ramping Accelerometer Error, Random Errors)

FOURTH DAY

- Kalman Filtering
  - Develop Measurement, Observation, Control Vector, and Error State Dynamic Equations
  - Derive Gain Matrix that Provides Minimum Covariance
  - Examples: Quasi-Stationary Fine Alignment (Derive Kalman Filter Terms, Produce Partitioned Version), Dynamic Moving Base Alignment (Derive Observation/Measurement Equations)
- Covariance Simulation Programs
  - Construct Equations Used to Evaluate Kalman Filter Performance
  - Covariance Analysis Simulation Program Configuration
- Trajectory Generators
  - Trajectory Shaping
    - Segment Parameter Selection
    - Quick-look Projection
    - End-of-segment Data Generation
  - Trajectory Regeneration
    - Segment Junction Smoothing
    - Create Integrated Angular Rate and Specific Force Acceleration Increments
    - Generate Attitude, Velocity, Position Outputs
- System Testing
  - Schuler Pump Test (Horizontal Angular Rate Sensor Bias, Composite Errors, Initial Heading Error)
  - Drift Test (Composite Horizontal Angular Rate Sensor Error)
  - System Level Angular Rate Sensor Noise Estimation Test (Angular Rate Sensor Random Output Noise)
  - Rotation Test (Angular Misalignments Between Sensor Input Axes, Angular Rate Sensor Scale Factor Errors/ Asymmetries, Accelerometer Bias, Scale Factor Errors/Asymmetries, Sensor Assembly Misalignment Relative to Mount)