TWO-DAY ON-SITE INTRODUCTORY SHORT COURSE ON STRAPDOWN INERTIAL NAVIGATION SYSTEMS

By Strapdown Associates, Inc.

Strapdown Associates, Inc. (SAI) offers a Two-Day Short Introductory Course On Strapdown Inertial Navigation Systems for interested organizations, to be provided at the host selected site location in the contiguous United States and Canada. This is a shortened version of the original four and a half day Introductory Course offered by SAI to the Aerospace industry and in Minneapolis, Minnesota from 1982 - 2009. As with the original course, the Short Course is designed for engineering, management and marketing personnel who have a fundamental background in engineering, but no former background in inertial navigation or complex mathematics.

The standard price for the two-day course during Calendar Year 2015 is $10,000 plus $195 per attendee which covers the following items:

Presentation of the course to any number of attendees at host facility using host presentation aids. Paul G. Savage (president of Strapdown Associates, Inc. and lecturer for the original 4½ day course) is the Short Course lecturer.

Handout material for course attendees.

Subsistence for the course time period.

Travel expenses.

Handout material for the Short Course comprises the following two books (also used for the 4½ day course):

Introduction to Strapdown Inertial Navigation Systems - 712 page "Yellow Book" containing copies of the two-day and 4 ½ day course slide material including a detailed text describing each slide.

Strapdown Inertial Navigation Lecture Notes - 376 page reformatted "Blue Book" detailing the analytical theory of strapdown inertial navigation.

A detailed description of the Short Course follows, including a resume of the Short Course lecturer Paul G. Savage and a description of the handout material.

For further information or to schedule a Short Course, contact SAI by email at pgs@strapdownassociates.com; or by telephone or Fax at 763-479-1981

TWO-DAY INTRODUCTORY SHORT COURSE
ON STRAPDOWN INERTIAL NAVIGATION SYSTEMS

By Strapdown Associates, Inc.

Instructor: Paul G. Savage

Available For Presentation On-Site At Host Facility

COURSE DESCRIPTION AND TARGET AUDIENCE

The Two-Day Strapdown Inertial Navigation Short Course is a shortened version of the original four and a half day Introductory Course offered by Strapdown Associates, Inc. in Minneapolis, Minnesota from 1982 - 2009. As with the original course, the Short Course is designed for engineering, management, and marketing personnel who have a fundamental background in engineering. Sufficient introductory material is included so that attendees need no former background in inertial navigation or complex mathematics. The emphasis in the course is on providing down-to-earth explanations of basic principles associated with strapdown systems and hardware/software components. Because many elements of strapdown inertial navigation are inherently analytical in nature, the course addresses the analytical aspects, but primarily from a functional and operational standpoint. Detailed mathematical derivations are avoided and referenced instead to the lecture notes handout material.

COURSE OBJECTIVES

Provide a basic understanding of 1) The theory, operation, and performance characteristics of a strapdown inertial navigation system (INS), 2) The distinction between a strapdown and gimbaled INS, and 3) Kalman filtering theory and its application to strapdown INS aiding.

COURSE SYLLABUS

- Inertial Navigation Principles
- Calculating INS Velocity And Position From Inertial Sensor Data
- INS Initialization
- Gimbaled Platform Reference Stabilization
- Strapdown Attitude Reference Computations
- Strapdown Computer Algorithms
- Inertial Sensors
- Strapdown System Thermal and Mechanical Design
- Inertial Navigation System Error Characteristics
- Kalman Aided Inertial Navigation
- Strapdown Inertial System Testing

COURSE HANDOUT MATERIAL

Introduction to Strapdown Inertial Navigation Systems - 712 page "Yellow Book" containing slides for the original 4 1/2 Day Course and for the Short Course including a detailed text describing each slide.

Strapdown Inertial Navigation Lecture Notes - 376 page "Blue Book" detailing the analytical theory of strapdown inertial navigation.

DAY 1 AGENDA

Fundamental Concepts - Vector Concepts, Coordinate Frames, Vector Transformations, Navigation Parameters, Gravity, Specific-Force Acceleration

Inertial Navigation Principles - Inertial Navigation Concept, Strapdown Compared to Gimbaled Inertial Navigation Systems, Fundamental INS Operations

Inertial Navigation Position/Velocity Equations - Geographic, Free, and Wander Azimuth Navigation Coordinate Approaches, Vertical Channel Stabilization

System Initialization - Position/Velocity, Attitude/Heading, Strapdown Compared To Gimbaled Systems

Gimbaled Platform Reference Stabilization - Three and Four Gimbal Platforms, Gimbal Lock

Strapdown Attitude Reference Operations - Attitude Parameters (Euler Angles, Direction Cosines, Quaternions, Rotation Vector), Acceleration Transformation (Sculling Effects), Attitude Determination (Coning Effects)

Inertial Sensors

Computer Interfaces

Accelerometers - Mechanical Pendulous Accelerometer, Vibrating Quartz Beam Accelerometer, MEMS Silicon Accelerometer

Gyros - Spinning-Wheel Gyros, Ring Laser Gyro, Fiber Optic Gyro, Vibrating-Quartz Rate Gyro, MEMS Vibrating-Silicon Rate Gyro

DAY 2 AGENDA

Strapdown System Thermal and Mechanical Design - Design For Mechanical and Thermal Packaging, Laser Gyro Mechanical Dither Complications, Examples of Strapdown Inertial Navigation Systems - Developmental and Production Configurations

Strapdown Inertial Navigation System Error Characteristics - System and Sensor Analytical Error Models, Schuler and Earth Loop Navigation Errors, Initial Alignment Error Effects, Correlated Errors, Similarities Between Strapdown and Gimbaled System Error Behavior, Unique Strapdown Sensor Errors, Strapdown INS Error Budgets

Kalman Aided Strapdown Inertial Systems - Basic Inertial Aiding Concept, Inertial Aiding Filter Interfaces, Kalman Filters - State Vector Notation, Optimal Gain Determination, Optimal Versus Suboptimal Kalman Filters, Covariance Performance Analysis, Applications of Kalman Filtering to Aided Strapdown Inertial Navigation

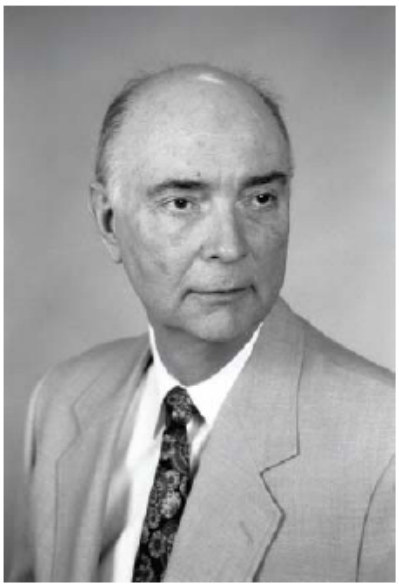
Strapdown Inertial Navigation System Testing - Performance Indices, Laboratory Testing, Mobile Van Testing, Flight Testing, Strapdown System Test Design Considerations

Supplemental Topics - GPS Aided INS, In-Air Transfer Alignment, Tactical Missile Midcourse Guidance, Strapdown Attitude/Heading Reference System (AHRS), Land Vehicle Odometer Aided Strapdown INS, Sculling/Coning Algorithm Errors, Others Selected Per Attendee Request (As Time Permits)

ORGANIZATIONS THAT HOSTED THE ORIGNAL 4 ½ DAY INTRODUCTORY COURSE

US Naval Air Development Center, Honeywell Avionics Divisions, McDonnell Douglas Corporation, Allied Bendix Guidance Systems Division, US Naval Weapons Center, Sandia National Laboratories, U.S. Army Avionics R&D Activity, Holloman AFB - Central Inertial Guidance Test Facility, US Naval Avionics Center, Lear Siegler Instrument Division, Texas Instruments, Rockwell International, General Dynamics Convair, Bell Aerospace, US Naval Surface Warfare Center, Sundstrand Instrument Division, Brazilian Naval Commission, Singer Kearfott Division, Northrop Electronics Division, Wright Patterson AFB, Environmental Research Institute of Michigan, Contraves, Norwegian University Of Science And Technology, Eastman Whipstock, C. S. Draper Laboratory, Boeing Aerospace Company, United Space Alliance - NASA Johnson Space Center, U.S. Army Missile Command, NASA Kennedy Space Center, Systron Donner, Johns Hopkins Applied Physics Laboratory, US Naval Warfare Center, Lockheed Martin Misiles & Fire Control, NASA Goddard Space Flight Center, Lockheed Martin Astronautics

PROFILE OF INSTRUCTOR



Paul G. Savage is an internationally recognized expert in the design and test of strapdown inertial navigation systems, and president of Strapdown Associates, Inc., a company he founded in 1980. Strapdown Associates has provided software and engineering services to government agencies and aerospace companies for strapdown inertial system configuration definition, development of flight software, simulation, and testing. Mr. Savage has published and presented numerous papers on strapdown inertial systems and computational elements.

From 1974 to 2009 Mr. Savage served as author/speaker on several NATO AGARD and RTO technology transfer lecture series tours. From 1981 to 2009, he provided his *Introduction To Strapdown Inertial Navigation Systems* course to the aerospace industry. Since 2011 he has provided a two-day focused version of the *Intro To Strapdown* course on-site at host facilities in the continental United States. He has written and published the textbook *Strapdown Analytics* (available from Strapdown Associates) detailing the analytical aspects of strapdown inertial navigation system design.

From 1963 to 1980, Mr. Savage was employed at Honeywell Avionics Division as Senior Principal Engineering Fellow where he led engineering design teams and provided technical consultation to Honeywell engineering managers for system design, analysis, software development, simulation, and integration/test in the evolutionary development of laser gyro strapdown inertial navigation systems for military and commercial aircraft. From 1971 through 1975, he was the engineering manager and system design engineer for the Honeywell LINS-0 strapdown inertial system, the first to prove the readiness of laser gyro strapdown inertial navigation technology for aircraft applications as demonstrated during a landmark flight test series at Holloman Air Force Base in 1975.

Mr. Savage is a graduate from the Massachusetts Institute of Technology where he received his MS and BS degrees in Aeronautical Engineering in 1960. He is an Associate Fellow of the AIAA.

Introductory Course Books On

STRAPDOWN INERTIAL NAVIGATION SYSTEMS

Paul G Savage
Strapdown Associates, Inc.

From 1981 to 2009, Strapdown Associates, Inc. (SAI) provided its 4 ½ day **Introductory Course On Strapdown Inertial Navigation Systems** to the general public in Minneapolis-Minnesota and on-site at contracting host facilities. Two books by the course instructor Paul G Savage were provided as handout material to each attendee:

Introduction to Strapdown Inertial Navigation Systems

712 page paperback "Yellow Book" containing the Introductory Course presentation slides with accompanying detailed text descriptions. This book **is** the full Introductory course. It addresses the systems, sensor, and software aspects of strapdown inertial navigation system design, Kalman filter aiding, performance analysis, and test. The book can be readily comprehended by engineering, management and marketing personnel having a fundamental engineering background. Sufficient introductory material is included so that readers need no former background in inertial navigation or complex mathematics. The emphasis in the book is on providing down-to-earth explanations of basic principles associated with strapdown systems and hardware/software components. Because many elements of strapdown inertial navigation are inherently analytical in nature, the course addresses the analytical aspects, but primarily from a functional and operational standpoint. Detailed mathematical derivations are avoided and referenced instead to the supporting book - **Strapdown Inertial Navigation Lecture Notes**.

Strapdown Inertial Navigation Lecture Notes

376 page reformatted paperback "Blue Book" containing a compilation of technical material prepared by Paul G Savage including detailed derivations of strapdown inertial navigation equations, computational algorithms, Kalman filtering techniques, and descriptions of inertial systems/sensors described in the Introductory Course.

The 4 ½ day course is no longer being provided, however, the course books are now being provided as handout material for an SAI two-day on-site Introductory Short Course On Strapdown Inertial Navigation Systems. The books can also now be purchased directly from SAI at www.strapdownassociates.com.

Introduction To Strapdown Inertial Navigation Systems - Course Book Contents

Fundamental Concepts
- Vector Concepts
- Navigation Parameters
- Gravity and Specific Force Acceleration

Inertial Navigation Principles
- Inertial Navigation Concept
- Strapdown Compared to Gimbaled Inertial Navigation Systems
- Fundamental System Operations
- Strapdown Skewed Sensor Redundancy

Inertial Navigation Position/Velocity Equations
- Geographic, Free Azimuth, Wander Azimuth Integration Approaches
- Vertical Channel Stabilization

System Initialization
- Position/Velocity, Attitude/Heading
- Strapdown Vs. Gimbaled Systems

Gimbaled Platform Reference Stabilization
- Three and Four Gimbal Platforms, Gimbal Lock

Strapdown Analytical Reference Equations
- Acceleration Transformation
- Attitude Determination - Euler Angles, Direction Cosines, Quaternions

Strapdown Reference Computer Algorithms
- Acceleration Transformation - Sculling, Errors
- Attitude Determination - Coning, Errors
- Real-Time Computation -Multi-rate Design
- Software Design Tradeoffs
- Interface With Sensor Compensation
- Dynamic Environment Design Considerations

Inertial Sensors
- Inertial Sensor/System Computer Interfaces
- Inertial Sensor Input/Output Requirements
- Accelerometers
  - Pendulous Electrically Servoed Accel
  - Mechanically Servoed Gyro Accelerometer
  - Vibrating Quartz Beam Accelerometer
  - Silicon MEMS Accelerometer
- Angular Rate Sensors
  - Floated Rate Integrating Gyro
  - Tuned Rotor Gyro
  - Electrostatic Gyro
  - Ring Laser Gyro
  - Fiber Optic Gyro
  - Vibrating-Quartz Rate Sensor
  - Vibrating-Silicon MEMS Rate Sensor
  - Sensor Electronics
  - Sensor Error Mechanisms
  - Environmental Effects
- Angular Rate Sensors (Continued Next Column)
- Angular Rate Sensors (Continued)
  - Laser Gyro Design Details - Performance Versus Design Parameters, Lock-in Compensation, Mechanical Dither Complications

Strapdown System Thermal/Mechanical Design
- Functional Hardware Operations
- Basic Design PhilosophyMechanical and Thermal Design Approaches
- Design For Laser Gyro Mechanical Dither
- Design For Skewed Sensor Redundacy
- Examples of Contemporary Strapdown Inertial Navigation Systems - Developmental and Production Hardware Configurations

Strapdown Inertial Navigation System Errors
- System and Sensor Analytical Error Models
- Schuler and Earth Loop Error Propagation
- Similarities Between Strapdown and Gimbaled System Error Behavior
- Unique Strapdown Sensor Error Effects on System Accuracy - System Initialization, Navigation Performance, Maneuver Induced Errors, Correlated Errors
- Typical Strapdown INS Error Budget

Aided Strapdown Inertial Navigation Systems
- Basic Inertial Aiding Concept
- Examples of Aided Inertial Systems
- Inertial/Aiding Filter Interfaces
- Kalman Filter Theory - State Vector Notation, Optimal Gain Determination In Simulated and Real Time, Optimal And Suboptimal Filters, Covariance Performance Analysis
- Kalman Filtering Applied to Strapdown Aided Inertial Navigation - Typical Examples, Special Strapdown Design Considerations

Strapdown Inertial Navigation System Testing
- Performance Indices
- Laboratory Testing and Calibration -Test Methods, Strapdown Test Design Methodology, Hardware/Software Test Considerations, Sensor/System Testing
- Mobile Testing - Van And Flight Testing
- Strapdown System Test Considerations

Supplemental Material
- Strapdown System Configurations
- Sculling And Coning Algorithm Errors
- Covariance Propagation Algorithms
- Direction Cosine Matrix Orthonormality
- Navigation Errors At High/Low Latitudes
- Rate Gyro Digital Integration Error Under Vibration