3-DAY CERTIFIED COURSE

# Introduction to Finite Element, Boundary Element, and Meshless Methods

## An Introductory 3-Day Course with Applications including Hands-on Exercises

**April 12–14, 2019**
University of Nevada Las Vegas,
Las Vegas, NV, USA

ASTFE
American Society of Thermal and Fluids Engineers

# SCOPE

This course stems from our experiences in teaching numerical methods to both engineering students and experienced, practicing engineers in industry. The emphasis in this course deals with finite element, boundary element, and meshless methods. Much of the material stems from courses we have conducted over many years at our institutions, as well as from AIAA home study and ASME short courses presented over several decades, including suggestions and recommendations of our colleagues and students. There are numerous books on applied numerical methods, many of them being finite element and boundary element textbooks available in the literature today. However, there are very few books dealing with meshless methods, especially those showing how nearly all of these numerical schemes originate from the fundamental principles of the method of weighted residuals. We find that when students once master the concepts of the finite element method (and meshing), it's not long before they begin to look at more advanced numerical techniques and applications, especially the boundary element and meshless methods (since a mesh is not required). Our intent in this course is to provide a simple explanation of these three powerful numerical schemes, and to show how they all fall under the umbrella of the more universal method of the weighted residuals approach.

**The course is divided into three days, beginning with the finite element method on Day 1, then progressing through the boundary element method on Day 2, and finally ending with the meshless method on Day 3. Each technique serves as a stand-alone description, but it is apparent to see how each conveniently connects to the other techniques.**

We begin on **Day 1** by introducing the basic fundamentals of the finite element method using simple examples. Particular attention is given to the development of the discrete set of algebraic equations, beginning with simple one-dimensional problems that can be solved by inspection, and continuing to two- and three-dimensional elements. Once these principles are grasped, we then introduce the concept of boundary elements on **Day 2**, and the relative ease with which one reduces the dimensionality of a problem (a great relief when solving large problems, or problems with infinite domain boundaries). The boundary element technique is a natural extension of the finite element method, and becomes greatly appreciated by users.

On **Day 3**, we introduce the meshless method. The method is simple to grasp, and simple to implement. The power of the method is becoming more appreciated with time. The meshless method has been shown to yield solutions with accuracies comparable to finite element methods employing an extensive number of elements, yet requiring no mesh (or connectivity of nodes). We have used it for structural analysis, fluid flow, heat transfer, environmental transport, and various biomedical applications.

We will provide computer files that will be used to illustrate the setup and subsequent solutions of example problems (these will also be made available at fbm.centecorp.com). These codes run on PCs utilizing MATLAB. In addition, FORTRAN, MathCad, and MAPLE versions are also available.

# OBJECTIVES

**The objectives of the course are:**

- ✓ Introduce the basic concepts of the finite element method, the boundary element method, and the meshless method utilizing the Method of Weighted Residuals
- ✓ Discuss the advantages and limitations of each method
- ✓ Demonstrate the capabilities of each method on a variety of problems
- ✓ Provide “hands-on” access to simple computer codes that run on PCs
- ✓ Emphasize fundamentals through algebraic examples

# WHO SHOULD ATTEND

This course is intended for those who wish to understand the basic concepts of the finite element method, the boundary element method, and meshless methods, and how they become implemented in computer programs.

**The course is suitable for both postgraduate students and graduate engineers and scientists in industry and government.** Those with a basic understanding of calculus and a familiarity with PCs (Windows or Mac) will have sufficient background necessary for this course. Students with an engineering or mathematical background should have no difficulty in grasping the underlying principles of the methods and their applications to various fields.

# COURSE INSTRUCTORS

## Dr. Darrell W. Pepper

### The University of Nevada Las Vegas, Las Vegas, NV

Dr. Pepper is presently Professor of Mechanical Engineering and Director of the Nevada Center for Advanced Computational Methods at the University of Nevada Las Vegas (UNLV). He served as a Distinguished Visiting Faculty at the US Air Force Academy in Colorado Springs, CO from 2011-2013. He was an ASME Congressional Fellow in 2004, working in the office of Senator Dianne Feinstein (D-CA) where he handled science and engineering issues for the Senator. He served as Interim Dean of the College of Engineering and was Chair of the Department of Mechanical Engineering from 1996-2002. He obtained his BSME, MSAE, and Ph.D. degrees from the University of Missouri-Rolla (now Missouri S&T). Prior to his academic career, he worked in various technical and managerial positions for Du Pont at the Savannah River Laboratory in Aiken, SC, served as Chief Scientist of the Marquardt Company, an aerospace propulsion company in Van Nuys, CA, and co-founded and was CEO of Advanced Projects Research, Inc., an R&D company in CA. He has published over 300 technical papers in the areas of fluid flow, heat transfer, and environmental transport, including seven textbooks on finite element and related numerical techniques. Dr. Pepper is Editor-in-Chief of the Journal of Computational Thermal Sciences, a Life Fellow of ASME, and Fellow of Wessex Institute of Technology.

## Dr. Alain Kassab

### The University of Central Florida, Orlando, FL

Dr. Kassab earned his PhD in Mechanical Engineering in 1989 from the University of Florida and is currently a Professor in the Mechanical and Aerospace Engineering Department at the University of Central Florida in Orlando. He has over 25 years of experience in research and development in computational heat transfer, computational fluid dynamics, inverse problems, boundary elements, meshless methods and bioengineering resulting in over 300 scientific publications. He has authored two books on boundary elements, contributed chapters on boundary elements in heat transfer in the Handbook of Numerical Heat Transfer and Advances in Heat Transfer. He has co-organized and co-edited 10 international conferences in boundary elements and meshless methods. He is a Fellow of the ASME and the Wessex Institute of Technology. He is Editor of the international journal Engineering Analysis with Boundary Elements, Associate Editor of Inverse Problems in Science and Engineering, and is a member of 3 journal editorial boards.

## Dr. Eduardo Divo

### Embry-Riddle Aeronautical University, Daytona Beach, FL

Dr. Divo is Professor of Mechanical Engineering at Embry-Riddle Aeronautical University where he also serves as the Associate Chair, PhD Program Director and Biomechanical Systems Track Coordinator. He has developed and taught over 30 undergraduate and 8 graduate courses ranging from mathematical analysis, programming and numerical methods to bio-fluid mechanics and biomechanics. Dr. Divo is actively involved in bioengineering research including cardiovascular hemodynamics, lung dynamics, biomechanics, muscle and tissue mechanics, radiotherapy, and others. His fundamental research concentrates on numerical modeling techniques such as Meshless Methods and the Boundary Element Method with applications to bioengineering, fluid dynamics, heat transfer, fluid-structure interaction, inverse problems and optimization. His work has led to over 200 articles in international journals and conference proceedings as well as various books and chapters. He is also President and CEO of Central Technological Corporation (Centecorp) where he manages R&D projects in the modeling and simulation area.

# COURSE OUTLINE

0

## Overview

- The Method of Weighted Residuals (MWR)
- Review of Basic Numerical Methods
    - Finite Difference Method
    - Finite Volume Method

1

## Day 1: The Finite Element Method

- History
- MWR and the Weak Statement
- One-Dimensional Elements (linear, quadratic, cubic)
- Two-Dimensional Elements
    - Triangles
    - Quadrilaterals
- Creating a Mesh
- Three-Dimensional Elements (Tetrahedral, Hexahedral)
- Time-Dependence
- Resolving Steep Gradients in Advection Terms
- Applications
    - Solid Mechanics
    - Transport/Environmental
    - Heat Transfer
    - Fluid Flow
        Incompressible
        Compressible
- Hands-on Exercises with the Numerical Codes

2

## Day 2: The Boundary Element Method

- Overview
- Green's Third Identity for Potential Problems
- The 2D Heat Conduction Problem
- Analytical versus Numerical Solutions
- Two-Dimensional Boundary Elements
- Three-Dimensional Boundary Elements
- Dual Reciprocity Boundary Element Method
- Inverse Problems
- Hands-on Exercises with the Numerical Codes

3

## Day 3: The Meshless Method

- Overview
- Radial-Basis Functions
- Localized Collocation Meshless Method versus Least-Squares
- Finite-Differencing
- Upwinding
- Automatic Point Distribution
- Applications
    - Heat Transfer
    - Fluid Flow
    - Biomedical
    - Porous Media
- Hands-on Exercises with the Numerical Codes

# REGISTRATION

**Fee: $500**

The Fee for the course covers instructional material costs, a copy of the book *Introduction to Finite Element, Boundary Element, and Meshless Methods, by D.W. Pepper, A. Kassab, and E. Divo, ASME Press, 2014*, a complete set of computer codes, break refreshments, and lunch each day. Each participant will receive a certificate of the course completion. All fees must be paid in advance at least two weeks before the start of the course. Pay by credit card, check, money order, or request to bill employer.

**Please use the form that can be found online at:**
**http://www.astfe.org/courses/febemm2019/**

Cancellations must be received at least two weeks before the course begins; substitutions will be accepted. In the event that insufficient registrations or any situation beyond our control warrants cancellation of the course, participants will be notified immediately and a full refund will be issued.