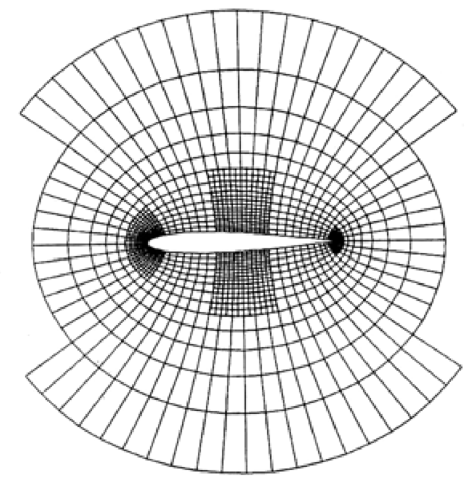
FINITE ELEMENT METHOD IN FLUID MECHANICS & HEAT TRANSFER

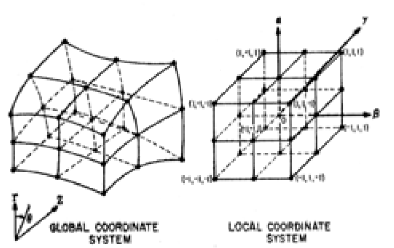
AERSP-560



64 × 16 coarse grid with one level of refinement.

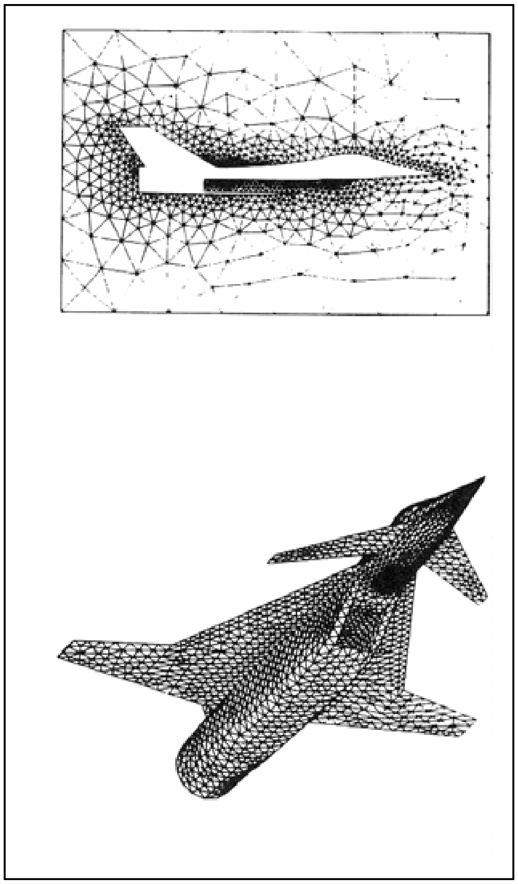
Department : Aerospace Engineering
Instructor : Dr. Cengiz Camci
Time and Place : T & R , 4:15 - 5:30 pm 173 Willard Building
Prerequisites : Fluid Mechanics, Thermodynamics, advanced calculus, matrix algebra, computer programming (Fortran or C++)
Grade : Computer assignments and a final exam
Credits : three credits

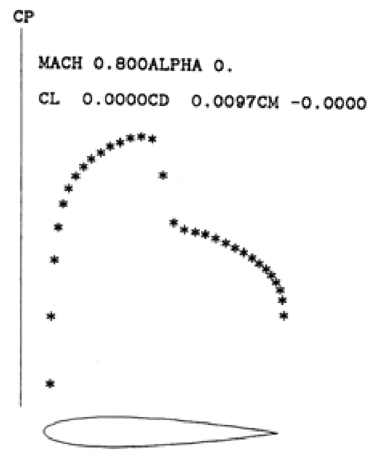
This course is intended to provide a thorough introduction to the basic ideas employed in the application of finite element techniques to especially fluid flow and heat transfer problems. A student who successfully completed this course should be able to perform quick analysis of small problems using the finite element method and write full sized application codes for analyzing fluid flow and heat transfer problems. Additionally, mastery of the material provided in this course will enable the student to more intelligently use commercially available codes based on the finite element method.



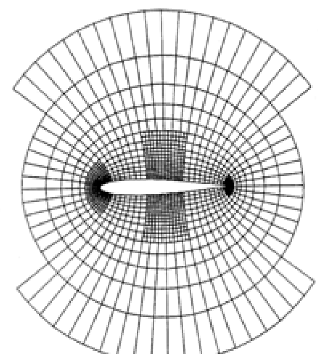
Finite element in cylindrical and local coordinate system.

PLEASE CONTACT CENGIZ CAMCI IF YOU HAVE INTEREST IN THIS COURSE





Pressure coefficient using a 64 × 16 coarse grid.



TYPICAL SEQUENCE OF LECTURES

Introduction to finite element method, interpolations
Numerical integration, iso-parametric elements
Variational principles, method of variations
Method of weighted residuals
Potential flow solutions
Transient heat conduction, parabolic diffusion problems
Full potential equation solutions
Incompressible viscous flow through the solution of Navier-Stokes equations
Coupled heat transfer/flow solutions
Natural/forced convection
Density dependent convective diffusion
Penalty method
Flow/Heat transfer solutions for turbomachinery internal flow configurations

AEROSPACE 560
Finite Element Method in Fluid Mechanics and Heat Transfer

A. Bulletin Listing

1. Designation: AERSP
2. Number: 560
3. Title: Finite Element Method in Fluid Mechanics and Heat Transfer
4. Abbreviated title : Finite Elements in Thermo-fluids Engineering
5. Credits,class periods, practicum periods: 3,3,0
6. Description: A thorough introduction to the basic ideas employed in the application of finite element techniques to especially fluid flow and heat transfer problems encountered in aerospace engineering and mechanical engineering .

B. Course Outline

Introduction
- Mathematical Tools
- Foundations of Fluid Mechanics and Heat Transfer

An Introduction to Finite Element Analysis Using "Galerkin Weak Statement"
- A Model One Dimensional Problem
- The Weak Statement
- Derivation of a Symmetric Weak Formulation
- The Galerkin Procedure
- Removal of the Arbitrariness
- The Galerkin Procedure and Finite Element Discretization
- Construction of the Trial Space Set
- Finite Element Matrix Calculations
- Development of the Local Coordinate System
- Element Conductivity Matrix
- Element Load Matrix
- Assembly Procedure
- A Solution for the Model Problem
- A Higher Order Formulation

Flow Between Two Parallel Plates (Poiseville Flow)
- A Galerkin Weak Statement Solution

- Compressible Subsonic Potential Flow
    - Linearized Theory For Thin Airfoils
    - A (GWS) Solution to Prandtl-Glauert Equation

- Unsteady Transport with Fluid Motion
    - Unsteady Energy Equation + An Imposed 1D Velocity Field
    - Galerkin Weak Statement and Discretized (GWS)
        - Family of Single Step Time Iterative Algorithms
            - Explicit Euler, Trapezoidal, Backward Euler

- Viscous Incompressible Unsteady Flow (Laminar) in 2D
    - A Stream-function/Vorticity Formulation of 2D Navier Stokes Equations
    - (GWS) for the Equation L2ψ = -ω
        - Removal of Arbitrariness
    - (GWS) for the Vorticity Transport Equation
        - Removal of Arbitrariness
    - Element Matrix Formulation for the Stream Function/Vorticity Formulation
    - Development of the Time Marching Procedure
    - Calculation of Stream Function Values at Nodal Points
    - Calculation of Velocity Components
    - Remarks on the Recovery of the Pressure Field

- Examples of Finite Element Solutions of 2D Unsteady Viscous Flow
    - Unsteady Viscous Flow Around a Cylinder
    - Unsteady Viscous Flow Facing a Back Step
    - Unsteady Viscous Flow Around a Cylindrical Obstacle on its bed
    - Wind Driven Flow in a Rectangular Cavity
    - Flow in a Channel of Finite Width with a Rectangular Obstruction

- Thermal Fluid Flow (2D, Viscous, Incompressible, Unsteady)
    - Natural Convection in an Enclosure
    - A Stream Function Vorticity Formulation and Thermal Energy Equation with Buoyancy Force Terms
    - (GWS) and Interpolations on Stream Function, Vorticity and Temperature

- An Incompressible Turbulent Boundary Layer Solution using the Finite Element Method
    - (GWS) for x Momentum Equation,
    - Removal of Arbitrariness, Boundary Conditions
    - Calculation of Cross Stream Velocities
    - A (GWS) Solution for the Continuity Equation

- Computer Programming Aspects of Finite Element Analysis in 2D

C. Justification Statement

1. Instructional Objectives:
The objectives of this course are to cover the basic ideas employed in the application of finite element techniques to especially fluid flow and heat transfer problems. Although there are many existing courses dealing with finite element analysis, non of the current offerings specifically deal with fluid flow and heat transfer problems in depth. Almost all of the existing courses are focussed on structural mechanics and dynamics applications with minimal coverage on viscous flow and heat transfer. The techniques discussed in this course have wide application potential in Aerospace Engineering, Mechanical Engineering, Nuclear Engineering (thermo-hydraulics) and Chemical Engineering. A student who succesfully completed this course will be able to perform quick analysis of small scale problems using the finite element method and to write full sized application codes for analyzing fluid flow and heat transfer problems. Additionally, mastery of the material provided in this course will enable the student to more intelligently use commercially available codes based on the finite element method.

2. Evaluation Methods of the Course:
Homework assignments, computer projects, midterm and final exams

3. Relationship of Course to Other Courses :
This is the only finite element course specifically dealing with fluid mechanics and heat transfer including viscous unsteady flow and convective heat transfer . Other course offerings in the area of Finite Element Method at the College of Engineering are as follows :

ME 461	Applied Finite Element Analysis
Emch 560	An Introduction to the Finite Element Method of Analysis
Emch/ME 563	Nonlinear Finite Element Analysis

The course outlines of the courses listed above are enclosed to this document.

4. Relationship of Course to Major/Minor/Option or General Education:
This course would be required for Aerospace Engineering Students specializing in Thermal Turbomachinery research and Heat Transfer. It

would be optional for Aerospace and Mechanical Engineering Students who desire some background in the basics of Finite Element Method of Solution in Fluid Mechanics, Aerodynamics and Heat Transfer.

7. Consultation with other Departments and Academic Support Units:
Faculty in Mechanical Engineering and Engineering Science and Mechanics who offer courses in related areas were consulted to ensure there would be no significant overlap of material. A memo of support and suggestions from Dr. H.R.Jacobs is attached. This memo was obtained in 1993 during the first offering of the course.

6. Frequency of Offering and Enrollment:
The course will be offered every two years during the spring semester. This course was offered four times (Fall 1993, Spring 1995 , Spring 1997 and Fall 1998). The enrollment was 12, 10, 12 and 12 respectively.

D. Effective Date

Spring Semester 1999