

Academic Year: ( 2017 / 2018 )

Review date: 08-08-2017

Department assigned to the subject: Bioengineering and Aerospace Engineering Department

Coordinating teacher: DISCETTI , STEFANO

Type: Compulsory ECTS Credits : 6.0

Year : 4 Semester : 1

**REQUIREMENTS (SUBJECTS THAT ARE ASSUMED TO BE KNOWN)**

Fluid Mechanics  
Thermal Engineering

**OBJECTIVES**

The goal of this course is to introduce students to the basic principles and methodologies of turbomachinery design. The students are expected to achieve a fundamental and applied knowledge of the working principles and design guidelines of axial and radial turbomachines.

**DESCRIPTION OF CONTENTS: PROGRAMME**

Introduction. Dimensional Analysis

- Definition of a turbomachine. Different kinds and applications.
- Main defining variables, dimensions and fluid properties. Units.
- Dimensional analysis and performance laws. Compressible flow analysis. Specific speed: machine selection. Model testing.

Fluid mechanics and thermodynamics equations

- Equations in integral form.
- Euler equations for turbomachines.
- Definition of Rothalpy.
- Definition of adiabatic / polytropic efficiency. Enthalpy-entropy diagrams.
- Equations in differential form.

Two-dimensional cascades

- Introduction. Definition of stream surface,  $m\chi-\chi$  plane, blade-to-blade analysis.
- Cascade nomenclature for compressors and turbines.
- Cascade kinematics: velocity triangles. Cascade dynamics: forces, momentum. Cascade enthalpy and entropy change: losses.
- Compressor cascade performance. Compressor characteristics: enthalpy rise, pressure recovery, deflection, deviation and loss. Blade loading: surface velocity distribution, diffusion factor. Compressor cascade correlations: optimum solidity, polar curve. Diffuser efficiency.
- Turbine cascade performance. Turbine characteristics: turning angle, Zweifel coefficient. Surface velocity distribution: Back Surface Diffusion parameter. Turbine cascade correlations: loss, optimum pitch-chord ratio.
- Cascade wind tunnel testing. Description of tunnels, measurements. Unsteadiness.

Axial flow turbines: two-dimensional stage theory

- Dimensional analysis of a single turbine stage. Velocity triangles, loading and flow parameters, reaction. Repeating stage hypothesis.
- Thermodynamics of a turbine stage. Total-to-total stage efficiency. Row loss-stage efficiency relation
- Reaction. Effect on efficiency. Optimum reaction
- Smith chart. Empirical versus reversible.
- Flow characteristics of a multistage turbine.
- Stress/Cooling/Detailed design. Design criteria.

Axial flow compressors and fans: two-dimensional stage theory

- Dimensional analysis of a single compressor stage. Velocity triangles, loading and flow parameters, reaction. Repeating stage hypothesis.
- Thermodynamics of a compressor stage. Total-to-total stage efficiency. Row loss-stage efficiency relation.

- Loading-Flow coefficient chart. Reaction choice. Lift and Drag in terms of  $\zeta$  and  $\zeta_c$ . Diffusion Factor and solidity selection. Estimation of compressor efficiency. Simplify off-design performance.
- Blade element theory.
- Stall and surge phenomena.

#### Three-dimensional flow in Axial Turbomachines

- Theory of radial equilibrium. The indirect problem: free-vortex flow, forced-vortex flow, general whirl distribution. The direct problem.
- Compressible flow through a blade-row.
- Constant specific mass flow.
- Off-design performance of a stage (free-vortex turbine).
- Actuator disc approach. Blade-row interactions. Computer methods solving through-flow problem.
- Secondary flows. Loss, angles and helicity.
- Three-dimensional losses. Types and models.
- Three-dimensional design features. Lean, sweep and bow.

#### Centrifugal compressors, fans and pumps

- Introduction and definitions. Centrifugal compressor parts.
- Theoretical analysis of a centrifugal compressor. Dimension-less performance parameters. Inlet, impeller and diffuser equations.
- Optimum design of a centrifugal compressor inlet.
- Radial flow turbo-machine blading design/selection
- Slip factor. Correlations.
- Performance of centrifugal compressors.
- Diffuser system. Vane and vane-less diffusers.
- Chocking in centrifugal compressor stage.

#### Radial turbines

- Introduction. Types of inward flow radial turbine.
- Thermodynamics of the 90 degrees IFR turbine
- Basic rotor design. Rotor efficiency definition. Mach number relations. Loss coefficients.
- Optimum efficiency considerations. Minimum number of blades.
- Design criteria. Pressure ratio limits.

### LEARNING ACTIVITIES AND METHODOLOGY

Theory sessions.

Problem sessions working individually and in groups.

Lab-sessions.

### ASSESSMENT SYSTEM

In order to pass the subject, two requirements need to be met:

- 1) to have a MINIMUM mark of 4.0/10 in the end-of-term exam;
- 2) to have a minimum overall mark of 5.0/10 (weighing 60% the end-of-term exam mark and 40% the mark of the continuous evaluation).

**% end-of-term-examination:** 60

**% of continuous assessment (assignments, laboratory, practicals...):** 40

### BASIC BIBLIOGRAPHY

- R. I. Lewis Turbomachinery Performance Analysis, John Wiley & Sons Inc, 1996
- S Larry Dixon, Cesare Hall Fluid Mechanics and Thermodynamics of Turbomachinery, Seventh Edition, BH (Butterworth-Heinemann), 2013

### ADDITIONAL BIBLIOGRAPHY

- Budugur Lakshminarayana Fluid Dynamics and Heat Transfer of Turbomachinery, John Wiley & Sons Inc, 1995
- Korpela, S.A. Principles of Turbomachinery, Wiley&Sons, 2011
- Saeed Farokhi Aircraft Propulsion, John Wiley & Sons Inc, 2008