Turbomachinery Design

Academic Year: (2022 / 2023) **Review date: 20-05-2022**

Department assigned to the subject: Aerospace Engineering Department

Coordinating teacher: DISCETTI , STEFANO

Type: Electives ECTS Credits : 6.0

Year : 4 Semester :

REQUIREMENTS (SUBJECTS THAT ARE ASSUMED TO BE KNOWN)

Fluid Mechanics I
Fluid Mechanics II
Thermal Engineering

OBJECTIVES

The goal of this course is that the students acquire a theoretical and applied knowledge of the working principles and design procedures of axial and radial turbomachines, and of their application to solving design problems in aerospace propulsion.

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 streamsurface, m¿-¿ plane, blade-to-blade analysis.
- Cascade nomenclature for compressors and turbines.
- Cascade kinematics: velocity triangles. Cascade dynamics: forces, momentum. Cascade entalphy 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. Diffusor 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 ¿ and ¿. 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 75% the mark of the continuous evaluation and 25% the end-of-term exam mark).

The continuous evaluation includes 2 partial exams (each one corresponding to 15% of the final mark) and reports of laboratory practices (corresponding to 45% of the final mark).

% end-of-term-examination:	25
% of continuous assessment (assigments, laboratory, practicals…):	75

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