SYLLABUS

<table>
<tr><td>Name of the course:</td><td colspan="3">Introduction to hydrodynamic stability</td></tr>
<tr><td>Level of studies:</td><td colspan="3">Master degree, doctoral studies</td></tr>
<tr><td>Direction, specialization:</td><td colspan="3">all</td></tr>
<tr><td colspan="2">Code:</td><td>Semester: 2</td><td>No. Of ECTS: 3</td></tr>
<tr><td colspan="2">Level of the course: advanced</td><td colspan="2">Type of the course: elective</td></tr>
<tr><td>Total volume: 70 h</td><td>Lectures: 30 h
Tutorials: 0 h
Consultations: 5 h
Project: 15 h</td><td colspan="2">Self-study: 20 h</td></tr>
<tr><td colspan="4">Course director: prof. dr hab. inż. Jacek Szumbarski</td></tr>
<tr><td colspan="4">Educational goals:

C1. Goals and principles of stability analysis in fluid mechanics
C2. Presentation of main mechanisms/scenarios/criteria of hydrodynamic instabilities
C3. Presentation of theoretical foundations of linear stability theory applied to parallel flows.
C4. Presentation of the normal mode approach to linear stability on the example of flows in channels with corrugated walls.
C5. Presentation of selected numerical methods for linear stability analysis
C6. Presentation of the methodology of research of a phenomenon of transient disturbance growth and explanation of its role for laminar-turbulent transition scenarios.
C7. Presentation of the concepts of convective and global instabilities and modeling of wave packets and related mathematical tools.
C8. Development of basic skills in numerical analysis of selected stability problems, also by means of self-developed computational tools.</td></tr>
<tr><td colspan="4">Assumed competences:

1. Knowledge and skills in fluid mechanics on the 1st level of mechanical engineering studies
2. General orientation and skills in basic numerical methods
3. Basic knowledge and skills in mathematical analysis, linear algebra and differential equations, typical for the 1st level of mechanical engineering studies.</td></tr>
<tr><td colspan="4">Learning outcomes (knowledge)

EW1 – Student knows basic instability scenarios including typical examples.
EW2 – Student knows general principles and concepts of linear stability analysis, understands the concepts of asymptotic stability and the normal mode method.
EW3 – Student knows classical criteria of instability of inviscid parallel flows.
EW4 – Student understands the role of fluid viscosity in the hydrodynamic instabilities
EW5 – Student knows the goals and methods of analysis of a transient growths of small disturbances
EW6 – Student understand the difference between convective and global instabilities, and he/she is able to give adequate examples.

Learning outcomes (skills)

EU1 – Student is able to describe physical mechanisms of basic forms of hydrodynamic instabilities
EU2 – Student is able to derive the set of equations for small disturbances in a general parallel flow
EU3 – Student is able to verify classical stability criteria for a given parallel flow
EU4 – Student can propose and formulate a numerical method for stability analysis of selected flow cases
EU5 – Student is able to justify the need for transient disturbance growth analysis and proposed an adequate numerical approach to such problem
EU6 – Student is able – by his/her own or in a team – to solve numerically a given stability problem and properly interpret results of the calculations</td></tr>
</table>

Learning outcomes (social skills)

ES1 – Student is able to work productively in a teams, take up responsibility and provide on time required results.

Content of the course

Lectures	Hours
Introduction: overview of main concepts, definitions and tools from linear algebra, analysis and differentia equations.	2
Elements of stability and bifurcation theory on the example of simple dynamical systems.	2
Basic forms and mechanisms of hydrodynamic instabilities. Examples.	2
Theory of linear instability for inviscid flow. Selected criteria of instability.	4
Linear theory for viscous parallel flows. The Orr-Sommerfeld and Squire equations. The Squire's theorems.	4
Case study – detailed linear stability analysis of the Poiseuille flow.	2
Case study – linear stability analysis of the flow through the channel with corrugated walls. Application to intensification of mixing in a laminar regime.	4
The problem of transient growth of subcritical disturbances – general formulation and solution methods.	2
Case study – transient disturbance growth in the Poiseuille flow	2
Case study – transient disturbance growth in the flow through the corrugated channel	4
Elements of the spatial stability analysis. Dynamics of wave packets, Gaster's transformation, convective and absolute instabilities. Examples.	4
Project (15 h) The project consists in development of a part or whole computer code and its application to a given hydrodynamic stability problem. Dependently on the level of complexity/difficulty and expected workload, such project will be realized individually or in pairs. The outcome of the project includes a complete written report, seminar presentation and full computer code developed by the author(s).	

Recommended reading

1. Materials (PDF presentations) provided by the lecturers.
2. Scientific publications suggested by the lectures
3. P.G. Drazin, Introduction to hydrodynamic stability, Cambridge University Press, 2002.
4. Francois Charru, Hydrodynamic Instabilities, Cambridge University Press, 2011.

Student's workload

Form of activity	Hours
Contact hours (lectures)	30
Contact hours (consultancy)	5
Self-study, work on the project	35
SUMM	70

Didactic tools

1. Lecture presentations (PDF, Power Point)
2. Instructions to home projects
3. Home problems
4. Related websites and repositoria

Evaluation methods

Elements evaluated and contributing to the final grade: outcome of the tests from the lecture material, activity in solving the home problems, the outcome (including quality of the final report and seminar presentation) of the individual (or team) project.

Realization of learning outcomes

Learning outcome	Relevance for the whole program	Teaching objectives	Didactic tools	Evaluation
EW1		C1,C2	Lecture, self-study	Numeric mark (2 to 5)
EW2		C2, C3	Lecture, self-study	As above
EW3		C2,C3	Lecture, self-study	As above
EW4		C2,C3	Lecture, self-study	As above
EW5		C6	Lecture, self-study	As above
EW6		C7	Lecture, self-study	As above
EU1		C1,C2	Self-study, homework, project	As above
EU2		C3,C4,C6	Self-study, homework, project	As above
EU3		C2,C3,C4	Self-study, homework, project	As above
EU4		C5,C6,C8	Self-study, homework, project	As above
EU5		C6	Self-study, homework, project	As above
EU6		C5,C8	Self-study, homework, project	As above
ES1		C8	project	