**Title of the Unit:** Aerodynamic Optimization

**Unit code:** MU5MEF39

**Total time per student:** 14h lecture 4h tutorial 12h lab+project

**Credit number: 3** ECTS

**Master’s degree:** x Mecanics Robotics & Auto. Cont. Electrical Eng.

**Master program:** E3A : CIMES Syscom IPS

AR : SAR ISI

MECA : MS2 x MF2A EE x CompMech xACOU EE APP

**Semester:** S1 S2 x S3 S4

**Teaching language: x** French xEnglish

**Involved students:** xSorbonne Université x Other (to be specified): ENSAM

**Localization:** xPMC campus Other (to be specified):

**Objectives of the unit:**

This teaching unit aims to introduce students with notions of optimization (mainly shape optimisation) in aerodynamics. Through this class, students will learn to pose the mathematical problem (optimization problem with or without constraint), to determine the conditions of existence and uniqueness of a solution (in finite and infinite dimension) and to numerically solve the problem of optimization using gradient type algorithms (also known as descend algorithms) with constant, variable or optimal step, projected gradient type algorithm and Newton type methods (with focus on a least-square algorithm named SLSQP), as well as an introduction to machine learning algorithms by the neural network method. The dual (or adjoint) problem will also be introduced to present the analysis of sensitivities in optimization which is an approach related to the optimization of a quantity of interest (QoI). We will consider for example: the aerodynamic coefficients integrated around a wing profile (such as ONERA M6 and/or NACA0012), or a pressure signature on an objective zone for a 3D flying vehicle configuration or a scramjet configuration.

Other than the theoretical aspects students will have practical objectives of implementation and analysis of various optimization algorithms (mentioned above) using Python under Jupyter notebooks. Numerical simulations will be performed with the open-source SU2 multi-physics code from Stanford University (https://su2code.github.io/) which uses the C programming language and Python scripts for optimization. The pre-processing of the numerical simulation problems will be done with gmsh (mesh generator) and the post-processing with ParaView.

**Knowledge and skills mastered at the end of the unit :**

At the end of this course, students will have developed scientific, methodological and pluri-disciplinary skills:

* Define an optimization problem and analyze the existence of the (local or global) solution
* Numerically search of the optimal solution with an efficient choice of algorithm (taking into account both accuracy and computational costs), and connection with machine learning (AI) type approaches
* Understand and use the adjoint problem for sensitivity analysis and an efficient computation of the optimality condition
* Effective use of advanced numerical tools developed in the SU2 code
* Validation of the new configurations (designs or shapes) using the knowledge acquired in fluid mechanics (mainly compressible aerodynamics)

**Detailed content of the unit :**

* General reminders or definitions: introduction of an optimization problem, interest of convexity, existence and uniqueness for local and global solution (on finite and infinite dimension spaces)
* Optimization without constraint and with constraints (equality or inequality): introduction of the Lagrangian
* Optimality conditions: Euler equation, saddle point, Kuhn-Tucker theorem
* Dual problem: continuous and discrete adjoint formalism, link with sensitivity analysis
* Optimization algorithms: gradient type algorithms, Newton and machine learning (neuron network)

**Prerequisites of the unit :**

functional analysis (variational problem, Riesz theorem, Lax-Milgram, energy minimization problem), linear algebra, numerical interpolation and integration, resolution of linear systems, finite element and volume methods, CFD, programming in Python

**Evaluation of the unit (informative) : CC (3 Quizz) /40 + TP-Projet /60**

**Bibliography :**

Papalambros, Panos Y., and Douglass J. Wilde. *Principles of Optimal Design: Modeling and Computation*. 2nd ed. Cambridge, UK: Cambridge University Press, 2000. ISBN: 9780521627276.

Vanderplaats, Garret N. *Numerical Optimization Techniques for Engineering Design*. 3rd ed. Colorado Springs, CO: Vanderplaats Research and Development Inc., 2001. ISBN: 9780944956014.

Philippe Ciarlet *Introduction to numerical linear algebra and optimisation.* Cambridge University Press, 2018, ISBN: 9781139171984

Grégoire Alaire. *Analyse numérique et optimisation - Une introduction à la modélisation mathématique et à la simulation numérique ,* Ed. Ecole Polytechnique, 2005. ISBN:2-7302-1255-8

**Teaching sequence (informative) :**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| week | lecture | tutorial | lab | project | test |
| W1 | L1 (4h) |  |  |  |  |
| W2 | L2 (2h) | T1 (2h) |  |  |  |
| W3 | L3 (2h) |  | Lab1 (2h) |  | Quizz 1 |
| W4 | L4 (4h) |  |  |  |  |
| W5 |  |  | Lab2 (4h) |  | Quizz 2 |
| W6 | L5 (2h) | T2 (2h) |  |  | Quizz 3 |
| W7 |  |  |  | Project 1 (4h) |  |
| W8 |  |  |  | Project 2 (2h) |  |
| W9 |  |  |  |  |  |
| W10 |  |  |  |  |  |
| W11 |  |  |  |  |  |
| W12 |  |  |  |  |  |
| W13 |  |  |  |  |  |
| W14 |  |  |  |  |  |

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