Computational Optimisation Design: Assignment 2025-26

Optimisation has shown tremendous benefits in the field of engineering design, particularly in aerospace engineering, during the last two decades or so. For this assignment, the aim is to develop optimisation solvers and apply them to the design of wing airfoil. This assignment is divided into three parts. Part C is optional. Any programming language (MATLAB, Python, Java, C++, C#, Fortran etc.) can be used. The individual report must be submitted electronically via Canvas.

Assignment A: Development of Optimisation Solvers

In this part of the assignment, an advanced optimisation solvers introduced in the lectures (such as, Genetic Algorithm, Particle Swarm Optimisation, or Simulated Annealing, etc.) will be developed. Next, the performance of these optimisers will be investigated using an optimisation test function, called Griewank function, that is easy to describe but harder to solve. Griewank Function is an n dimensional function defined as follows.

$$f(x) = \sum_{i=1}^{n} \frac{x_i^2}{4000} - \prod_{i=1}^{n} \cos\left(\frac{x_i}{\sqrt{i}}\right) + 1, \qquad -600 \leq x_i \leq 600$$

The 2-dimensional form of Griewank function is given below and visualised in Figure 1.

$$f(x_1, x_2) = \frac{x_1^2}{4000} + \frac{x_2^2}{4000} - \cos\left(\frac{x_1}{\sqrt{1}}\right)\cos\left(\frac{x_2}{\sqrt{2}}\right) + 1, \qquad \begin{cases} -600 \leq x_1 \leq 600 \\ -600 \leq x_2 \leq 600 \end{cases}$$

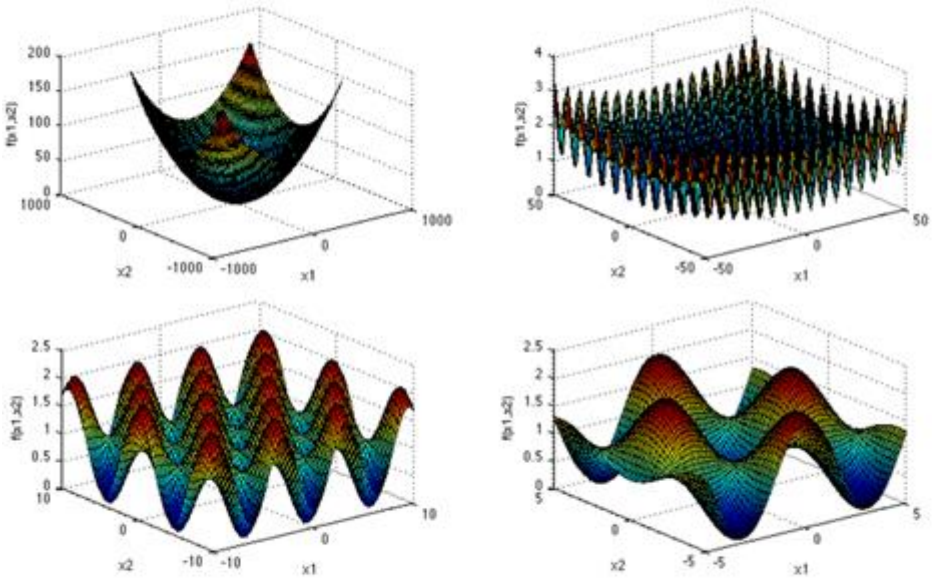

Figure 1: Griewank Function (Two-Dimensional)

As shown in Figure 1, this function has a global minimum at origin, i.e., $x^* = (x_1^*, x_2^*) = (0, 0)$, but has multiple local maxima and minima. It is therefore a hard optimisation problem to solve. On the plus side, however, all the design variables are of the same type (continuous variables) and have similar (in fact, identical) scales, all the constraints are inequality ones (and indeed just lower and upper bounds), and the feasible space is not disjoint.

Assignment A is comprised of the following three tasks.

A.1: Write a computer program for a stochastic optimisation solver covered in the lectures (Genetic Algorithm, Particle Swarm Optimisation, or Simulated Annealing).

A.2: Formulate minimisation optimisation problem for 5-dimensional Griewank Function with design variables ranges between -600 and $+600$.

A.3: Run the optimisation solver (developed in A.1) on the 5-dimensional Griewank Function (developed in A.2).

Assignment B: Airfoil Optimisation using XFOIL

In this part of the assignment, aerodynamic optimisation of wing airfoil will be conducted using XFOIL software, which is an opensource program from Mark Drela (MIT) available at https://web.mit.edu/drela/Public/web/xfoil/. The aim of this exercise is to utilise the optimiser, developed in Assignment A, to identify a range of different wing airfoils that provide the best aerodynamic characteristics (such as lift coefficient, drag coefficient, moment coefficient etc.) for given conditions.

Assignment B is comprised of the following four tasks.

B.1: Write a function to automate the creation of airfoil, execution of XFOIL program, and extraction of parameters (lift coefficient, drag coefficient, moment coefficient etc.) from the output file(s). Class-Shape-Transformation (CST) airfoil parameterisation method can be used.

B:2: Formulate the multi-objective optimisation problem. Use the airfoil parameters (e.g., three on the top surface and three on the bottom surface) as design variables, and aerodynamic characteristics of the airfoil, such as lift, drag, and moment coefficients as objectives/constraints.

B.3: Run the developed optimisation solvers, from Assignment A, on the optimisation problem defined in B.2, using angle of attack value of 3°.

B.4: Evaluate and compare the performance of the optimiser and investigate the effects of changing the algorithms' control parameters. For instance, in the case of Genetic Algorithm, the effect of different population sizes, numbers of generations, different crossover and mutation probabilities, and different selection schemes.

Assignment C: Airfoil Optimisation using Surrogate Model

In a real flight, the angle of attack may fluctuate around its design value, which will influence the airfoil's lift, drag, and moment coefficients. Consider the angle of attack as a random variable following a Gaussian distribution with a mean of 3° and a standard deviation of 0.1°, complete the following tasks:

C.1: Compute the mean and standard deviation of the output lift, drag, and moment coefficients at the optimal design point obtained from Section B.

C.2: Perform a Robust/Reliability based Design Optimization by reformulating the objective/constraint functions as defined in Section B.

Assuming that there is a limit on the number of XFOIL runs (as if it takes hours to perform the calculation), complete the following tasks:

C.3: Construct a surrogate model to predict the lift, drag, and moment coefficients given the same design variables as in Section B.

C.4: Perform a deterministic optimization using the surrogate model and compare the results with the optimal solution obtained from section B.

Report Content

When writing your report, consider the following:

- Report should be between 3000 to 5000 words, excluding source code.
- Include (in Appendices) listings of the source code of the algorithms you have implemented. The listings of codes you have written should be reasonably well commented.
- Detailed description of the ways in which the algorithms work is not required. If you have implemented an idea of your own (which is by no means discouraged) or used a feature not described in the lecture notes, then the basic principles of this should be explained in your report. Discuss problem-specific implementation details, such as how you have chosen to handle any constraints.
- Present and discuss the results of the various optimisation problems formulations.