Robust Optimization of Coastal Environmental Impact from Oil Spills, Finding Optimal Position of Barriers

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ABSTRACT

Multidisciplinary Design Optimization (MDO) is achieving more and more agreement in the industry community. For these reasons, many new optimization methodologies have been developed. In particular, the optimization methodologies capable to find stable solutions, is continuously raising importance for the industry. The name of this new optimization method is Robust Design.

The need for Robust Design method appears in many contexts. During the preliminary design process, the exact value of some input parameters is not known; consequently the aim is try to look for a solution as less dependent as possible on the unknown input parameters. Another important concern in the optimization problem is to find out a solution that is insensitive to small fluctuations in the operative conditions. In [1] a Multi Objective Robust Design Optimization that looks for solutions which are insensitive to fluctuations of the operative conditions is shown. Starting from the statistical definition of stability, the method finds, at the same time, good solutions for performance and stability.

The algorithm used to solve the multi-objective optimisation problem in [1] is MOGA (Multi-Objective Genetic Algorithm), that has shown its great efficiency, but has also revealed some limits due to the large number of computation required to obtain a good Pareto front, i.e. the set of not-dominated solutions that represent the best compromise for the two objectives (performance and stability). In [2] a different optimisation approach, based on Game Theory [3, 4], is proposed. The variables and the objectives are divided between two players, and the result is an equilibrium point (Nash equilibrium) that represents the best compromise of the two (contrasting) objectives. Even though the solution may be only a point of the Pareto front obtained by MOGA, that offers more than one solution to the designer's choice, the Nash approach has the great advantage, particularly important in a Robust Design problem for which the computational cost is heavy, of a higher convergence speed [5, 6].

Oil spills on the open sea and in coastal areas are one of the greatest threats to nature in maritime zones, with damaging effects for tourism, fishing and aquiculture. They are detrimental to the quality and useful properties of water, and can lead to the elimination of trophic chains.

In CEANI, software to help spill responders select appropriate response options to minimize

coastal environmental impacts when oil spills, has been designed [7]. This software consists on three programs that simulate the oil slick path, weathering and interaction oil slick-coast.

In this paper we propose the use of Robust Design Optimization to minimize coastal environmental impact from oil spills and we shown the results obtained from a hypothetical oil spill.

INTRODUCTION

The oil is the most transported product of base everywhere. The European Union occupies the first world place in the commerce of oil products. Eight hundred million tons are transported since or toward the EU ports every year. Its importing of crude oil represents approximately the 27% of the total world commerce. Around the 90% of that commerce with the EU is performed for sea and a continuous increase of this commerce due to the growing demand of oil products is foreseen.

Approximately ten million tons of crude oil are spilled to the sea each year. Nevertheless, only a 10% of the oil that is going to end up to the sea proceeds of marine accidents. Other sources are the atmosphere, the natural filtration, the contamination of the rivers and the urban runoffs, the oil refineries situated in the coast, the marine oil platforms, the operating discharges of the tankers (this type of spill is responsible for a 22% of the total and constitutes the greater individual contribution to the contamination by crude oil), and other causes (as the dumping in the Persian gulf during the Gulf War in 1991).

Considering an eventual oil spill in the sea, the idea is to optimize the available resources to mitigate the coastal environmental impact that can be produced. In this way we have design a preliminary problem that try to minimize the length of the coast that is affected by a hypothetical oil spill in the sea. So we try to optimize the location of a straight barrier in a sub-domain of the probable spill zone. In this way, the point to hitch one of the extremes of the barrier (Eastern and Northern variables) and the angle that forms this barrier with the East direction have been considered like variables. As well as, the wind module and direction have been considered like variables with uncertainties. That gives a total of seven variables: Eastern, Northern, angle and, average and standard deviation of the module and the direction of the wind for each design. The fitness function has been evaluated with the program *slick path* developed in CEANI [7].

In this paper two strategies to solve the Robust Design problem are presented, the latter one with the application of a new adaptive response surface.

ROBUST DESIGN OPTIMIZATION

The following equations represent the mean value (performance) and the variance (stability) of the function to be optimized by Robust Design approach:

$$\bar{f}(\bar{x}) = \frac{\sum_{n=1}^{N} f_n}{N}$$

$$\sigma^2(\bar{x}) = \sum_{n=1}^{N} \frac{\left(f_n - \bar{f}\right)^2}{N-1} \qquad (1)$$

In this paper, the uncertain parameters in the Robust Design are the wind direction angle and the wind velocity (see Table 1), and two strategies to solve the problem have been considered. In the first one, the fitness function to minimize is the mean of the lengths of coast affected by the oil slick, that are evaluated with the program *slick path* developed in CEANI [7], and the respective standard deviation $\sigma(\bar{x})$ has been considered as a constraint: $\sigma(\bar{x}) \leq 1000$. In Fig. 1 and 2 we can see two very similar solutions that have very different fitness function values.

The Simplex algorithm, implemented in the *modeFrontier* software, has been used in order to solve this mono objective optimization. In Fig. 3 we can see the mean and standard deviation value histories. It is possible to observe as a clear convergence has been obtained, reaching the goals of the optimization. There is a remarkable correspondence between the mean and the standard deviation as can be observed in Fig. 4, where the scatter plot between the two functions is shown.

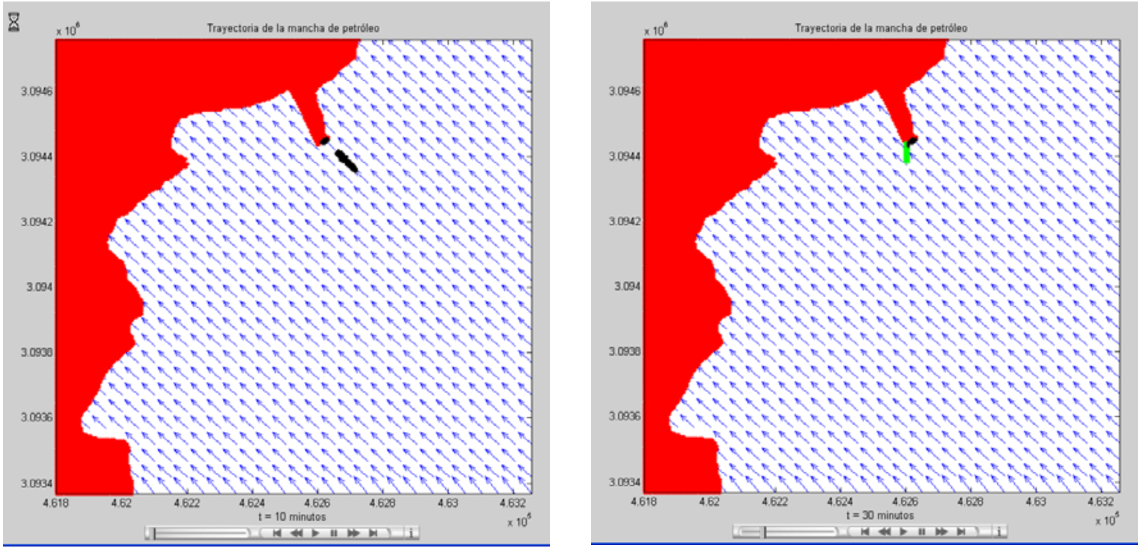

Fig 1. Slick path simulated for angle=-90º; Eastern=462,603 m; Northern=3,094,446 m; wind=2 m/s and win_dir=-70º.

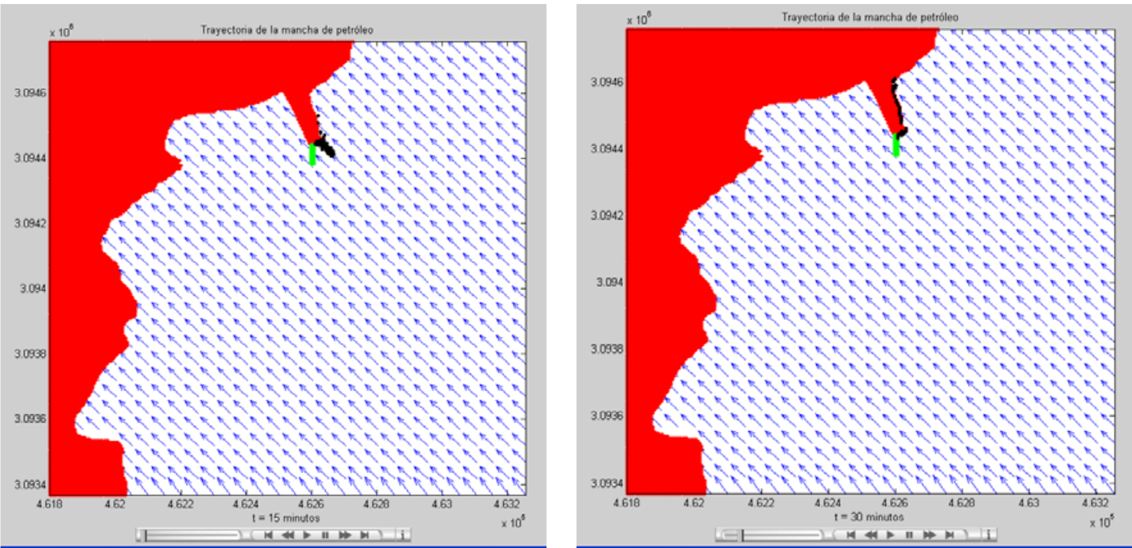

Fig 2. Slick path simulated for angle=-90º; Eastern=462,603 m; Northern=3,094,446 m; wind=2 m/s and win_dir=-65º.

Table 1. Variables of the problem. σ represents the uncertain parameters in the Robust Design.

Variable	Distribution	Scale	Lower Bound	Upper Bound	Base	Step
σ wind	Uniform	Delta=1.0	0.000E0	4.000E0	401	1.000E-2
σ wind_dir	Uniform	Delta=4.5	-1.350E2	4.500E1	181	1.000E0
angle			-9.000E1	4.500E1	136	1.000E0
Eastern			4.625E5	4.629E5	437	1.000E0
Northern			3.094E6	3.094E6	193	1.000E0

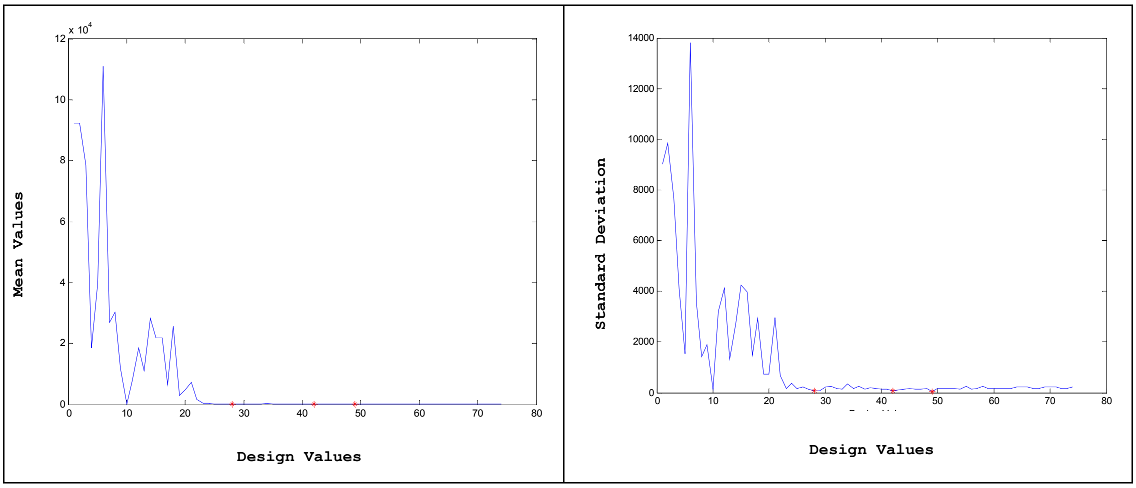

Fig 3. Mean and Standard Deviation Value Histories

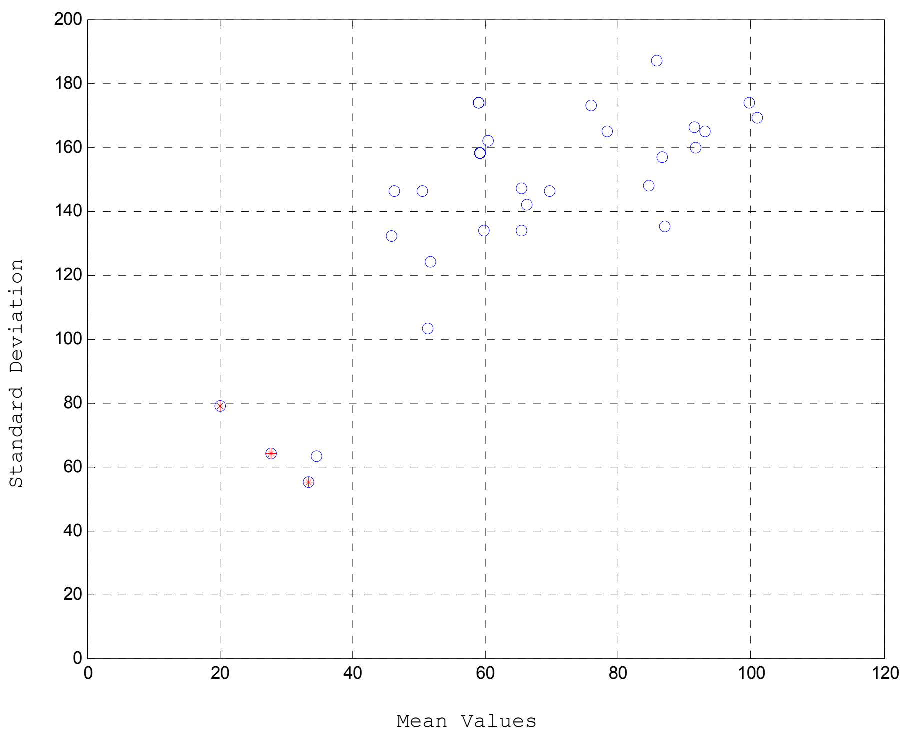

Fig 4. Scatter plot between mean and standard deviation of length cost affected by spilled oil.

From the equations (1) it is possible to observe that to obtain the values of the objectives to optimize it requires more than one calculation of the function. Consequently, when a numerical simulation needs high computing resources, the application of the Robust Design Optimization could become inapplicable caused of to much higher time consuming. For these reasons reducing the number of total simulation is a key point to make the Robust Design useful to the industry. One efficient numerical methodology to solve this problematic is the use of the Response Surfaces.

For the application of Response Surfaces in Robust Design, we present a different approach, based on statistical theory, called DACE [8]. The advantage of this methodology is the possibility of implement an adaptive response surfaces, which tries to minimised the statistical error between the real function end the extrapolated one.

In Fig. 5 it is possible to observe the adaptation of the DACE response surface on the real function. Even if the function is high non linear, the response surface with around 20 designs covers well the function, helping the solution of the Robust Design problem, in which is necessary an accurate calculation of the mean and standard deviation values of the objective functions (see Fig. 6).

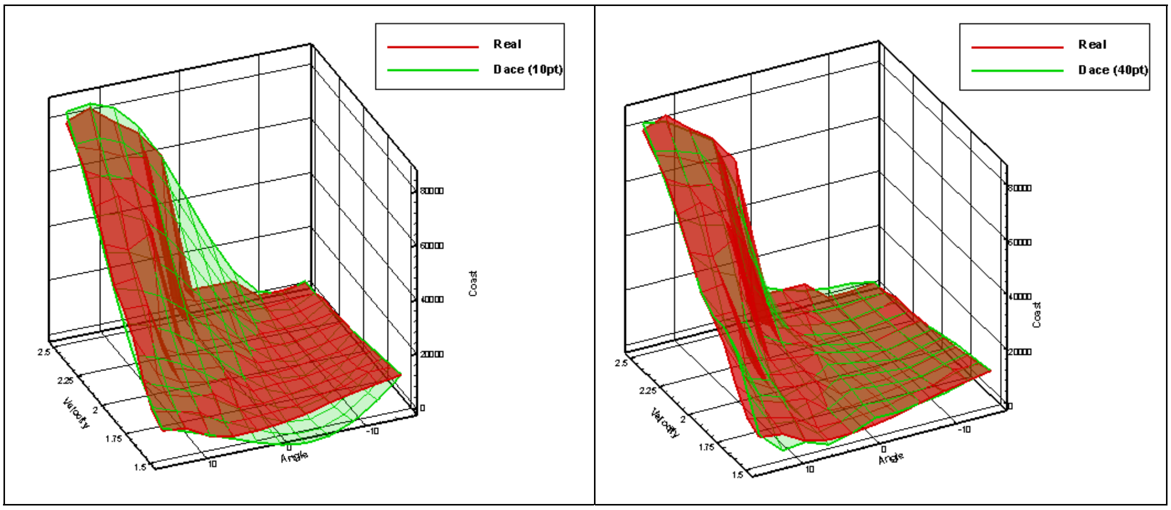

Fig 5. Response Surfaces by comparison

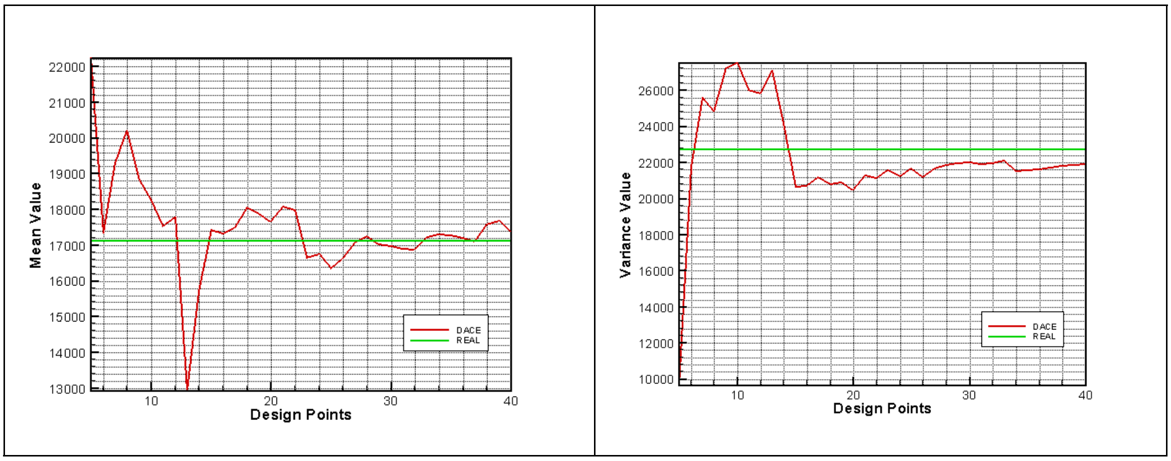

Fig 6. Mean and Variance Value Histories

CONCLUSIONS

Minimization of coastal environmental impacts from oil spills involves uncertainties in several of the input parameters, for example, module and direction of wind and currents or even the exact volume of the oil spilled. In this paper two strategies to solve the Robust Design problem is presented. The results obtained confirm us that this research line is a practical point of view concerning to the minimization of coastal environmental impacts from oil spills.

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