Title of the STS presentation:
Robust Design Optimisation by modeFrontier

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Keywords:
Robust Design Optimisation, Multi-objective optimisation, Response Surfaces, Game Theory
Optimisation algorithms, Aeronautics, Turbomachinery

Objectives:
This presentation deals with industrial applications, in aeronautic and turbomachinery fields,
of multi-objective and robust design optimisation, through the utilisation of the multi-objective
optimisation and design environment modeFrontier.
This code allows the easy process integration of any CAD/CAE commercial tool, and drives
the designer in a fully automatic optimisation of the objectives he has defined in his model.
A particular relief is given in this presentation in the application of the Game Theory algorithm
implemented in modeFrontier, MOGT, that allow to reach an optimal compromise solution
between the contrasting objectives in the fewest time as possible.
To reduce the number of simulations required is in fact particularly important in the design
under uncertainties, or so called Robust Design Optimisation, since this typology of
optimisation, that is becoming predominant in aeronautic design, usually requires an higher
number of simulations than the simple deterministic optimisation, since the behaviour of each
candidate solution is to be analysed for several samples characterised by fluctuations
(uncertainties) of input variables.
The application of MOGT algorithm and Response Surfaces, both available in modeFrontier,
will prove their efficiency in the Design under Uncertainties cases proposed in this
presentation.
Applications:
First, an example of a deterministic multi-objective optimisation, relative to the design of the cooling system of rotor blades, is shown to illustrate how modeFrontier can integrate several CAD/CAE tools in an optimisation process, using RSM algorithms to reduce the overall computation time required.

The application and efficiency of MOGT algorithm is then shown by another multi-objective optimisation case, relative to the design of an aeronautic combustor.

The applications of Multi-Objective Robust Design Optimisation are then relative to two different cases: in the first case, a transonic airfoil shape is optimised under fluctuations of Mach number using a 2D Eulerian code, and in the second case the performances of a supersonic aircraft are optimised under uncertainties of Mach number and cruise altitude using an analytic formulation.

Results:
The two examples relative to the deterministic multi-objective optimisation, shows very good results.

The blade cooling flow mass has been reduced of more than 20% and the heat transfer raised of 2% for an industrial prototype already existing, and thanks to the RSM this has required less than 50 CFD computations.

About the combustor, the NOX emission have been reduced from 181 ppm to 86 and the flow pattern factor, that quantify the temperature uniformity at the outlet, has been reduced from 1.98 to 1.44, and thanks to MOGT algorithm only 90 CFD designs have been required.

These first two application cases were useful to define and test an efficient and fast strategy (MOGT and RSM) to be used in the Robust Design cases.

About the airfoil optimisation case, the performances of the original RAE airfoil have been sensibly improved, both about mean performances (15% of drag reduction) and stability (standard deviation of performances reduced of above 50%), respecting all the constraints imposed and requiring not more than 300 computations.

About the aircraft performances optimisation, the design has been optimised with respect to maximum flight range, minimum take off weight, stability of range, take off weight and take off field length, respecting constraints on the take off field length, approach velocity and take off length, proving how the methodology could be efficient even with an high number of objectives and constraints.

Future:
The main task regarding the future is to apply Robust Design Methodology to most complex CFD application cases, like the blade cooling system or combustion analysis, applying the MOGT and RSM tools available in modeFrontier, already tested with success in the simplest 2D and analytical cases proposed in this presentation.

The limit to this task is due to the high computation effort required by the complex CFD analysis, but thanks to the efficiency of this methodology, and through the use of a cluster of CPUs, the task would be affordable.
Illustrations

Figure 1: Parameterisation of blade cooling system and CFD analysis

Figure 2: Combustor geometry and geometric parameterisation
Figure 3: multi-objective optimisation results and temperature field (combustor)

Figure 4: original NACA and optimised transonic airfoil: geometry and drag coefficient versus Mach number

Figure 5: supersonic aircraft optimisation workflow and selection of most robust solutions