Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

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A virtual environment for transparent distributed computing in evolutionary search

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Summary

Aeronautical design is a typical multi-disciplinary area, where analyses from several different disciplines are essential for a successful design. Design and optimisation in this area quite naturally lead to multi-dimensional design spaces and multiple independent objective functions. Evolutionary Methods (EMs) have proven to be very effective search techniques in multi-objective optimisation (MOO) studies. Multi-disciplinary design and optimisation (MDO) requires effective support of inter-disciplinary collaboration, especially with regard to the large variety of software tools and a heterogeneous ICT infrastructure that are normally used.

This paper presents a user-oriented ICT environment for MDO, MOO and EMs. This environment consists of a collection of relevant software tools that have been integrated as well-defined objects ("CORBA wrappers"), and supports easy creation of tool chains and CORBA based network communication. This environment has been applied to several MDO design cases, one of which is a MOO analysis of a blended-wing-body (BWB) aircraft configuration.

List of acronyms

ANN	Artificial neural network
BWB	Blended wing body
CAD	Computer aided design
CFD	Computational fluid dynamics
CORBA	Common object request broker architecture
COTS	Commercial off the shelf
GA	Genetic algorithm
GM	Gradient based optimisation method
GUI	Graphical user interface
ICT	Information and communication technology
MDO	Multi-disciplinary design and optimisation
MOGA	Multi objective genetic algorithm
MOB	Project acronym for EU project: A Computational Design Engine Incorporating Multi-Disciplinary Design and Optimisation for Blended Wing Body Configuration
MOO	Multi objective optimisation
OS	Operating system
RANS	Reynolds averaged Navier-Stokes
SQP	Sequential quadratic programming
WAN	Wide area network

List of symbols

C_d	Drag coefficient
C_{dl}	Aerodynamic performance
C_l	Lift coefficient
M_p	Pitching moment
M_{pA}	Absolute pitching moment
M_r	Roll moment
M_t	Total wing moment
M_y	Yaw moment

Contents

(13 pages in total)

1 Introduction

Evolutionary Methods (EMs) have proven to be very effective search techniques in multi-objective design studies[1]. This is in particular due to the capabilities of EMs to search globally through multi-dimensional design spaces and to deal effectively with multiple independent objective functions. Multi-dimensional design spaces and multiple independent objective functions are typically found in multi-disciplinary design problems. The different design parameters and objective functions are related to the different disciplines that are relevant for the design. For example in aircraft design both aerodynamic and structural mechanical analyses are essential for a successful design[2]. Such strongly multi-disciplinary design problems require effective collaboration among the different disciplines. Moreover, in multi-disciplinary design in combination with EMs a large variety of software tools and a heterogeneous ICT infrastructure are used. Therefore there is a strong need to facilitate multi-disciplinary collaboration and to provide support to effectively use the ICT infrastructure[3].
At NLR the SPINEware middleware system[4] is used to build user-oriented collaborative ICT environments in order to support engineers to conserve, maintain and exchange their specific knowledge and experience in their fields of expertise. One such environment has been developed specifically for the field of MDO. A set of required software tools for MDO, MOO and EMs are integrated into this environment, can be accessed from and executed on each of the different computers of the heterogeneous network, and can be easily executed via an intuitive GUI (graphical user interface). The environment comprises facilities for easy tool chaining, job and queue management, and distribution of parallel computations where CORBA is used for the communication over heterogeneous networks. This environment has been applied successfully in several design studies in which multiple objectives were treated in parallel and independently.
This paper presents a brief description of the ICT environment for MDO. Also two examples of application of this environment are shown: a comparative study of the use of a gradient based method (GM) and a genetic algorithm (GA) in MOO, and a MOO analysis of a pre-design case of a blended-wing-body (BWB) aircraft configuration[5].

2 The SPINEware ICT environment for MDO

The current situation with respect to the ICT environment that is normally in use in engineering departments that are involved in MDO, is characterized by some common aspects:

- Many different specialized application and analysis programs are used, both COTS and in-house developed
- these programs usually run on a variety of computer systems, are used directly from the operating system (OS), and have long learning curves
- engineers' knowledge and experience are often essential for usage
- effective exchange of this knowledge and experience among the different engineers is essential, but often poorly supported.

These aspects are addressed by the following recommendations:

- Use a flexible and easily accessible engineering environment for integration and usage of software tools,
- use objects to enhance definition and exchange components,
- use standards, as for example CORBA for communication in a heterogeneous ICT infrastructure,
- facilitate WAN distribution for multi-site environments.

These are considered as the motivation for the development of the user-oriented SPINEware environment for MDO that is currently in use at NLR (figure 1).

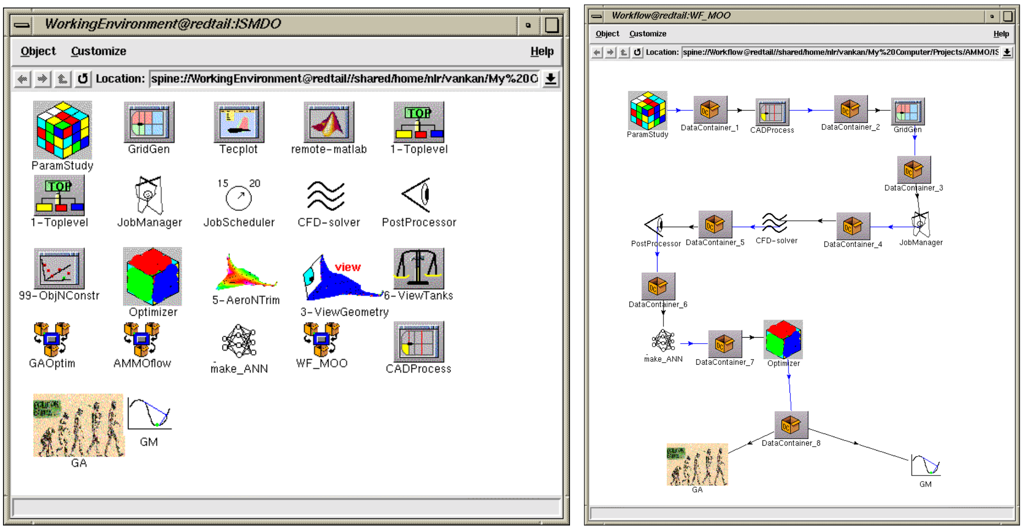

Figure 1: Examples of SPINEware browser windows of the tool library (left) and of a tool chain for an MOO process (right) as available in the MDO environment.

This MDO environment has been used in several MOO studies, of which a few examples are presented in the following chapter.

3 Eamples of Application

3.1 Analytical MOO test case for GM and GA

Because MOO is an important method in MDO, the capabilities of the MDO environment for MOO are evaluated here in some more detail. Beside a GA tool[6], also a GM tool is available in the environment for MOO. In this study the functionality of the tools is illustrated and their results are compared. The analytical 2-D 2-objective function shown in figure 2 is optimized using both the GM and GA tools for MOO.

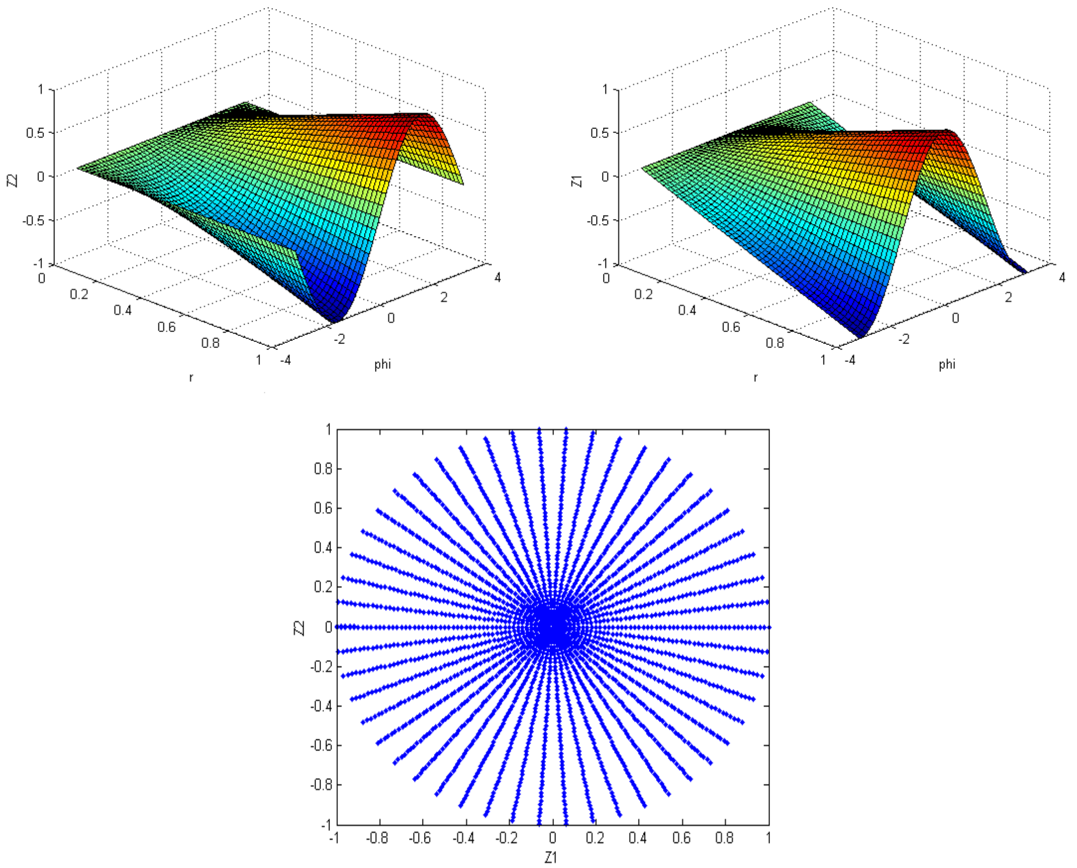

Figure 2: Analytical 2-D objective functions presented in the parameter space: z1= r cos (phi) (upper left) and z2= r sin (phi) (upper right). A sample of possible (z1, z2) values is presented in the objective space (lower).

The GM tool applies repeated single objective gradient based minimization runs constraining the non-minimizing objective, as illustrated in figure 3, in which a standard SQP minimization algorithm from the Matlab Optimisation Toolbox[7] is used. The GA tool applies a more or less standard MOGA technique[1].

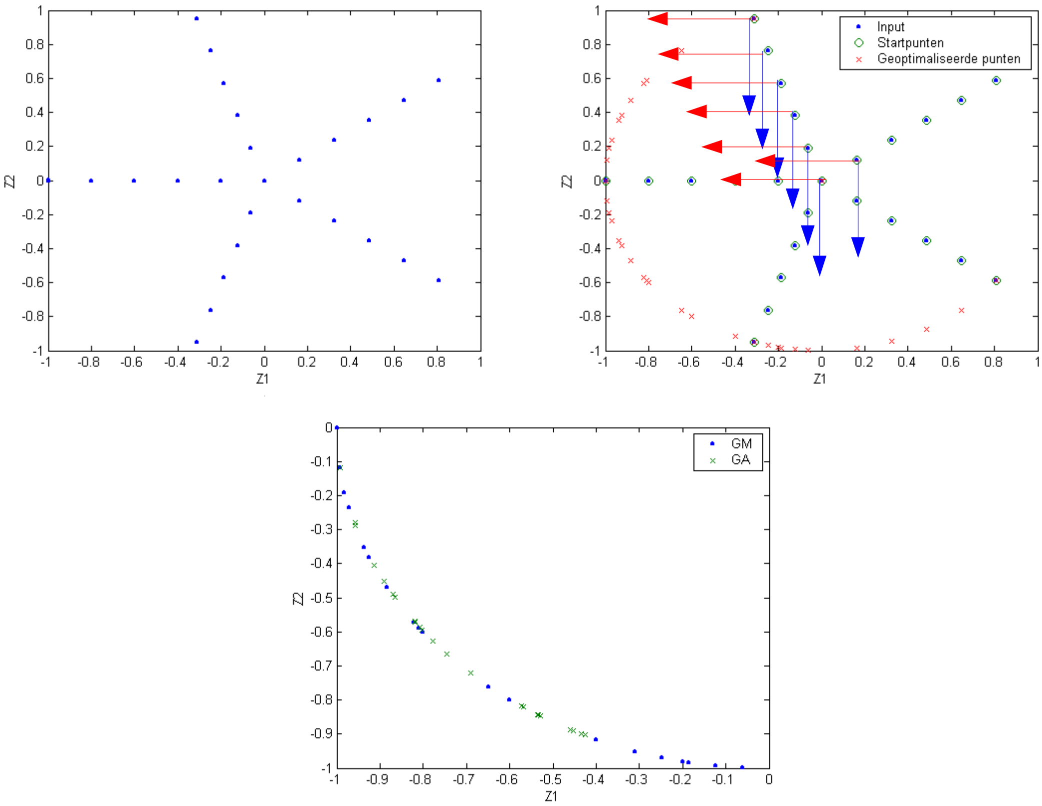

Figure 3: Initial population for both the GM and GA MOO runs (upper left) and illustration of the repeated objective-constrained minimization runs of the GM tool (upper right) for the analytical test case. The resulting Pareto fronts from both the GM and GA runs are given in the lower panel.

The results, i.e. the Pareto fronts, of both MOO runs compare well. The total computational cost in terms of number of objective functions evaluations is also comparable for both methods (2500 and 1700 for GM and GA, respectively).

3.2 MOO of a BWB aircraft

In the EU project MOB[5] an MDO study is conducted on a new BWB aircraft configuration. As a preliminary design analysis, a MOO study is applied to some key multi-disciplinary properties of the BWB in cruise flight: aerodynamic performance (C_{dl}) based on C_l and C_d, structural mechanical wing loading (M_t) based on the roll and yaw moments, and flight mechanical unbalance (M_{pA}) based on the pitching moment. These properties are represented by the following three independent objective functions that are minimized by MOO:

$$
\begin{aligned}
Cdl &= \frac{Cd}{Cl} \\
Mt &= \sqrt{Mr^2 + My^2} \\
MpA &= |Mp|
\end{aligned}
\tag{1}
$$

The BWB design parameters that are varied relative to the BWB reference configuration, are the wing twist, wing sweep, and angle of attack in cruise flight:

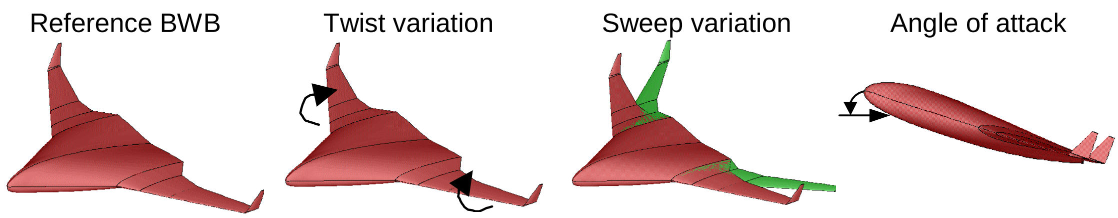

Figure 4: Illustration of the design parameters twist, sweep, and angle alpha used in the BWB pre-design study.

The objective function values can be evaluated from simulations of the air flow around the BWB under the cruise flight boundary conditions using a CFD solver for RANS equations. However, because these simulations involve large scale and time consuming calculations for CAD geometry re-generation, flow domain discretisation and CFD computation, an Artificial Neural Network (ANN) is used for approximation of the considered BWB properties from which the objective function values are derived. The results of the MOO of the objective functions based on the ANN approximated values are shown in figure 5.

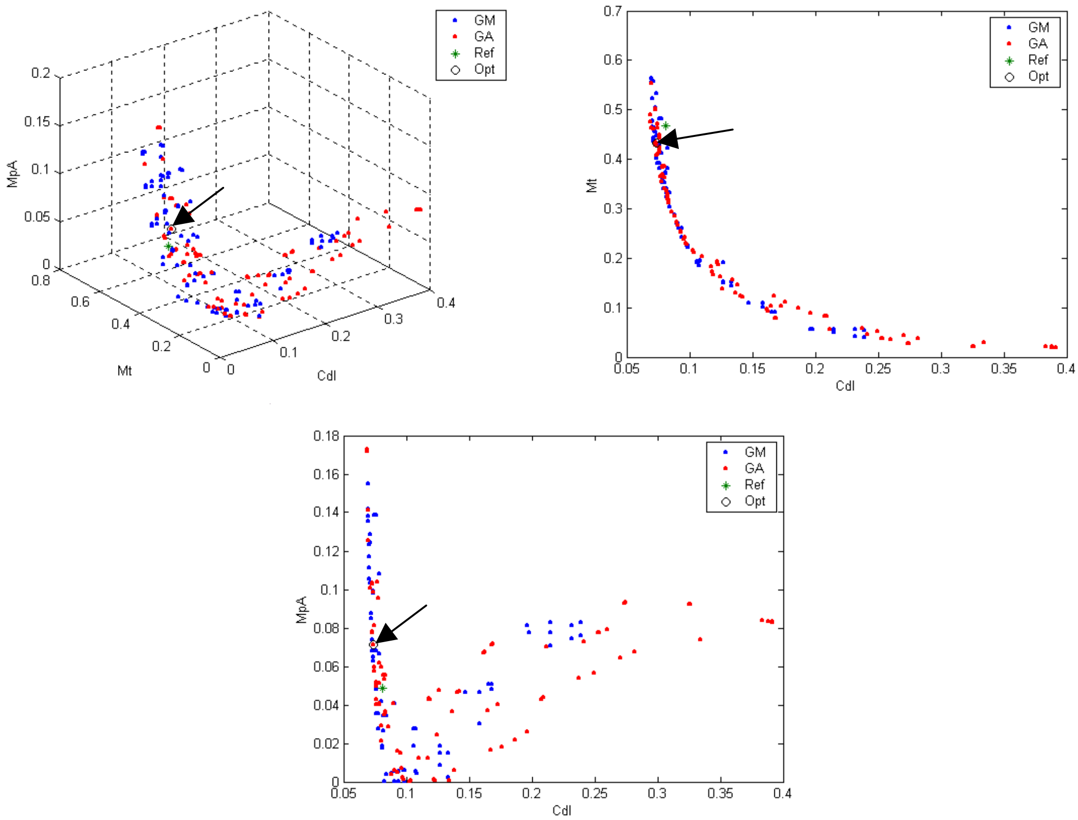

Figure 5: Resulting Pareto fronts for the BWB design found by the GM and GA MOO tools, presented in the 3-D objective space (upper left) and projected in the Cdl-Mt and Cdl-MpA planes (upper right and lower, resp.).

From the resulting Pareto front a compromised optimal solution is selected as suitable design, for which the exact objective function values are evaluated and compared to the ANN approximations.

	ANN	CFD	Error %	Ref. BWB	Change %
Cdl	0.0741	0.0734	0.9537	0.0812	-8.7438
Mt	0.4334	0.4330	0.0924	0.4670	-7.1949
MpA	0.0715	0.0712	0.4213	0.0485	+47.4227

Table 1 : Objectives values of the BWB MOO study.

The relatively small errors indicate that the ANN approximation used in this study predicts the objective function values with acceptable accuracy. In the selected optimal design point, two of the three objectives have improved relative to the reference BWB configuration (Table 1).

4 Concluding remarks

- Multidisciplinary design and optimisation requires flexible and easily accessible engineering environments for integration and usage of a large variety of software tools.
- SPINEware provides the means to build and use such engineering environments on distributed heterogeneous networks.
- ANN, GM and GA are efficient complementary analysis tools in MOO.
- A distributed engineering environment for MDO has been used successfully in a MOO pre-design study of a BWB aircraft.
- The Pareto front provides many different competing design candidates.
- The ANN approximation model in the BWB study predicts the CFD results with sufficient accuracy.

Acknowledgements
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5 References

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