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Progress towards a multi-disciplinary analysis and optimisation capability for air vehicle assessment and design - a UK research establishment view.

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ABSTRACT

This paper considers progress towards establishing a Multi-disciplinary Design Optimisation (MDO) capability for assessment and design. Some basic questions are posed and answered on the basis of experience gained by DERA as a result of participation in a series of recent National and International projects undertaken in partnership with UK and European industry and government research agencies. Issues addressed include the definition of MDO; its function within concurrent engineering; the role of product models; the definition and execution of the MDO process under user control; the use of trade-off studies for requirements capture; and the degree to which MDO can support detailed design work. The need for the adoption of standards in the definition of the product model is highlighted.

INTRODUCTION

Multi-disciplinary design optimisation enables the effectiveness of products to be optimised and supports trade-off studies between the design objectives from diverse disciplines. The MDO process is intended for use within the context of a modern engineering design environment, which is characterised by the commercial imperative to reduce time cycles and costs. These commercial pressures, together with the immense volume of design, manufacturing and maintenance data inherent to complex modern equipment, demand a heavily computerised environment.

Current practice, as exemplified by Concurrent Engineering (CE), is to move the design of complex equipment away from a process involving a sequence of specialist departments and to emphasise its multidisciplinary nature through the use of integrated product teams. Both the structural integrity of engineering products and the demonstration of the performance of proposed designs are increasingly reliant on the use of computer models created during the design process. Although the software tools existing within individual disciplines may be reasonably mature, the challenge is now to provide the tools necessary to support such an integrated approach.

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The scope of MDO is limited to the design of products based on the simulation of physical objects in their environment. The use of multiple simulations is a key concept of MDO. This may involve diverse tools such as fluid flow solvers (to determine local and overall external forces), structural analysis and detail stressing (to determine structural deformations and internal stresses), electromagnetic analysis (to determine radar signatures from local and overall returns from incident beams), cost modelling, and tools for design for reliability. The physics modelling may be mathematical or experimental but the simulation of 'human interaction' effects, for example through the use of flight simulators, is excluded.

At a general level, when considering the overall mission performance of an aircraft, tools exist to aid the conceptual design of both military and civil aircraft, and are used during the early stages of the project. Figure 1 shows the 3 phases of project design and 3 corresponding levels of tools. Although a fully multidisciplinary approach is adopted at the conceptual design stage only the simplest, Level 1, empirical models are employed to approximate the physics which influence the overall design. Currently most MDO applications, for use in the preliminary design phases of a project, are based on major simplifications in mathematical modelling at level 2, such as beam structural models or panel methods for aerodynamics.

The objective today is to achieve the same degree of integration with Level 3, state-of-the-art analyses. The limiting factor in the use of proven models of this type is the capacity of current computation technology. Analyses using computational fluid dynamics, computational electro-mechanics, or detailed finite element models are separately capable of pressing computer resources to the limit, and this is compounded by the introduction of sensitivity calculations and optimisation. With the continuing advance of computation technology it can be expected that analysis methods will migrate up the pyramid shown in figure 1.

DERA has for many years been involved in multi-disciplinary optimisation in two areas; (1) using semi-empirical, Level 1, methods for concept assessment and to study the effect of changes in operational requirements, through the development and application of Multivariate optimisation (MVO)[1,2], and (2) using Finite Element methods in structural design, including linear methods for aerodynamic analysis, through the development and application of the

Paper presented at the RTO AVT Symposium on "Aerodynamic Design and Optimisation of Flight Vehicles in a Concurrent Multi-Disciplinary Environment", held in Ottawa, Canada, 18-21 October 1999, and published in RTO MP-35.

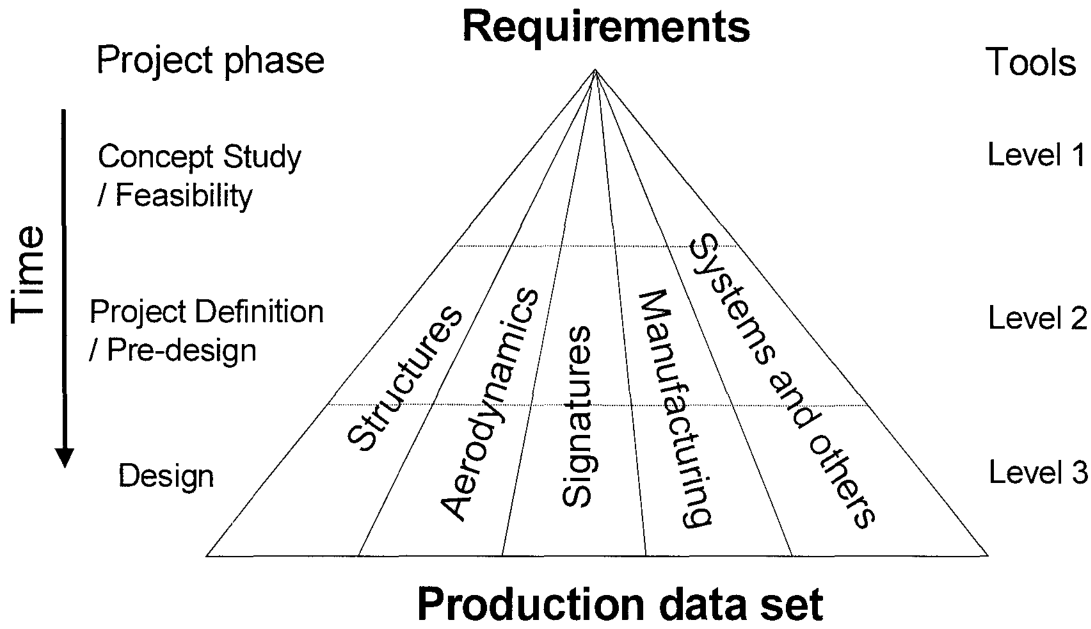

Fig 1 Project phases and tools for multi disciplinary design

STARS system[3]. From experience gained in these two areas the present authors embarked in 1995 on an examination of the potential and means for MDO. The fundamental difference of this MDO work from the earlier work has been that it has incorporated higher fidelity, Level 2 or 3, modelling in at least two disciplines. Because it was not clear what were the major issues and potential problems in achieving a viable MDO, a rapid-prototyping approach was followed initially. Previous work defining and building an MVO system had shown that it was not possible to predict in advance where the weakest link in the chain would occur, so development effort could have been misdirected if a rapid prototyping approach had not been followed. Subsequent work has comprised a series of relatively short-term projects, funded by UK government military and civil customers, and the Commission of the European Union. All the projects have had a strong industry participation.

In the next section of the paper the contribution of DERA to a series of projects is summarised. Several of these projects are the subject of separate papers at the RTO AVT Symposium on Aerodynamic Design and Optimisation of Flight Vehicles, and the reader is referred to papers 13, 14 and 15 for detail.

Drawing on the experience gained in these projects the following section attempts to identify the issues for implementation of an MDO process. This is approached via a series of questions and answers. The paper concludes by identifying the prime issues and some next steps required to progress towards providing an MDO tool that can be more generally used for air vehicle concept design and assessment.

CHRONOLOGY OF MDO PROJECTS

Wing Aeroelastic Optimisation

The GARTEUR Action Group SM(AG21) on multi-disciplinary wing design (1995-1999) covered the integration of strength and aeroelastic aspects of the design of high aspect ratio wings typical of modern regional transport aircraft, as illustrated in figure 2. The DERA contribution was based on the use of the in-house structural optimisation code, STARS[3] which, like several others, embodies aeroelastics as a tightly-coupled functionality. Both the aeroelastic predictions and design strategies to come out of the optimisation have been compared with those of the other partners within the group. While several European companies had long had the capability of combining aeroelastic design with basic strength requirements within the context of what are principally structural design codes, the GARTEUR Action Group provided a forum for the validation and comparison of the capabilities of the participants. Such comparison was felt to be important since experience has shown that significantly different 'solutions' can found by different groups. Unless analysis codes are thoroughly benchmarked valid conclusions on the relative merits of these codes in a design and optimisation environment cannot be made.

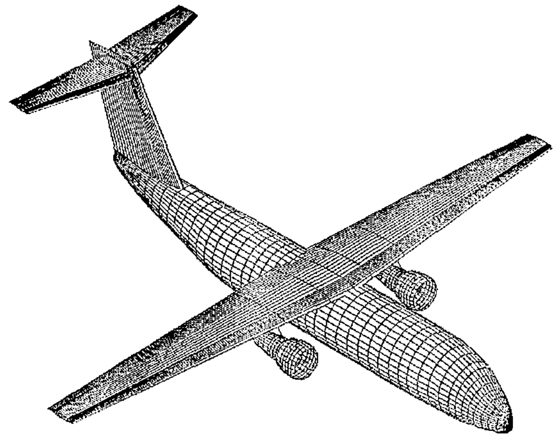

Figure 2 Regional transport aircraft used for wing aeroelastic optimisation

The MPEST project

In this 1 year project (1995-1996) an **M**DO **P**rototype for the **E**valuation of **S**oftware **T**ools (MPEST) was constructed and demonstrated[4]. Funded by the UK MOD the prototype was assembled by British Aerospace Sowerby Research Centre, with additional contributions from DERA, BAe Airbus and Rutherford Appleton Laboratory. The prime aim was to assemble software for the key functional elements of an MDO framework and, by exercising these on a simple aerodynamic / structural optimisation problem, identify priority areas for development. Figure 3a shows the framework used. A 2-dimensional Fowler flap design problem was used with the analysis methods being deliberately kept simple; a 2-d panel code for aerodynamic analysis and a simple beam model for the structural analysis of the trailing-edge flap track (figure 3b). This simple technical task had all the elements required to explore MDO issues. The framework consisted of elements for user-control, optimisation control, geometry generation, aerodynamic and structural analyses, and a data repository. The process by which an optimum solution to the flap problem was generated is shown in figure 3c.

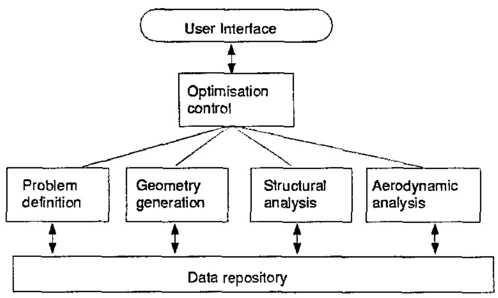

Figure 3a. MDO framework used in the MPEST project

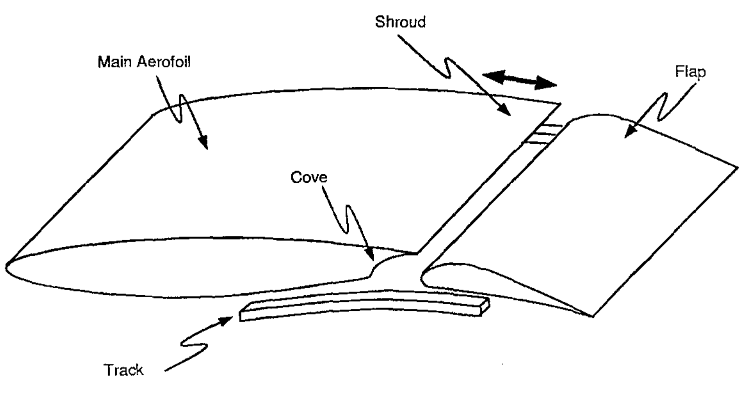

Figure 3b. Geometry of flap section used in the MPEST project

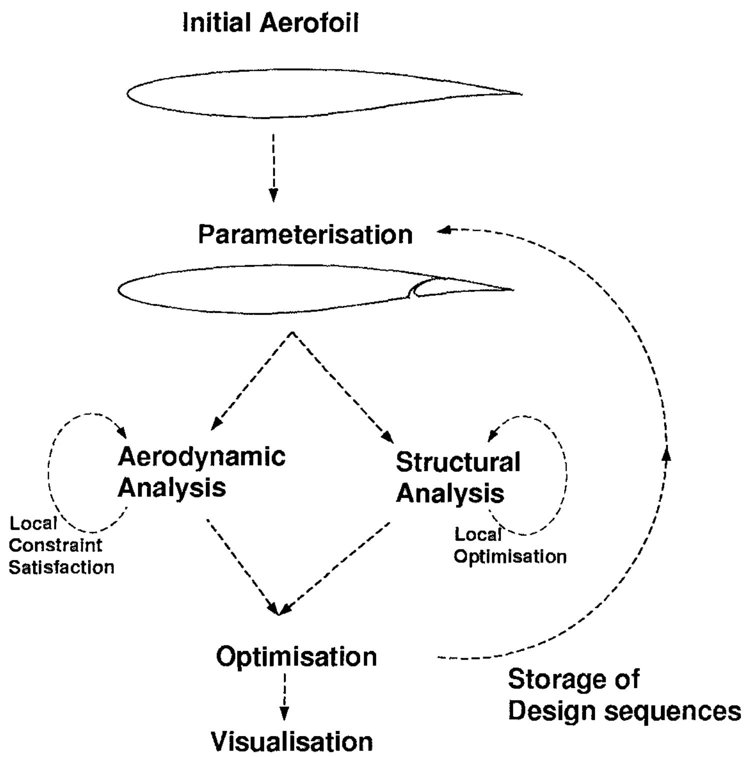

Figure 3c. MPEST optimisation process

This project showed the value of geometric parameterisation to accelerate re-design and the need for a plug-and-play capability for the software elements. The importance of process control, a user interface to track the solution of potentially complex problems and standards-based data structures were clear. The issue of whether MDO should be a distributed or integrated process was raised. While distributed processing can speed analysis and hence permit more comprehensive cross-discipline modelling, a single process would avoid complexity of control.

The EU MDO project

The next project, on the Multi-disciplinary Analysis and Optimisation of Aerospace Vehicles, was led by British Aerospace Airbus and funded by the European Commission. It comprised research on civil aircraft wing design by 14 partners. This two-year European project (1996-1998) represented a first step into multidisciplinary analysis and design optimisation of aerospace vehicles for many of the partners. The application selected to demonstrate new capabilities developed during the project was based on the A3xx concept currently under development by the Airbus partners. A whole aircraft model was provided for aeroelastic and controls studies, but the design activity was focused upon the wing. The project is described in detail by Allwright[5] from British Aerospace, who led the project.

All partners in the project participated in the definition of the research tasks and then separate groups were responsible for specialist investigations. The project was supported by the software infrastructure group with participants drawn from each of the research task groups. The final stage of the activity was to draw together the lessons learnt from the project as recommendations. Further progress towards a full MDO capability was made, with the major advance being the introduction of aerodynamic design optimisation and the combination of aerodynamics and structural design to reduce the Direct Operating Cost (DOC). Some consideration was also given to issues of aircraft stability and control.

Groupings of partners within the project analysed a baseline configuration and examined alternative wing design aspects. This served both to ensure that corresponding product variants were modelled within each discipline and also to reduce the requirement for problem-specific data flow between disciplines. The issue of process control was also addressed with a variety of approaches being investigated. A range of approaches was also evident in the role of the optimiser, with some frameworks treating it as just another process within the chain and others allowing the optimiser to control the whole process. These areas are considered in more detail below.

Aerodynamic and Structural design. The objective of the work was to develop and demonstrate a capability for the aerodynamic and structural design of a wing which would minimise the direct operating cost (DOC) of the A3xx concept aircraft. The majority of the wing optimisation work used a few gross wing design parameters (area, aspect ratio, rear spar location, sweep, crank thickness and tip twist).

A strong need was perceived to use familiar legacy codes within a loose-coupled modular framework that enabled the output from every process to be evaluated before proceeding. The DERA-specific work introduced multiple flight conditions into the optimisation. This task illustrated the need for flexibility within an MDO process, to allow the user to configure the optimisation process to accommodate multiple assessment tools, specific to each problem.

Product models and TDMB. The complexity of the data flow that links the disciplines of aerodynamics and structures, is illustrated in figure 4. This starts with a requirements system, which is assumed to be external to the MDO system, in which some freedom is assumed to exist to fine-tune the relative importance of various aspects of performance. An outline concept is then developed as a parameterised product model. This is followed by various assessments, here shown as aerodynamics and structures, with the possibility of making detailed shape and thickness changes for a given configuration.

Referring to figure 4 it is clear that large amounts of data, which may well be stored in separate databases, must be communicated between the component parts of the MDO system. The key issue for data transfer is the setting of common standards for the interpretation of information across disciplines. For MDO, the standards must cover all aspects of product geometry definition **and** design requirements, together with specific discipline-based data that reflects the constraints upon the design.

During the early meetings of the MDO project, a series of key activities were decided upon which defined the nature of the project. One was to adopt the BAe program TDMB[5] Technical Data Modeller and Browser) as the repository for the product model. TDMB provides a text editor user interface which supports a definition of data objects. It can then be expanded to store instance data capable of representing several variants of the product together with performance data derived from aerodynamic and structural analysis.

A fully parameterised representation of the aircraft configuration was developed, with tools to generate the aerodynamic data, finite element models and aeroelastic models used for performance assessment. This data-representation serves the project by providing partners with a common product model upon which design studies were based. The data models defined in TDMB will be exportable to the STEP/EXPRESS data definition language to enable future migration to other systems which conform to evolving standards for product models. The wider use of data which conforms to the STEP standards[6] is an important element of achieving the CALS objective of 'creating data once and using many times' through the product life cycle.

The use of a central data manager and browser in this project was shown to be of key importance to the success of the project in that it put in place a single product model from which specific contributing analysis models could be derived.

MDO process A major factor which will influence the overall success of any MDO implementation is the approach adopted to the co-ordination and scheduling of the diverse range of activities necessary to complete a full design cycle. This aspect of MDO must be adequately defined in the early stages of the development process in order to draw together the different disciplines and allow concepts to be explored.

A framework specification document was written by a group of partners in the project and some software tools were provided for evaluation. These included tools for software version management, data definition, database technology, process definition, process execution on distributed networks, data visualisation and optimisation. Several alternative frameworks were employed and evaluated against the user and system requirements previously developed. The frameworks assessed included commercial MDO frameworks and toolsets, a process-driven Workflow Management tool and Network middleware. The frameworks tended to operate with a pre-defined sequence of operations and failed to provide the user with sufficient flexibility to reconfigure the process during the early exploratory phases of a design study. The interactive definition of a complex process is a prime requirement of any optimisation framework.

The strength of a work flow management tool is the traceability and control it offers, whereby only approved users may initiate processes and this may only be done if the input data has not been invalidated by changes by an upstream process. Network middleware systems enabled the computer resources of the network of machines to be utilised with the facility that one may expect of a single machine, but tended to require user-intervention and were weak at running chained processes.

As might have been expected the purpose-written MDO frameworks provided the most flexible integration support but did not necessarily distinguish the process support aspects (including the registration of tools, the definition of process chains and their execution) from data management (product models and requirements) or from embedded tools (for the visualisation of various categories of data or optimisation functionality). Further development is needed if the frameworks are to operate in a standards driven environment accessing data from corporate data bases.

The role of the optimiser The role of the optimiser was also the subject of slight variation within the various partner frameworks. At the simplest level, the optimiser calls for function evaluations, possibly including gradients, at a sequence of design points and, in effect, controls the process. As the function evaluations call for increasingly time-consuming analyses with complex data interactions and, possibly, requiring user-intervention, this becomes a less attractive option.

An alternative approach is still to start the design cycle with the optimiser initiating a design change, but to return control to the framework for the performance assessment phase. The optimiser must then be capable of being restarted once the performance assessment is complete. In software terms, the optimiser may then appear as just another MDO process, to be called as required, but its controlling role within the process of design should still be recognised.

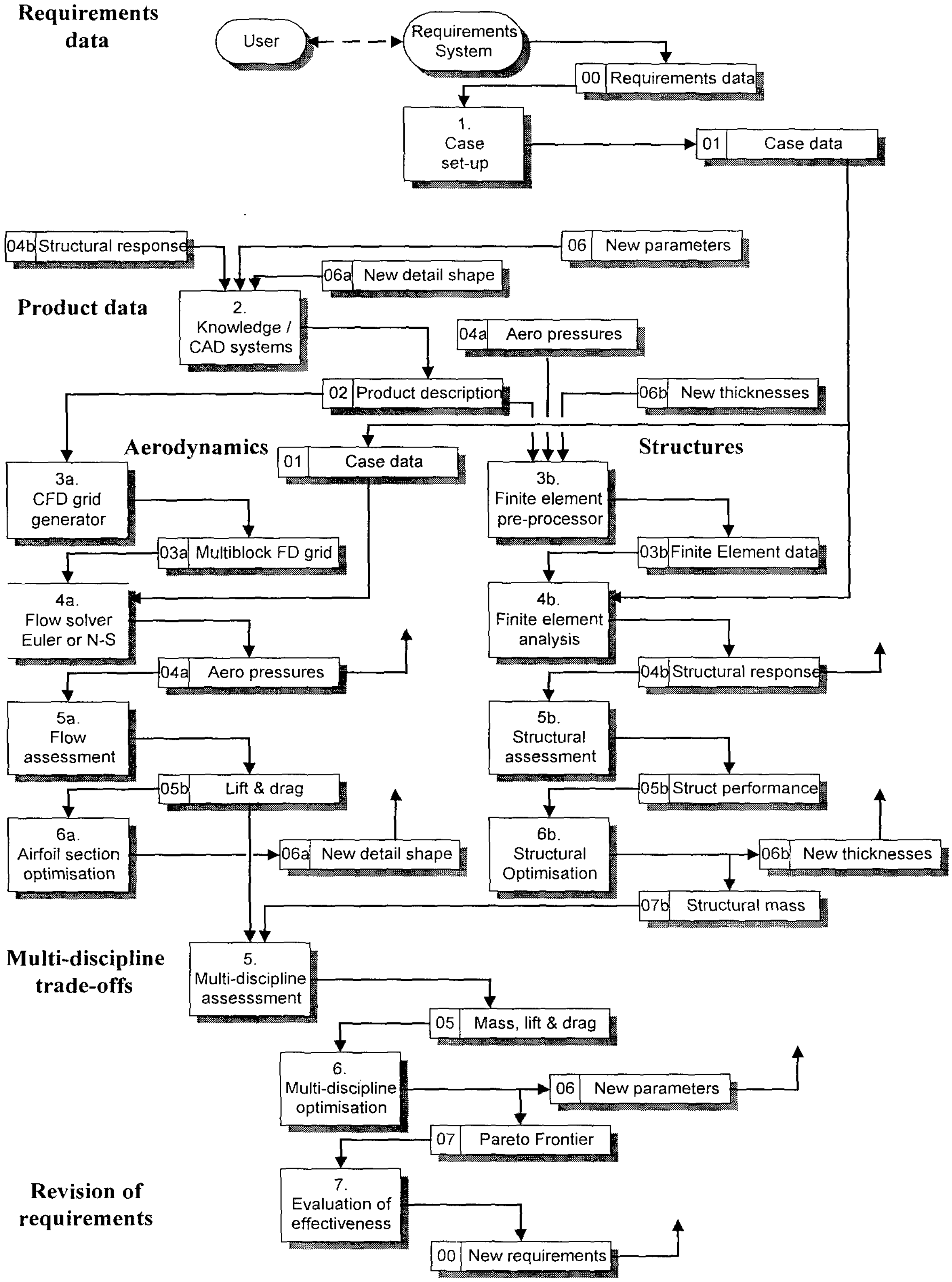

Figure 4. Data flow for multi-disciplinary design, showing software tools

The FRONTIER project

The FRONTIER project[7] (1996-1999) was led by British Aerospace Military Aircraft and funded by the European Commission. Although FRONTIER was a relatively small project, it had the widest scope in that it considered design against multiple objectives. The project partners consisted of universities who, in the main, acted as suppliers of new technology and industrial partners who provided user trials relevant to their industry sector. It comprised research to develop and evaluate a framework for multi-disciplinary optimisation, with multi-criterion decision making (MCDM) software to capture customer preferences, across a variety of mechanical engineering applications. The project also examined the capture of requirements. It is almost inevitable that the initial formulation of an MDO problem will not automatically lead to the required product, since the impact of constraints and the balance of conflicting requirements will not be fully understood at the outset. The Pareto frontier approach provides the user with visibility of potential design trade-offs and an ability to choose the relative importance placed upon multiple design objectives. Clearly, if cost were a criterion, this leads to a cost/performance assessment which is a key input to any requirement capture process.

In this project DERA evaluated the software tools developed for this purpose by other members of the FRONTIER Consortium, to explore combat aircraft wing design from a performance perspective. From multi-disciplinary aerodynamic and structural analyses, results for aircraft range (related to fuel volume, aircraft mass and drag) and supersonic sustained manoeuvre performance (related to aerodynamic drag) were derived. Figure 5, taken from the paper by Fenwick and Harris[8], shows that an envelope curve, the Pareto frontier, may drawn to encompass the performance results obtained for the family of wings of fixed planform which covered a range of wing thickness and spanwise thickness taper.

Requirement capture for military aircraft The user trial conducted by DERA in partnership with BAe was based on the design of a military wing and sought to achieve an acceptable compromise between aircraft range and turn performance. In this instance the aerodynamic model was taken as the master model, but in the longer term it would be expected that both the aerodynamics and structures models would be derived from a common product model. The approach taken is a multilevel Pareto-optimisation in which the wing thicknesses (wing-box depth) at various stations are used as top-level variables linking the structures and aerodynamic disciplines. The structural optimisation determines the sizes of the composite covers and sub-structure for each geometry, while the aerodynamic optimisation modifies the airfoil shape to maximise a weighted sum of lift to drag ratios corresponding to a supersonic turn condition and transonic cruise.

The supersonic turn rate and transonic range shown in figure 5 are then calculated from the drag, mass and fuel volumes. Each curve corresponds to a given spanwise thickness distribution but with the aerodynamic shape optimised to give differing levels of transonic to supersonic performance. In general the thicker wings give greater range due to their increased fuel capacity, but ultimately (case 9) higher drag will reduce the range.

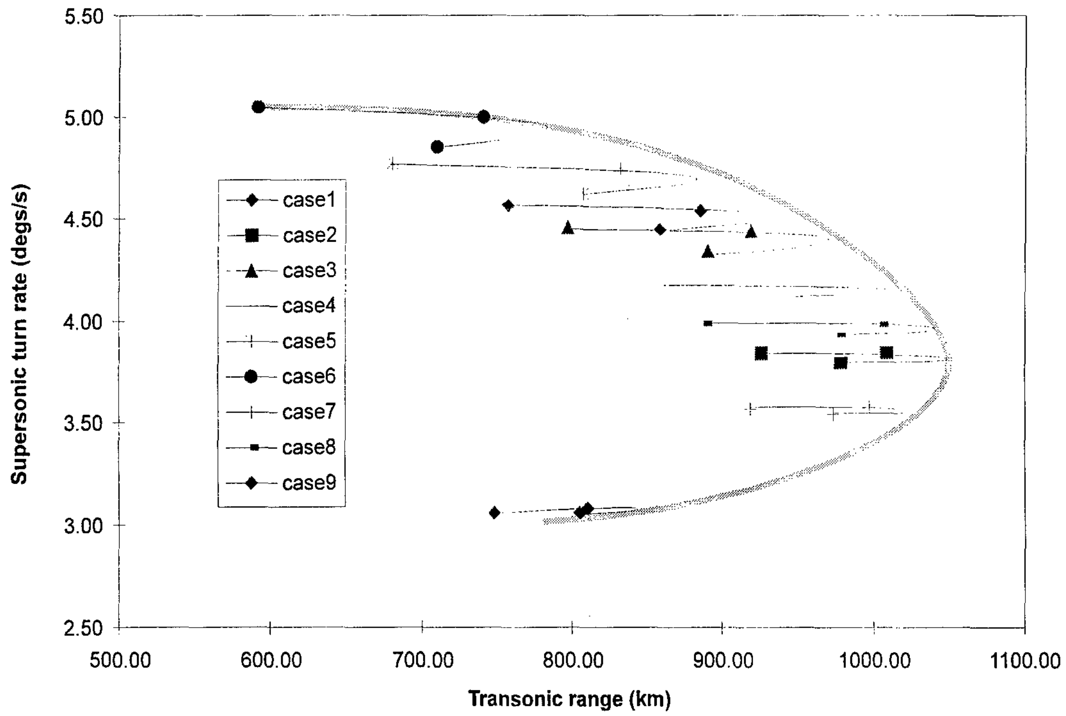

Figure 5. PARETO boundary

The Pareto frontier itself, indicated in grey in figure 5, bounds the region in which it is possible to design products to meet the conflicting requirements. The best products have performance characteristics which lie close to the 'top-right' part of the boundary. From here it is only possible to improve one characteristic at the expense of the other.

The use of genetic algorithms has been assessed as a method of achieving convergence to the boundary of the region. Typically such direct search methods require many function evaluations, each one of which calls a full structural optimisation for mass as well as an aerodynamic minimisation of drag for two flight conditions. The fact that these tasks are computationally intensive makes the activity appropriate for high-performance computing in the longer term, but to reduce the computing costs during the FRONTIER project, response surfaces were calculated for the wing mass and drag. The Pareto frontier could then be calculated on the basis of the cheaper response surface information rather than from further calls to the underlying design software. This enabled sufficient computing resources to be devoted to the assessment of genetic algorithms within the Pareto frontier approach, and to evaluating the MCDM software tool for deducing the weightings attached to the various design objectives from customer preferences. This aspect of the project was of particular interest as it extended the scope of MDO so that it assists with identification of the design requirements that the product should meet. The FRONTIER software provided a graphic demonstration of the ability to choose rapidly an appropriate mix of fighter and bomber requirements.

The ENHANCE project

The ongoing project ENHANCE (1999-2002), funded by the Commission of the EU, is addressing issues in Concurrent Engineering. This large European project (38 MEURO) has 53 partners drawn from the aeronautical industry and research community. The main objectives are to define new common ways of working, applicable from the initial design phase onwards, to propose a set of operational tools and to validate the new approach through a full range of industrial experiments. Central to the project is a set of 13 "COMMONs" each of which will define a common way of working within a given domain for engineering. It is planned to develop a set of Concurrent Engineering processes which will be adopted by all the parties. Implementation of these processes is expected to lead to large reductions in vehicle development timescales and costs, and to more effective and efficient utilisation of common exchange standards, leading to increased competitiveness.

DERA is contributing to the Common Scientific Calculation (COSCAL) element of the Product Engineering section of the project. Interfacing and integration of structural and aerodynamic analysis methods within a common data exchange environment are being defined and implemented.

DISCUSSION

Each of the projects summarised above has given a different perspective on MDO. In this section the discussions and conclusions from the individual projects are brought together and the major issues identified. To do this some basic questions need to be answered:

- Why do we need MDO?
- What are the necessary elements for MDO?
- How can these elements be put in place?
- What are the obstacles to be overcome?
- Who needs to take action?

Why do we need MDO?

Many answers have already been given to this question, but to summarise:

The military customer requires affordable and effective integrated air-vehicle systems, while industry aims to produce an air-vehicle system that meets customer requirements and produces a profit for its shareholders. To achieve these ends the military requirements and the potential solutions must be brought together with high fidelity of simulation, to reduce the cost and risk of a project. Industry needs a process to evolve concepts by bringing to bear quickly and effectively the full spectrum of their engineering design capabilities. The military customer needs a process to allow operational requirements to be evolved so that balanced concepts result for the warfighter. Thus responsiveness to evolving requirements is common to both parties. Reduced time for a design or assessment cycle allows more cycles to be completed in a given time, and a better product (cheaper for the same performance or higher performance for the same cost) to be defined. In the UK there is an increasing degree of overlap in the design and assessment processes because of the move to joint Industry / MOD project teams.

What are the necessary elements for MDO?

The following list captures all the elements required. They are listed in order of increasing difficulty of satisfaction across the potentially wide spectrum of users.

- Robust, compatible analysis codes
- Proven procedure for optimisation
- Data structure
- Requirements capture
- Framework architecture and hardware
- Control

Each of these is considered in detail in responding to the next question.

How can these elements be put in place?

Analysis codes The characteristics of any analysis code to be used for assessment, design or optimisation must be thoroughly evaluated for the regime in which it is to be applied. The range of applicability needs to be defined. When used in an optimisation process any shortcomings in the modelling of physics within an analysis method can potentially lead to erroneous conclusions and hence invalidate the process. A standard interface to pre-processing (e.g. geometry input) and post-processing (e.g. flow field analysis and visualisation) is required. Although this can be achieved for legacy codes by writing a software 'wrapper', it is preferable to have a standard interface built into the analysis software.

Optimisation Flexibility is required in the means by which an 'optimum' can be defined. For optimisation within a local area of design space or for a well-understood problem gradient / line-search methods are most effective. When exploring a large region of design space the genetic-algorithm (GA) type of method has the advantage of being able to avoid local optima. Thus for mathematical optimisation in a new problem use of a variety of methods is likely to be preferable, if the potentially large computational requirement of a GA element can be accepted. Response surface methods provide a means of reducing the computational requirements while capturing many of the prime features of the design space.

In considering real engineering problems it is generally found that the definition of constraints is a critical element of the problem definition. While methods for unconstrained optimisation are mature and can produce well defined optima, this is not the case for constrained optimisation methods. In particular few gradient-based methods can produce well-converged solutions for problems with a large number of non-linear constraints. With the GA type of method constraints can be handled by including in the objective function a penalty term made up of the sum of the magnitudes of the constraint violations, but this approach can produce poor convergence. For engineering design in industry, visibility of the design space is an important requirement so that trade-off studies may be made to guide a decision on the 'optimum'. Thus a series of analyses and sub-discipline optimisations may be preferred to a total optimisation. For an MDO system to be of general use it is necessary to provide all of these options.

Data Structure To allow re-use of an MDO method data describing the product (i.e. aerospace vehicle) needs to be defined in a 'standard' form so that analysis programmes can retrieve and deposit the necessary parameters. The data describing the vehicle 'object' is not just geometric but will also cover the physical properties and performance of the product. To provide the widest possible commonality the product should be defined using an International standard with an associated data description language (e.g. STEP with the EXPRESS language). Because there are many ways in which an object can be described the choice of the model to characterise a product needs to be made by the prime customers for an MDO system, i.e. industry (for design, development and manufacture) and government procurement agencies (for requirements definition and project assessment). With the current trend to integrated product teams the responsibility for model definition falls naturally to industry.

Parameterisation of geometry is a particularly important aspect of a product model. Historically different methods of parameterisation have been used for each engineering discipline (e.g. finite elements for structures, point data or bi-cubic patches for CFD, and CAD for manufacture). The requirement for a product model is thus to provide the reference detailed description of the object in such a form that the necessary information can be readily extracted for all disciplines. A potential difficulty arises from the fact that geometry parameterisation can be combined with geometric design rules if full advantage is taken of the capability available within modern CAD tools for implementing knowledge-based systems. As a result a product model can become proprietary, holding the accumulated knowledge of specialist designers. This type of product model could not therefore be released to the general R&D community so it is essential to separate the two functions.

Requirements capture Problems that are likely to be tackled with MDO are typically sufficiently complex that they have no unique definition. Requirements can be translated into alternative combinations of optimisation objectives, or constraints, or bounds on design variables, and can be applied at low or high-level in the MDO process. The capture of requirements for an MDO problem needs to be comprehensive as the omission of 'obvious' or 'trivial' requirements can result in unrealistic solutions. It is important to distinguish between requirements that are genuine constraints (e.g. to prevent overlap between components in a vehicle) and design 'rules' derived from established design practice that potentially limit the available design space. For design in industry the latter encapsulate best practice and thus they are often proprietary in nature, giving the company a competitive edge in the market place. It should be noted that the imposition of constraints of this nature removes some degree of design freedom and thus can potentially limit performance.

Framework architecture and hardware. Many alternative software architectures have been examined by workers in the MDO field. The most suitable approach will be determined by the particular problem being addressed and the computing resource available. While it is not possible to be more prescriptive than this, all frameworks should comprise elements with identifiably separate functions, and be implemented in an object-oriented form, so that the framework can be readily adapted as the design problem evolves (and typically grows in size). The framework needs to be suitable for implementation on networked computers, partly to link specialised analysis groups but also to allow parallelisation of any optimisation elements.

Control From an industry standpoint the weapon system designer wishes to make design judgements across a large number of issues, including commercial ones. Thus he will emphasise man-in-the-loop control of the MDO process, so that the process may be altered to provide the information on the specific design trades he requires. At the other extreme an automatic large-scale optimisation could be defined that required no user interaction within the process. Experience indicates that results from a single optimisation of this type are of little use. Knowledge of the design space in the vicinity of the "optimum" is essential before any judgement on the worth of a design can be reached. Thus a series of optimisations is necessary, probably with systematic changes to constraints and / or objective functions. A user interface is therefore required which supports process definition and execution, and allows iteration without a man-in-the-loop (although, initially, user intervention is vital). Analysis methods must be automated and results displayed in a multi-disciplinary format. Experience from the MDO project recounted above indicates that the control element should also include the definition of the role of the optimiser: is it in control of the process or controlled by the process?

What are the obstacles to be overcome?

From the above discussion based on the experience of participation in MDO projects in the past 5 years, five issues need to be addressed to progress MDO from a research-based activity to one that will be of real value to industry and procurement agencies:

- Control of a distributed MDO process – who is in charge of the problem solution?
- Interactive definition of the MDO process to match problem requirements
- Definition of a product model for general use
- User confidence in results from analysis codes
- Audit of overall optimum by specialists from disciplines

Two other areas are important for improving the effectiveness of MDO, but progress is likely to be evolutionary and driven in part by advances in computation technology:

- Optimisation methods and strategy
- Geometric parameterisation

Who needs to take action?

Considering the first five issues listed above it is clear that the lead responsibility for their resolution rests largely with industry, as they are central to the concept definition process. In the UK this responsibility may devolve to a joint industry / military project team. Research agencies will continue to develop new technologies and demonstrate them. They can assist industry in the technology insertion process for the selected tools. The last two issues are likely to continue to be addressed by research projects developing new approaches and improved methods for the integration of disciplines. It will be essential for this work to be focused on realistic engineering problems generated in partnership with industry.

CONCLUSIONS

A number of developments relevant to the practical use of MDO have been identified by reference to a sequence of collaborative research activities in which DERA has participated. It is believed essential for the credibility of an MDO process that it should be able to accommodate the design processes used by engineers within industry to assess and validate their products.

Seven areas have been identified that need to be addressed to advance MDO. Of these the prime factor currently limiting further development of MDO is the lack of a product model to act as a standard for data accessed across disciplines. To achieve this it is essential that the data storage function be decoupled from rule storage (expert knowledge) function that co-exist in some CAD-based product models, because of the potentially proprietary nature of design rules. It is desirable to use STEP to standardise the form in which product data is shared and exchanged amongst processes.

A good framework for MDO that provides a flexible user interface for the definition, execution and monitoring of MDO processes is essential and further development of clear architectures for such software is still required. While conceptual design tools are often close-coupled, loosely coupled systems appear to be more appropriate to MDO in that they assist the verification of results by specialists. Some loss in process efficiency or even the generation of sub-optimal designs is acceptable provided the design process is understood and credible.

The future role of Research Agencies in advancing MDO is seen as developing and validating new technology for integrating analyses and optimisation, and assisting industry and procurement agencies in the insertion of the resulting tools into their design and assessment processes.

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