Modelling for Aeronautical Applications

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January 15, 1997

1 Introduction

The sophistication of contemporary aviation technology is placing ever increasing demands for modelling on engineering personnel. The specialized and detailed description of complex components is essential, but effective communication between disciplines is also required. In aviation engineering support, and in research and development, the integration of results must be improved, so that global project aims can be satisfactorily achieved.

A model of an artifact or an activity provides a simplified representation of that entity. The aim of modelling is to capture the important features without including unnecessary detail (Winston 1984). Different disciplines and activities have distinct views of the important features of the item being modelled, so various models of a single entity are generally created. Models may be physical, as used in wind tunnels, geometric, as in wire-frame models generated by CAD-CAM systems or mathematical, as in the numeric analyses used to compute aircraft trajectories. These disparate models are representations of the same entity, and will be specialised according to discipline and activity. Thus modelling has two aspects — the model representation, and the model analysis — which are the focus of this paper.

It is the interplay between model representation and analysis which is most important for complex modelling tasks. While it is appropriate to develop distinct models, an *integrated* approach to modelling would help to bridge the gap between engineering specialities. The specific goal we have in mind is to achieve such integration in the mathematical structure of models: their implementation; and how their results are interchanged as a project develops.

Examination and classification of the usual simplifying assumptions should enable us to discover a useful 'super-model'. From an understanding of the commonality, and differences, between models optimized for different specialities, and how these relate to the 'real' aircraft, we hope to work towards a common representation — a concise statement of all of the information relevant to a complex aeronautical modelling project.

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Hence we dissect the modelling process in order to see how a common representation might be related to particular specialities so that the interplay between them is mediated by a common layer — a *lingua franca* for interdisciplinary aeronautical modelling activities.

In outline, Section 2 begins by discussing discipline based specialization of model representations. Section 3 follows by developing the complementary aspect of activity based specialization in the methods for model analysis. Section 4 develops the idea of a common representation to smooth their interplay. The closing section reviews the paper and offers concluding remarks.

2 Discipline-based Specialization of Models

Modern aircraft are complex systems, and disciplinary experts focus on different aspects of the aircraft design to produce effective solutions and perform a variety of analysis tasks. Different models are appropriate for each analysis, as illustrated with two examples in Figure 1. In the lower left corner, the aerodynamicist's view is represented by a surface panel model to be used in a flow solver, such as VSAERO (Quick 1995). In the upper right corner, the structural dynamicist's view is represented by a lumped–mass model for vibration analysis (Dunn 1996). The two approaches reflect widely different representations of an aircraft model. However, in aeroelastic analysis, both representations are needed and the two must interact with one another (Gupta 1996). Other examples include finite element models for structural analysis (Jones & Callinan 1978), rigid–body flight dynamic models for system identification (Feik 1978), and point mass models for operational analysis (Tidhar, Selvestrel & Heinze 1995). Each of these representations is different: each is appropriate to its purpose.

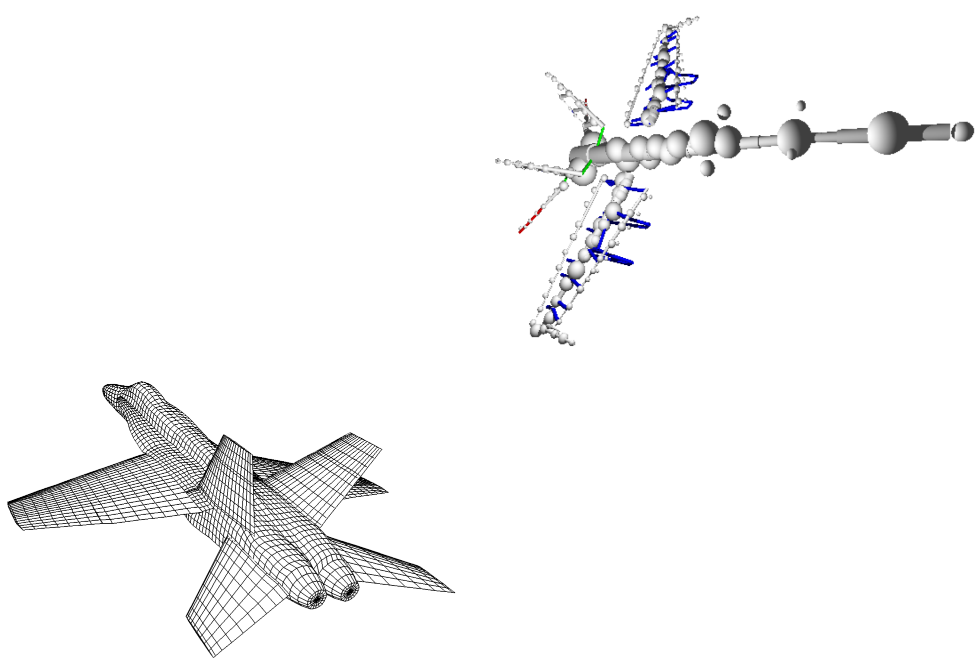

Figure 1: Different models serve different purposes

Table 1: Scope of aeronautical modelling activities

ACTIVITY	INPUTS	NATURE OF MODEL	OUTPUTS	APPLICATION
ballistic trajectory prediction	store aerodynamics, inertial properties	3-dof rigid body	time-x-y-z trajectory	weapon precision, ballistic tables
structural analysis	material properties, geometry	finite element or finite difference	stresses, strains, loads	design process
handling qualities evaluation	pilot control inputs	flight dynamic	aircraft response	safety validation, cost/benefit, mission effectiveness
stores clearance prediction	configuration, flight condition	store aerodynamic /aircraft flight dynamic model	air/store interaction, stores release	platform safety, mission effectiveness
prediction of aeroelastic effects	aerodynamic surface excitation	unsteady aerodynamic /mass model	load frequency spectrum	flutter clearance for stores
input design	desired flight path	flight dynamic	aircraft response	optimal manoeuvring
operational employment of aircraft	scenarios, missions	individual aircraft store sensors, pilot model, tactical doctrine	exchange ratios, operating schedules	new/improved tactics, purchase advice, resource allocation
pilot in-the-loop simulation	pilot control input scenarios	pilot and flight dynamic models	aircraft response procedures	human/aircraft interface, aircrew workload
platform design	mission roles, design concepts	structural, aerodynamic	strength, lift, drag, performance	design concepts

The broad scope of aeronautical modelling activities is shown in Table 1. Each model is characterised by its internal nature and by its inputs and outputs. Furthermore, the internal structure may be completely specific to the task while the input and output may be a subset of a global representation. This observation is particularly relevant for activities that require the involvement of several disciplinary specialists, such as the investigation of aeroelastic effects, which includes aerodynamic and structural investigations. In those cases, the analysis details of each specialist need not be communicated, but data sharing is essential. A central data model should be shared by all the disciplines, and specialization should involve a mapping from the general shared model to the specific local inputs and outputs. In geometric modelling, for example, a Non-Uniform Rational B-Splines (NURBS) (Farin 1988) geometry model might be shared, and specialized panel models might be separately optimised for CFD and for structural computations. These disciplinary activities require different concentrations of panels and so a common panel model would be inefficient.

3 Activity-based Specialization of Models

Computational models are classified in Figure 2, indicating the core activities of prediction, evaluation and optimization. In prediction, a known set of inputs are given, and the model is used to predict a corresponding set of outputs. In evaluation, a number of inputs are trialed and the output behaviour evaluated to determine the best alternative, or relative success at meeting a specified condition. In optimization, feedback operates to vary inputs and/or the model itself according to the resultant output. Thus one attempts to harness both the predictive and evaluative capabilites of a model to achieve design goals, often in an iterative process of model refinement.

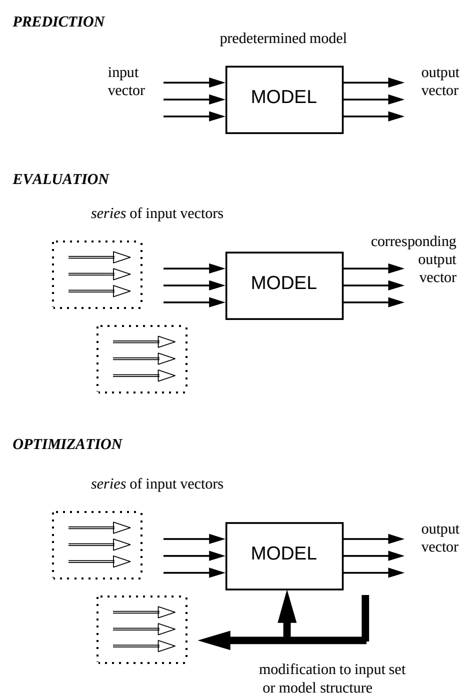

Figure 2: Hierarchical classification of computational models

Techniques can be characterised along the dimensions of scope, use of knowledge, adaptiveness and strategy complexity. In Table 2, a range of techniques are shown. Use of knowledge refers to the amount of prior information that is required in order to facilitate each technique. Adaptive techniques, such as maximum likelihood and genetic programming fall into the class of optimization schemes, since the model is improved each iteration, based on the results of previous configurations.

It is important to match the model to the type of activity being performed. When a large input set is used to conduct a preliminary survey of a particular domain, a model with moderate accuracy and low computational cost is appropriate. If minor refinements of an established design are being explored, the input set will be more selective and the output tolerance higher, hence more expensive analyses with greater computational cost are warranted. Analyses that provide reasonable functional accuracy may produce wildly inaccurate gradient information, which makes them unsuitable for calculus-based optimization. In this situation, the model may

Table 2: Modelling techniques

	SCOPE	USE OF KNOWLEDGE	ADAPTIVENESS	COMPLEXITY
FINITE INPUT SET *e.g. test all then evaluate*	global	low	fixed	simple
SELECTIVE INPUT SET *e.g. choose wisely then test all*	global	medium	fixed	simple
LOCAL GRADIENT *e.g. simplex, maximum likelihood*	local	high	adaptive	intermediate
GLOBAL ADAPTIVE *e.g. genetic programming, simulated annealing*	global	moderate	adaptive	complex

be modified by using a large input set to survey the space, and then fitting a smooth *response surface* through the surveyed data points. This produces a specialized response surface model that is well-matched to the optimization activity, and this approach is beginning to be practiced by engineers performing multidisciplinary optimization.

4 Common Representation

The preceding sections have demonstrated the need for a shared representation across disciplines, which is specialized for particular analysis activities. The quality of the common representation is measured by the freedom one has to pass from it (via concretion) to a representation optimized for a particular discipline, and, in the other direction (via abstraction) from the model output (via a concrete activity) to an element of the common representation. Evaluative and design procedures can also be "interfaced" to the abstract level.

Elements of a common representation might include:

- surface geometry (e.g. via NURBS)
- mass concentration (panels with mass)
- loads (point loads, or distributed loads)
- deflections (dynamic geometry)

A concretion layer - an abstract common representation - can be specialized to the discipline involved. For example, One might pass from a NURBS geometry description to a panel model optimized for CFD, or an alternative panel model optimized for structural computation.

The presence of an abstraction layer allows the model to have its inputs or outputs processed in some manner to prepare it for the activity in mind. For example, a predictive model which is good at generating discrete function points, but not gradients might be augmented with a filter in order to produce the required information.

Hence, the concepts of concretion and abstraction layers provide means by which the model can be altered to match either discipline or activity. This scheme would give the user greater control over their modelling processes and improve interaction with other specialists.

5 Conclusion

Clearly, the focus of interdisciplinary discussion must be on finding a generally useful common representation, and an understanding of the concretion and abstraction processes for particular disciplines and activities.

It is constructive to appreciate the methodological similarities in what have been regarded as disparate areas of aeronautical engineering support, research and development. Many of these are mathematically based, and make similar assumptions and simplifications. Examination of the similarities enables us to conceive more general and sophisticated methods for manipulating models. Ultimately, one hopes that newer methods will enable us to deal with complex models more effectively.

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