Towards the Optimisation of Adaptive Aeroelastic Structures

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ABSTRACT

Adaptive Aeroelastic Structures are receiving much interest at present world-wide due to the potential of improved drag performance, as well as roll and loads control, via changes in the internal structure rather than using traditional control surfaces. Previous work has demonstrated the feasibility of implementing a number of different adaptive aeroelastic concepts and some of this research is discussed. Consideration of the stiffness distribution that is required to meet aerodynamic performance requirements whilst meeting structural and aeroelastic constraints is made. The use of a genetic algorithm, or similar search algorithm, is required in order to be able to deal with the large number of different possible design cases that arise from even from the most simple of design cases. Some sample results from a simple rectangular wing structure are shown. The relationship between the desired stiffness distribution and what could be achieved using more sophisticated adaptive aeroelastic structures in practice is considered.

INTRODUCTION

There is a growing interest in the development of adaptive aeroelastic structures to allow aeroelastic deflections to be used in a beneficial manner [1,2]. They are a subset of Morphing Structures, but rather than attempting to change the wing plan-form, the stiffness of the structure is adjusted to influence the aerodynamic performance. Such an approach will lead to more efficient aircraft designs. For example, the wing twist could be adjusted throughout the entire flight in order to maintain a shape giving optimal lift-drag ratio for maximum range, and also as a means of roll and loads control. Other concepts are being developed to change the wing leading and trailing edge shape in order to adjust the lift coefficient, and also to change the wing planform shape. In recent years, a number of research programmes, for example the Active Aeroelastic Wing [3] and the Morphing Programme [4], have started to develop active aeroelastic concepts. In Europe, the 3AS (Active Aeroelastic Aircraft Structures) research programme [5] developed and demonstrated various active aeroelastic concepts on a number of large wind tunnel models.

Part of the 3AS research programme, and continuing work at the University of Manchester [6], was devoted towards investigating the use of changes in the internal aerospace structure in order to control the static aeroelastic behaviour. Such an approach is desirable, and arguably advantageous compared to other possible concepts. For instance, the use of leading and trailing control surfaces to control wing twist can lead to increased drag and poor observability characteristics. The use of smart materials (e.g. piezo and shape memory alloys) has received considerable attention in recent years, but still suffers from limits in the amount of force required to twist a wing.

The key idea exploited in the Adaptive Internal Structures approach is to make use of the aerodynamic forces acting upon the wing to provide the moment to twist the wing. By changing the position of the shear centre of the wing, the bending moment, and hence the amount of twist, will also change. A far smaller amount of energy is required to adjust the structure compared to that required to twist the wing and keep it in that shape. Such an approach is very attractive for active aeroelastic wing concepts and leads the way for the adaptive structural control of aerodynamic performance as well as roll and loads control.

Prototype experimental studies [6] have demonstrated that it is possible to change the wing shear centre position, and the bending and torsional stiffness, by using spars that can move in a chord-wise sense, or can rotate. However, having demonstrated that such adaptive devices can be made to work, there is a need to be able to decide the most effective way of implementing adaptive aeroelastic structures. Obviously it is infeasible to move the massive internal structures of large commercial aircraft, e.g. A380, close to the wing root, however, the wing structure is much smaller towards the wing tip and this region also has a much greater effect upon the aerodynamics.

This paper reviews some of the current work that is being performed to use optimization methods to determine the most beneficial stiffness distributions and shows some sample results on a simple rectangular wing structure. Conclusions are drawn as to the best approach to take with the optimization process and the feasibility of using such approaches to enable adaptive aeroelastic structures to be used for the fullest extent in practice.

ADAPTIVE AEROELASTIC STRUCTURES

The key idea exploited in the Adaptive Internal Structures approach is to make use of the aerodynamic forces acting upon the wing to provide the moment to twist the wing. Consider the schematic of the wing shown in figure 1, with the lift acting at the aerodynamic centre on the quarter chord. By changing the position of the shear centre of the wing, the bending moment, and hence the amount of twist, will also change. A far smaller amount of energy is required to adjust the structure compared to that required to twist the wing and keep it in that shape. Such an approach is very attractive for active aeroelastic wing concepts.

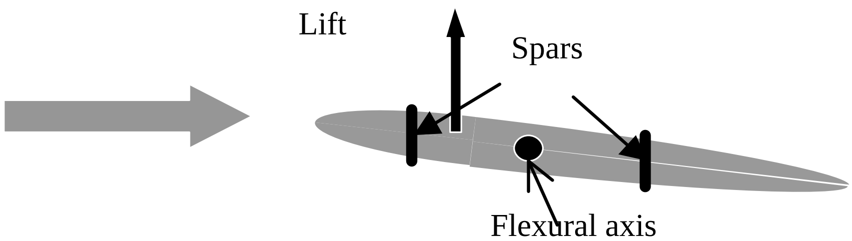

Figure 1. Schematic of Typical Wing Cross-Section

Research at the University of Manchester has investigated the use of a number of different adaptive aeroelastic concepts including the use of rotating spars and spars that can move in a chord-wise manner. Figure 2 shows the underlying spar/rib structure for prototype wind tunnels that were designed, manufactured and tested successfully to demonstrate both concepts.

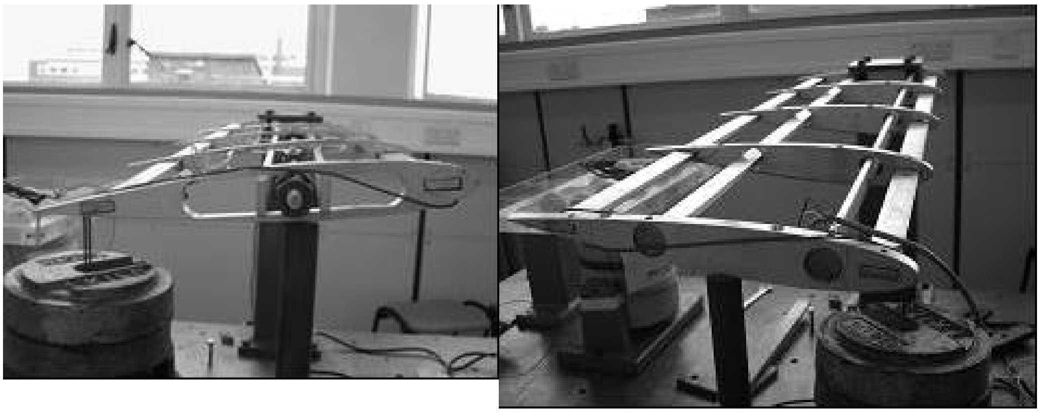

Figure 2. Adaptive Internal Structures Prototype Models – Moving and Rotating Spars Concepts

AERODYNAMIC PERFORMANCE REQUIREMENTS

Aircraft are designed currently to meet a maximum lift/drag ratio at some single point mid-way through the cruise condition. Consequently, the aircraft is off-optimum throughout the flight due to its changing fuel load and distribution. Further points that need to be considered are that often flight control considerations enforce a flight path at a non-optimal height and speed.

The use of adaptive aeroelastic structures concepts enables the bending and twisting properties to change along the wing, which in turn can be used to control the lift and drag at any particular flight and fuel loading condition. Although the lift and drag as primarily functions of the local angle of incidence (and hence twist) along the wing, due to the coupling between the bending and torsion modes of a swept wing it is not possible to simply consider torsion in isolation of bending, and vice versa.

For any given time in the flight path and altitude, the amount of lift that is required will be the same and consequently the problem of maximising the C_L/C_D ratio reduces to minimising the drag. This approach is complicated somewhat if fuel distribution is also considered, and consequently the amount of lift required reduces throughout the flight with diminishing fuel load. Some aircraft employ fuel management systems that redistribute the fuel throughout flight to ensure that aeroelastic constraints are met, and this would once again complicate the optimum employment of adaptive aeroelastic structures.

EXAMPLE ADAPTIVE AEROELASTIC WING STRUCTURE

Consider the finite element model of the prototype wind tunnel model shown in figure 3. The effect of rotating the spars can be achieved by simply varying the second moment of area properties of the spars (future work will consider the ribs as well) and it is also straightforward to move the spars in a chord-wise manner as well. As we are only considering the problem in a static aeroelastic sense, there is no need to worry about modelling the system as the changes in internal structure are made. However, dynamic effects such as flutter must always be considered as a constraint as well.

As each of the spars in the wind tunnel model was able to rotate between 0 and 90 degrees, this could lead to a large number of possible configurations, depending upon the increment between the different rotation angles that was considered. In the case covered here, it was also assumed that the spars were divided in four separate sections, between each set of ribs, which could independently assume any rotation angle. Lift and Drag coefficients were determined for all configurations considered and are shown in figures 4 and 5. Fig 6 shows the divergence speeds

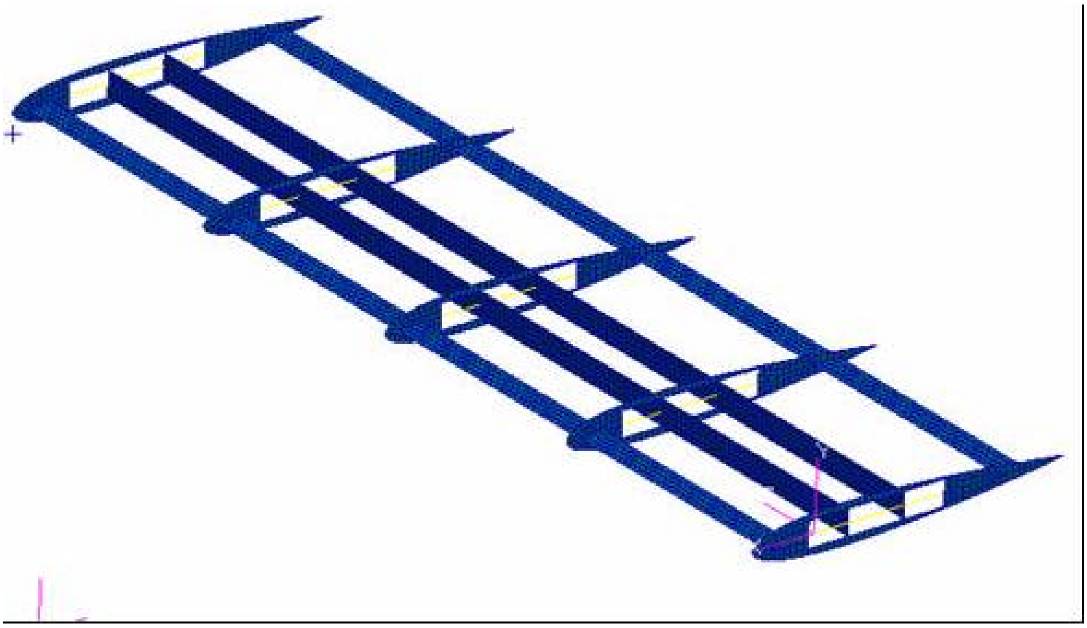

Figure 3. Typical Finite Element Model of Wind Tunnel Prototype

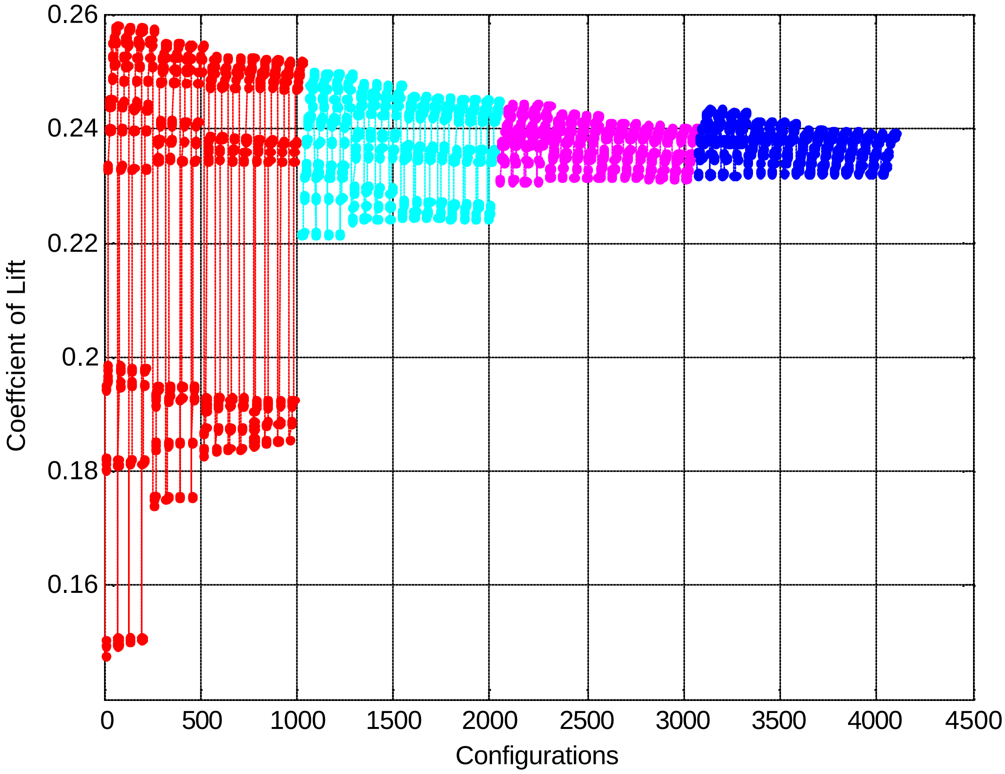

Figure 4. Lift Coefficients for Different Structural Configurations

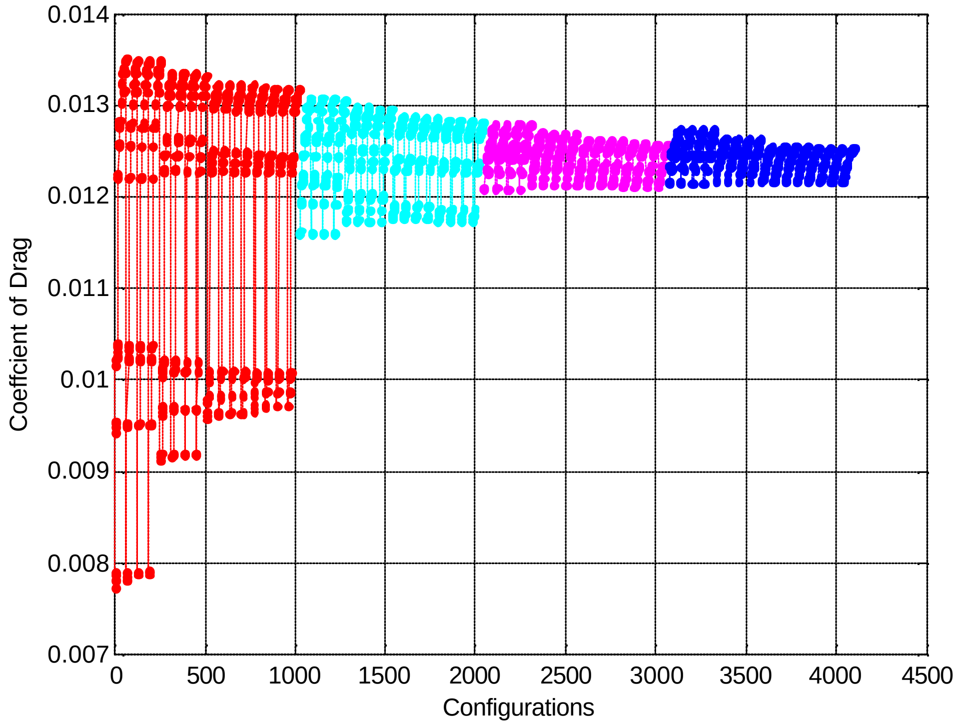

Figure 5. Drag Coefficient for Different Structural Configurations

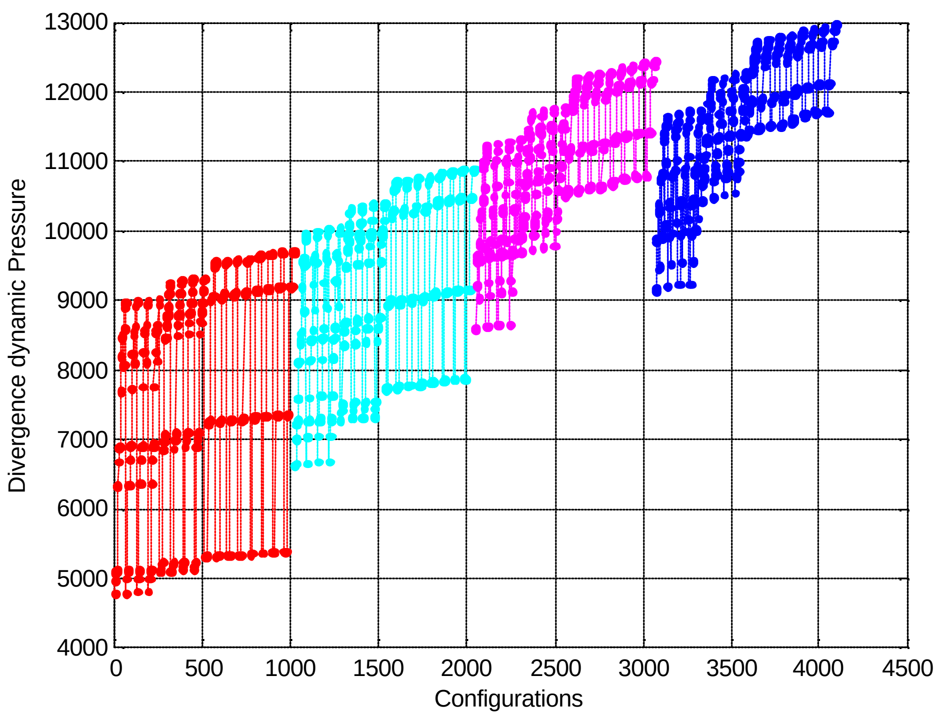

Figure 6. Divergence Dynamic Pressure for Different Structural Configurations

It can be seen that even with a relatively sparse number of possible spar orientations (only 0/30/60/90 degrees were considered) that there are an extremely wide range of different lift and drag coefficients that need to be considered along with constraints such as the divergence speed. Therefore it is prohibitive to consider the problem of determining the internal spar orientation that results in either maximum lift / drag ratio, or minimum drag for a range of different speeds and altitudes without using some form of optimisation technique.

OPTIMISATION STRATEGY

It was felt that the most appropriate way to set about optimising the use of the rotating spars in this example was to employ a Genetic Algorithm as these are particularly adept at searching through the design space in an efficient manner. Other factors in favour of the use of a directed Random Search method are that the design space is relatively smooth, and that by setting up a macro to link the genetic algorithm with the aeroelastic computation package, it was possible to get the estimates for each structural configuration in a matter of tens of seconds. Convergence to the best structural stiffness layout was achieved by only considering a small subset of the total possible cases.

Other points that are being considered currently are the inclusion of different altitudes and flight speeds as well as different fuel loads and distributions.

CONCLUSIONS AND FUTURE WORK

An initial investigation has been made into the use of optimisation methods to determine the optimum orientation of the rotating spars adaptive aeroelastic structures concept. Further work is continuing to determine whether the rotating spars approach is the most effective, and whether the aerodynamic gains outweigh the extra weight and power penalties to use such an approach on full-scale aircraft. The next step is to consider shape optimisation tools to assess the structural layout of the spars and ribs for adaptive aeroelastic structures.

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