Conceptual Design of Future Aircraft Structures Incorporating Dynamic Loading


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Conceptual Design of Future Aircraft
Structures Incorporating Dynamic Loading

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The aviation industry’s progression toward unconventional, highly-integrated aircraft configurations, which are likely to experience dissimilar loading to conventional Tube-And-Wing aircraft, challenges the capabilities of existing conceptual design methodologies. The structural design process is driven by inertial loading resulting from static, quasi-static and transient load events which define performance requirements for aircraft structures. The impact of aero-elastic responses to dynamic load events on the structural design of the aircraft is poorly understood for unconventional airframe-propulsion system configurations. Modelling and analysis strategies which directly resolve dynamic loads early in the design

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process at a whole aircraft level facilitate investigation of the impact of dynamic loading on structural performance requirements, permitting rapid investigation of interdependencies and interactions which may exist between the aircraft and propulsion system. This paper details development of a flexible modelling and analysis framework, which leverages existing aero-elastic analysis and optimisation capability in commercially available software, for application during conceptual design. The framework is intended to be sufficiently generic to permit application to a range of aircraft configurations proposed for the 2050 timeframe. Dynamic analyses are incorporated in an optimization loop via generation of equivalent static loads (which capture applied aerodynamic and internal structural loads) through a proprietary python tool. A reference Tube-And-Wing aircraft for which significant public domain data exists (Boeing 777-200LR) is used to validate and benchmark framework performance.

I. Aims & Objectives

This research aims to develop structural modelling and analysis capability which will enable generation of appropriately representative conceptual design analysis models for unconventional aircraft configurations, permitting generic definition of structural performance requirements. This will be achieved by:

1. Identification of appropriate aero-structural modelling strategies which permit rapid analysis of static, quasi-static and transient load events on a whole aircraft model;
2. Development of an aircraft structural sizing framework which accommodates static, quasi-static and transient loading;
3. Generation of a validated framework which facilitates generic definition of structural performance requirements for a range of aircraft configurations.

II. Modelling & Analysis Framework

The modelling and analysis framework employed to incorporate transient load events in the structural design process for unconventional aircraft configurations is outlined in Figure 1.
III. Exemplar Results

Integrated aero-elastic loads models of Tube-And-Wing aircraft configurations can be generated via proprietary automated tools developed through this work, with a conventional Tube-And-Wing aircraft (Boeing 777-200LR) being used to validate the mass and stiffness distribution of the generated model (Figure 2.) The structural model is constructed from zero- and one-dimensional elements connected via splines to a two-dimensional aerodynamic (doublet-lattice) mesh.

Free-size optimisation of idealized wing, fuselage and tail structures, is performed to provide a refined mass and stiffness distribution (Table 1.) The optimization process intelligently integrates an equivalent static load approach that enables sizing of the aircraft geometry for both quasi-static (i.e. manoeuvre) and dynamic (i.e. gusts) loading, subject to maximum material stress ($\sigma_{allowable}$) constraints.

These models are used to investigate the influence of key powerplant integration parameters (i.e. engine mass, pylon stiffness) and modelling idealisation (i.e. rigid vs flexible pylon) on critical structural design loads. Figure 3
presents an example data set demonstrating how engine vertical load factor under gust loading varies depending on pylon modelling idealisation. The final paper will expand on these studies, additionally examining impact on the key aircraft structural design loads (such as wing shear force, bending moment and torsion) and optimised aircraft design.

Figure 2  Exemplar aero-elastic loads model of a conventional Tube-And-Wing aircraft configuration with a) cross-section properties visualized, and, b) aerodynamic mesh visualised.

Table 1  Objective function (mass) and max. constraint value history from free-size optimisation of structural properties for cruise gust load at t=0s. (Solution time 15mins, 33s on i7-6700 CPU (3.40GHz), 16GB RAM.)

<table>
<thead>
<tr>
<th>Iteration</th>
<th>Mass, m, kg</th>
<th>Constraint violation Max. stress ($\sigma_{max}$) – allowable stress ($\sigma_{allowable}$), MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.00E+05</td>
<td>5.79E+01</td>
</tr>
<tr>
<td>1</td>
<td>2.83E+05</td>
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</tr>
<tr>
<td>5</td>
<td>2.94E+05</td>
<td>2.01E+00</td>
</tr>
</tbody>
</table>
Figure 3  Acceleration time history of power plant centre of mass node during a gust load at cruise flight conditions for maximum aircraft mass.

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