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Short communication

Active gust load alleviation system for flexible aircraft: Mixed feedforward/feedback approach

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ABSTRACT

Lightweight flexible blended-wing-body (BWB) aircraft concept seems as a highly promising configuration for future high capacity airliners which suffers from reduced stiffness for disturbance loads such as gusts. A robust feedforward gust load alleviation system (GLAS) was developed to alleviate the gust loading. This paper focuses on designing a feedback controller which would improve the robust performance of the feedforward controller in reducing the peaks in wing root moments at very short gust lengths. The simulation results show that when the new feedback compensator is engaged with the feedforward controller, the performance of the GLAS system is improved significantly in terms of reduction in wing root moments for shorter as well as for longer gusts. This reduction in the wing root moment's peak provides potential structural benefits and weight savings.

1. Introduction

Current state-of-the-art aircraft such as Airbus A380 and Boeing 787 Dreamliner have pushed the limits of efficient conventional tube-wing configuration. As a result the aircraft designers investigate now alternative aircraft configurations such as the Blended Wing Body (BWB) concept. Several projects were undertaken in the European research programmes content such as ACFA (Active Control for Flexible Aircraft) 2020, NACRE (New Aircraft Concepts Research), VELA (Very Efficient Light Aircraft) and ROSAS (Research on Silent Aircraft Concepts) [2,18,15,7].

The transport aircraft BWB research and design efforts can be traced back to the 1980s. A comprehensive documentation of the US research efforts on the design of BWB subsonic transport aircraft, corresponding design issues and constraints, advantages and drawbacks existing with such configurations, as well as results from wind tunnel tests are presented in [17]. The research progress is demonstrated starting from a preliminary design study in 1988 for novel configurations up to the highly efficient Boeing BWB-450 baseline aircraft. Basically, three generations of BWB configurations are documented which were successively improved.

The European VELA project aimed at the development of skills, capabilities and methodologies required for the design and optimization of civil flying wing aircraft. Within VELA two baseline flying wing BWB configurations were developed [24]. The project was focused on development of aerodynamic and control derivatives and their impact on flight stability. In addition low speed tunnel tests were performed while comparing the results from the experiment with the predictions made using CAD and CFD software tools. Special setup of dynamic tests was dedicated to the validation of the effects of deflecting control surfaces and other dynamic characteristics of flying wing configurations. Optimization techniques were then applied to maximize the efficiency of these configurations, varying parameters such as chord length, twist angle and airfoil section shape [8].

Later on NACRE project was undertaken to drive the development of the key capabilities required for the improvement of the novel aircraft concepts from the experience gained in VELA. The NACRE project was broken down to mainly four work packages; first, novel aircraft concept; second, novel lifting surfaces; third, novel power plant installation and fourth, novel fuselage. The key technical achievements can be classified in two key areas: (1) Multidisciplinary Design and Analysis Capabilities for Components, which includes, (a) Open Rotor propulsion integration for noise shielding; (b) Powered Tail innovative integrated design & analysis; (c) Natural Laminar Flow wing design and transition prediction and (d) Flying wing configuration design and multidisciplinary assessment [14]. (2) Experimental Validation & Testing Techniques, which includes, (a) Rear engine integration (Aerodynamics & Noise improvement); (b) High-Energy absorption; (c) Fly-

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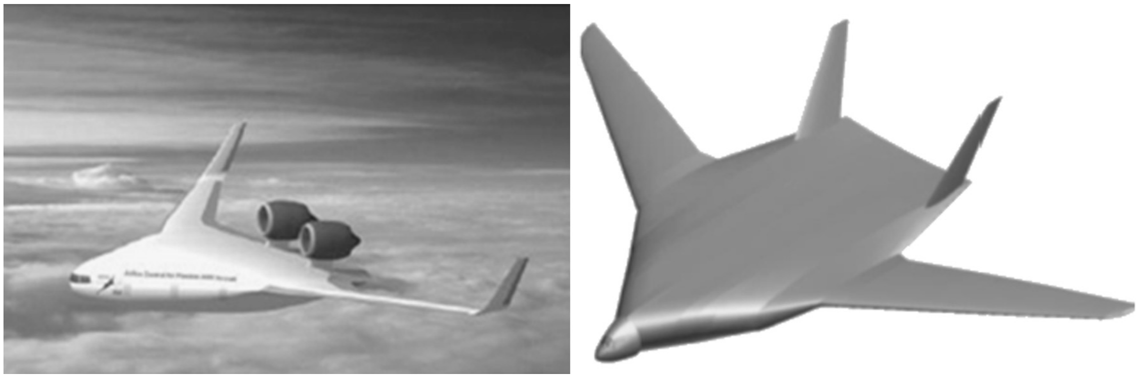

Fig. 1. Visualization of two selected BWB concepts ACFA2020 (left) [2] and NACRE (right) [3].

ing Wing cabin evacuation; (d) Innovative evaluation platform development [3,10,1].

Finally, within the ACFA2020 the predesign of a 450 passenger BWB aircraft is finalized achieving the major aircraft efficiency objectives regarding reduced fuel consumption and external noise. The project further studied robust as well as adaptive multichannel control architectures for loads alleviation and improvement of ride comfort and handling qualities of BWB type aircraft. One of the main goals of the project, however, was to investigate the system's aeroelastic properties with respect to modern control design methodologies. Thereby, the potential in structural load reduction, improving of ride comfort and attainable handling qualities were main drivers [9].

The dynamical models of the finalized BWB aircraft were developed for carrying out the controller design. The models were generated based on a refined Finite Element Model (FEM) and aerodynamic data [2]. Fig. 1 shows the two above mentioned finalized BWB concepts within the European projects.

For future high capacity airliners, the BWB concept appears to be highly promising. The aircraft configuration presents a compact lifting body with significantly increased lift-to-drag ratio with obvious environmental (lower noise level and CO_2 emissions) and economic (lower fuel consumption, reduced operational expenses) consequences [17,20,23,21]. The lightweight BWB structure suffers however from reduced stiffness compared to the classical tube-wing configuration.

This aspect of reduced stiffness is further emphasized if thin lifting surfaces and the use of composite materials for aircraft structures are considered, leading to light weight flexible structures. When this type of aircraft passes through the turbulent atmosphere, it develops significant structural vibrations. Aircraft motion of this kind results in reduction of structural lifetime due to large dynamic loads and the consequent level of stresses. The amplitude of the aircraft's structural response, caused by gust excitation depends upon two factors. First, the amount of energy transferred from the gust disturbance to the structural modes; and second, the dissipation of any energy absorbed from gust by active structural damping. In addition, when the amplitude of the response of the elastic motions is comparable to that of the rigid body motion, an interaction or coupling of the rigid body energy and the elastic energy can appear leading to detriment of the flying qualities of the aircraft [19,22].

Current Gust Load Alleviation systems work primarily on the error feedback principle [5,30,33]. The first peak in the wing root moments (induces maximum load in the construction) determines the required sizing of the wing root joint reinforcement. Potential weight savings can be realized if the reduction in wing root moments is achieved. What is of special concern is therefore the 1st peak's reduction in the wing root moments, which is regarded as non-achievable by purely feedback solution [27]. Therefore com-

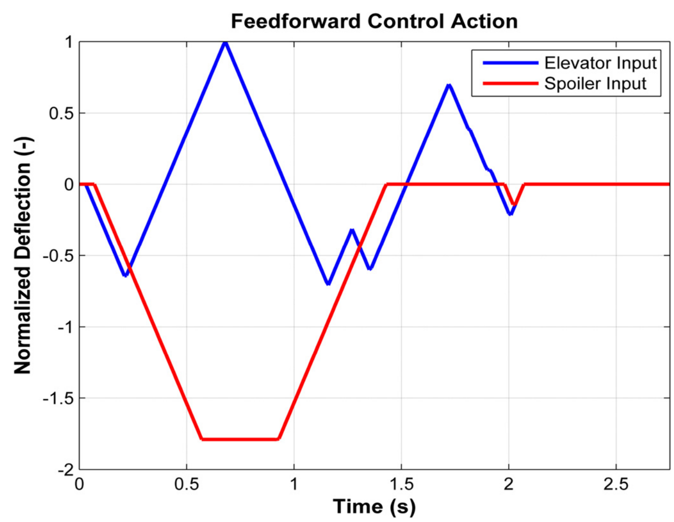

Fig. 2. Normalized feedforward control inputs [29].

bined feedforward plus feedback control can significantly minimize structural deflection due to air turbulence such as gusts [31,28]. If the sensors are placed smartly they could measure the r.m.s. (root mean square) vertical acceleration (along z-axis) at a number of locations on the aircraft. In order to precisely determine the effects of the wing bending relative to the center of gravity (CG) of the aircraft sensors are to be placed at the CG, wingtip right node and wingtip left node in principle. A related detailed treatment on optimal placement of sensors for this problematic issue is outlined in [12,16,25]. The acceleration of the wing relative to the CG is defined as η_z law (see Section 3.1) which actually gives the measure of wing bending, induced by a gust for instance.

To alleviate this gust loading, a triggered feedforward (FF) control strategy, see Fig. 2, was elaborated at EADS Innovation Works, Munich. Fig. 2 shows the normalized control signal with respect to the maximum elevator deflection. A pre-computed control sequence for ailerons and spoilers is triggered once the aircraft hits a gust, which is detected by an alpha-probe (angle-of-attack probe) placed at the node of the aircraft [29]. The pre-defined FF control sequence was designed to be robust with respect to different aircraft mass cases, altitudes, Mach numbers and gust lengths.

This FF control approach appears very efficient, according to high-fidelity simulations [29] for alleviation of the wing root bending and torsional moments for long gusts especially, which are the "sizing gusts" in fact – they produce largest impacts on the construction. However, a price paid for this are slightly increased wing root moments for shorter gusts, compared to the non-controlled