www.ijiarec.com

ISSN:2348-2079

Volume-10 Issue-1

International Journal of Intellectual Advancements and Research in Engineering Computations

Design and optimization of a tail wing using smart materials

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ABSTRACT

A load-bearing morphing skin concept to improve the aerodynamic performance of an aircraft Tail wing is proposed. The concept uses a smart material morphing upper skin coupled to a typical aluminum Tail wing structure. A three-step finite element analysis-based optimization scheme is developed using the minimization of the mass of the smart material skin as the objective function, while ensuring it best fits the target morphed aerodynamic profiles. The optimization results are further simplified to ease manufacturing. A series of analytical validations are performed to ensure the structural integrity of the morphing skin as part of the original Tail wing section subject to the design limit loads. Finally, the deformation of the skin is validated experimentally on a testbed model under 1g design limit load and several morphing conditions. The experimental results show that skin deformations are in line with the finite element analysis predictions for both the design limit loads and the target morphed shapes. This validates that the finite element analysis-based optimization procedure developed here is appropriate for the design of a morphing Tail wing section with active aerodynamic improvement capabilities, while preserving its structural integrity.

Keywords: Tail wing Structures, Morphing aircraft, Design of Morphing Tail, Piezoelectric Smart

INTRODUCTION

A tailplane, also known as a horizontal stabiliser, is a small lifting surface located on the tail (empennage) behind the main lifting surfaces of a fixed-Tail wing aircraft as well as other non-fixed-wing aircraft such as helicopters and gyroplanes. Not all fixed-wing aircraft have tailplanes. Canards, tailless and flying Tail wing aircraft have no separate tailplane, while in tail aircraft the vertical stabiliser, rudder, and the tail-plane and elevator are combined to form two diagonal surfaces . The function of the tailplane is to provide stability and control. In particular, the tailplane helps adjust for changes in position of the centre of pressure or centre of gravity caused by changes in speed and attitude, fuel consumption, or dropping cargo or payload.

The earliest forms of aviation, efforts have been made to minimize drag resulting from discontinuous flight control surfaces. The Wright brothers solved roll control using a Tail wing-warping mechanism in their first flying machine. Other remarkable historical examples are Holle's adaptive systems for modifying leading and trailing edges and Parker's variable camber Tail wing used to increase cruising speed by continuously varying the geometrical Tail wing characteristics by means of a proper arrangement of the internal structure.

Since that time, the idea of creating motion using flexible structures became unreasonable from the viewpoint of engineering design since engineering practice gradually tried to avoid flexibility, and many systems were designed to be rigid. Traditional metals, such as aluminum, stainless steel, and titanium, dominated the aerospace industry for over fifty years, as they were considered lightweight, inexpensive, and state-of-the-art. Meanwhile, the interest in cost-effective fuel-efficient aircraft technologies increased gradually, and metals started ceding territory to new alloys and composite materials designed to offer lighter weight, greater strength, better corrosion resistance, and reduced assembly and manufacturing costs. Once only considered for noncritical interior cabin components, composite materials are now occupying the space of traditional materials for a wide range of aircraft components, including Tail wing, fuselage, landing gear, and engine.

An optimization procedure for the shape design of morphing aircraft is presented. The process is coupled with a knowledge-based framework combining parametric geometry representation, multidisciplinary modelling, and genetic algorithm. The parameterization method exploits the implicit properties of the Bernstein polynomial least squares fitting to allow both local and global shape control. The framework is able to introduce morphing shape changes in a feasible way, taking into account the presence of structural parts, such as the Tail wing-box, the physical behaviour of the morphing skins, and the effects that these modifications have on the aerodynamic performances. It inherits CAD capabilities of generating 3D deformed morphing shapes and it is able to automatically produce aerodynamic and structural models linked to the same parametric geometry. Dedicated crossover and mutation strategies are used to allow the parametric framework to be efficiently incorporated into the genetic algorithm. This procedure is applied to the shape design of Reference Aircraft (RA) and to the assessment of the potential benefits that morphing devices can bring in terms of aircraft performances. It is adopted for the design of a variable camber morphing Tail wing to investigate the effect of conformal leading and trailing edge control surfaces. Results concerning four different morphing configurations are reported.

Title- Aerodynamic Performance Optimization of Smart Tail wing Using SMA Actuator
Author-Dileep E.1 , Nebish M.2 and Loganathan V.3
Year-2013

Airplanes found today in commercial, private or military use possess fix Tail wings that allow them to fly. The different shapes of Tail wings, camber angles, textures among other characteristics gives the aircraft its own aerodynamic properties. These properties allow the aircraft to fulfill the specific task for which it was intended. However, new technology and development has pushed forward the idea of a Tail wing that could have different aerodynamics properties by changing its form and shape. This would make it able to adapt itself to different flight conditions.

Titles-Investigation of Smart Material Actuators & Aerodynamic optimization of Morphing Tail wing
Author-Musavir Bashir, Debashish Smrutiranjan, Chirag Sharma
Year-2018

Description

The design of Tail wing s in traditional aircraft creates a configuration with optimal performance but that suits to a single flight condition only. As the vehicle moves away from the given condition performance too declines thereof. Conversely, birds can adopt their Tail wing profile to augment the performance at a wide range of flight conditions. Morphing technology offers aerodynamic proficiency over a wide range of flight conditions, and the key to enable this technology for adaptive structures is based on smart materials and actuators.

METHODOLOGY

The advantages of a morphing aircraft are based on an assumption that the additional weight of the morphing components is acceptable. Traditional mechanical and hydraulic systems are not considered good choices for morphing aircraft. “Smart” materials and structures have the advantages of high energy density, ease of control, variable stiffness, and the ability to tolerate large amounts of strain. These characteristics offer researchers and designers new possibilities for designing morphing aircraft. In this article, recent developments in the application of smart materials and structures to morphing aircraft are reviewed. Specifically, four categories of applications are discussed: actuators, sensors, controllers, and structures.

Piezoelectric Smart Structures

Smart structures are those equipped with sensors/actuators made of smart materials, which have the capability to control structure movement in such a way that makes the design more efficient. However, due to systematic complexity and multidisciplinary objectives, the optimization design of such structures in accurate shape control becomes very challenging. This paper proposes an integrated layout and topology optimization design method for accurate shape control of smart structures with surface bonded piezoelectric actuators.

The multi-point constraints (MPC) method is used to simulate the bonding connections between movable piezoelectric actuators and host supporting structures. A new weighted shape error function based on desired deflections of observation points is defined to fulfill accurate shape control of piezoelectric smart structure. Through the proposed method, the optimal position and orientation of each piezoelectric actuator as well as the topology configuration of host supporting structure are founded, which significantly improves the systematic actuating and morphing performance of piezoelectric smart structures. Further studies on the relationships of structural stiffness with shape morphing constraint and volume fraction constraint are carried out, and distortions of load carrying path in optimized designs are illustrated. With several numerical results, the proposed integrated optimization method is proved to be an efficient way to decrease the error between computed and desired surface and achieve the accurate shape control of piezoelectric smart structures.

METRIALS AND METHODS

1.Lead zirconate Titanate
2.Polyvinylidene Flouride
3.Quartz
4.Zinc Oxide
5.Barium Titanate

Tailplane types

The tailplane comprises the tail-mounted fixed horizontal stabiliser and movable elevator. Besides its planform, it is characterised by:

- Number of tailplanes - from 0 (tailless or canard) to 3 (Roe triplane)
- Location of tailplane - mounted high, mid or low on the fuselage, fin or tail booms.
- Fixed stabiliser and movable elevator surfaces, or a single combined stabilator or *(all) flying tail*.[1] (General Dynamics F-111 Aardvark)

Stability

A Tail wing with a conventional aerofoil profile makes a negative contribution to longitudinal stability. This means that any disturbance (such as a gust) which raises the nose produces a nose-up pitching moment which tends to raise the nose further. With the same disturbance, the presence of a tailplane produces a restoring nose-down pitching moment, which may counteract the natural instability of the Tail wing and make the aircraft longitudinally stable (in much the same way a weather vane always points into the wind

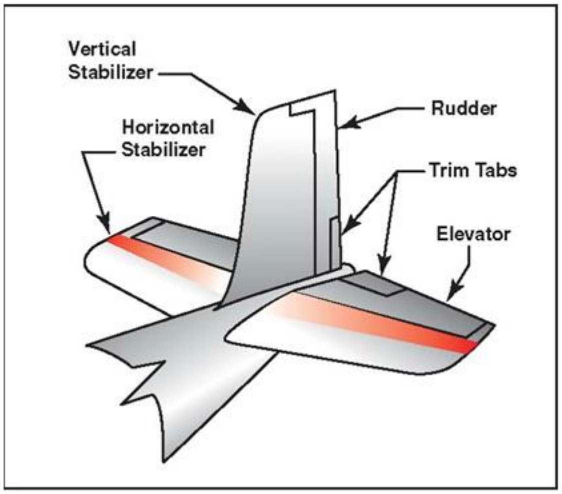

Fig 1: Empennage components.

Analysis

Extensive wind tunnel tests were performed on several Tail wing - body-tail combinations in subsonic flow to study the effects of Tail wing geometric parameters on the flow field over the tail. For each configuration, tail surface pressure distribution, as well as the velocity contour at a plane perpendicular to the flow direction behind the Tail wing was measured. The results show a strong effect of Tail wing to tail span ratio, as well as Tail wing aspect ratio, on the flow field downstream of the Tail wing. For low sweep Tail wings, as those considered here, Tail wing and body interference effects on the tail are associated with the Tail wing tip vortex and nose-body vortex.

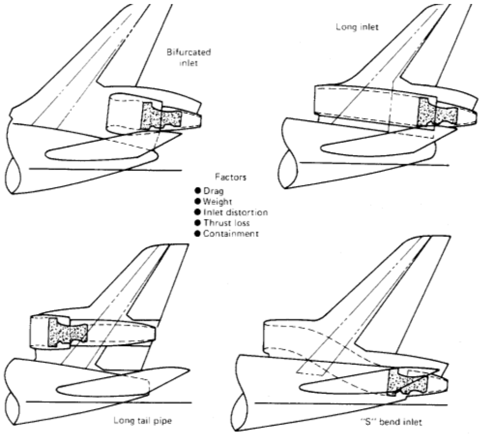

Fig 2: Surface pressure distribution on body–tail alone configuration

Advantages

The tailplane is often out of the disturbed airflow behind the wing and fuselage, giving smoother airflow over the elevators, which reduces drag. This configuration may reduce pitch control effectiveness if the elevators are outside the propeller slipstream, or improve it for many transsonic aircraft because it isn't in disturbed air behind the fuselage, particularly at moderate angles of attack.

An aircraft with a T-tail may be easier to recover from a spin, as the elevator is not in a position to block airflow over the rudder, which would make it ineffective, as can happen if the horizontal tail is directly below the fin and rudder.

The T-tail increases the effective aspect ratio of the fin because of 'end plate' effect, where proximity of a perpendicular surface (the horizontal tail and the fuselage in this case) improve aerodynamic efficiency because of reduced air pressure losses over the capped ends of the lifting surface, which in turn provides the same effect of the fin having a higher and more efficient aspect ratio.

Tail Design and Sizing

Tail wing design

Tail surfaces are used to both stabilize the aircraft and provide control moments needed for maneuver and trim. Because these surfaces add wetted area and structural weight they are often sized to be as small as possible. Although in some cases this is not optimal, the tail is general sized based on the required control power as described in other sections of this chapter. However, before this analysis can be undertaken, several configuration decisions are needed. This section discusses some of the considerations involved in tail configuration selection.

The conventional configuration with a low horizontal tail is a natural choice since roots of both horizontal and vertical surfaces are conveniently attached directly to the fuselage. In this design, the effectiveness of the vertical tail is large because interference with the fuselage and horizontal tail increase its effective aspect ratio. Large areas of the tails are affected by the converging fuselage flow, however, which can reduce the local dynamic pressure.

A T-tail is often chosen to move the horizontal tail away from engine exhaust and to reduce aerodynamic interference. The vertical tail is quite effective, being 'end-plated' on one side by the fuselage and on the other by the horizontal tail. By mounting the horizontal tail at the end of a swept vertical, the tail length of the horizontal can be increased. This is especially important for short-coupled designs such as business jets. The disadvantages of this arrangement include higher vertical fin loads, potential flutter difficulties, and problems associated with deep-stall.

Tail Sizing

Horizontal tails are generally used to provide trim and control over a range of conditions. Typical conditions over which tail control power may be critical and which sometimes determine the required tail size include: take-off rotation (with or without ice), approach trim and nose-down acceleration near stall. Many tail surfaces are normally loaded downward in cruise. For some commercial aircraft the tail download can be as much as 5% of the aircraft weight. As stability requirements are relaxed with the application of active controls, the size of the tail surface and/or the magnitude of tail download can be reduced. Actual tail sizing involves a number of constraints that are often summarized on a plot called a scissors curve. An example is shown below.

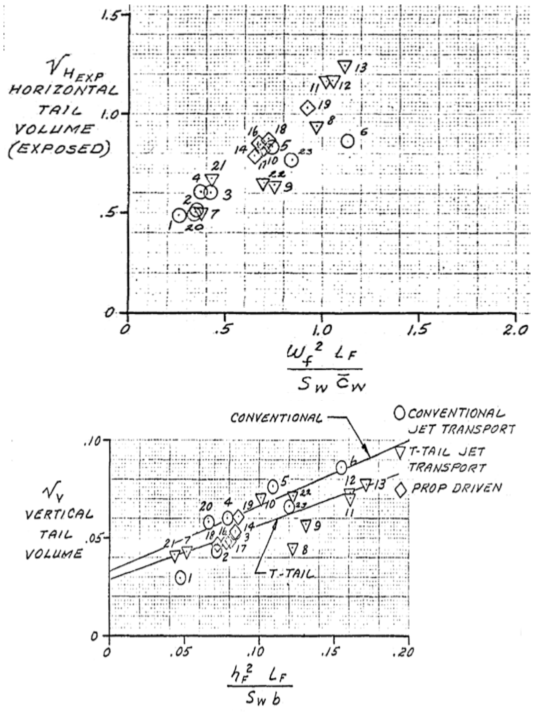

Fig 3: Tail design and sizing

CONCLUSION

Extensive wind tunnel tests were conducted on several Tail wing –tail combinations to study the effects of Tail wing geometric parameters on the flow field over the tail. The results show that, no matter what the Tail wing geometry is, the flow over the tail is deteriorated by the presence of the Tail wing at low angles of attack, where the flow over the tail alone configuration is completely attached. At high angles of attack, where the tail alone flow separates from the surface, the vortices developed on Tail wing and body re-attach the separated flow and enhance tail effectiveness at high incidence. However, the way the Tail wing and body vortices affect tail flow strongly depends on Tail wing geometry. The present results reveal that two factors are responsible for Tail wing – tail interactions; Tail wing tip/leading edge vortex and nose/body vortex. Tail wing tip vortex effects appear on the tail outboard position, extending in the span wise direction, while the body vortex signature on the tail is mostly concentrated on the tail inboard position and extends in the chord wise direction. The Tail wing aspect ratio is a dominant factor on tail flow; for low aspect ratio Tail wing s, the Tail wing tip/leading edge vortex signature at high angles of attack can be clearly seen on the tail outboard with the small effect of body vortex on the inboard section of the tail. For a Tail wing aspect ratio of unity, Tail wing tip vortex effects on the tail are not so important, and the dominant factor is the body vortex, which appears at the tail inboard extending in the chord wise direction.

Feature Enhancement

This paper presents the flutter analyses of the WISE aircraft using MSC Nastran. The analyses were carried out to the V-tail, one of the component where flutter might occur, by assuming rigid fuselage. Results of each analysis, in the form of velocity-damping and velocity-frequency curves, were evaluated to determine the critical flutter speed and frequency. First the analysis were conducted for sea level operation using KE, PK and PKNL methods which predict respectively the flutter speed of 1036 knot, 1037 knot, and 1037 knot. The three methods also consistently predict that the mode shapes involved in the flutter are the 5th mode and the 3rd mode. Then by using the PK-method, the analysis were repeated for air density variation. It is shown that the lower the air density, the higher the flutter speed is. It is concluded that tail flutter does not occur during the operation of the WISE craft with max operating speed of 80 knot.

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