APPLICATION OF A MAGNETORHEOLOGICAL FLUID TO THE AIRCRAFT WING

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The potential application of smart materials is being investigated by various researchers in the perspective of building intelligent systems. The main goal of this paper is a novel approach which will allow to gain new knowledge about the application of a magnetorheological fluid to the aircraft wing. Magnetorheological fluids, beside ferromagnetic and electrorheological fluids, belong to the non-Newtonian rheostable fluids, which are characterized by a yield point.

K e y w o r d s: smart material, magnetorheological fluid, vibration, aircraft wing, morphing.

1 INTRODUCTION

All structures vibrate to some extent. Usually in aerospace, robotics and automotive structures this vibration is not wanted and can lead to catastrophic failure. This failure may arise in the long term due to fatigue causing cracks, or it may occur quickly due to the material not being able to cope with the material stresses from the large amplitude displacement. Even if failure does not occur the resulting noise and vibration is often unpleasant, and certainly not a desirable feature in a consumer product. The aerospace industry is also eager to incorporate intelligent materials technology. More profound changes are looming in aerospace design based on smart materials. Many “smart” materials were invented more than 30 years ago, but their development and improvement over the past three decades has led to new, more varied uses of these adaptable materials. Smart materials have properties that can be altered by temperature, moisture, electric or magnetic fields, pH, and stress. Control of vibration and flutter plays an important role in the satisfactory performance of many aero-mechanical systems such as aircraft wings, helicopter rotors, propellers of a turbo-prop engines, or compressor and rotors of jet engines. With advances in active materials, it has become possible to integrate sensing, actuation, and control of vibration and flutter intrinsically in the design of the structure [5], [6].

In the past few decades, interest in morphing structures has increased due to the superior benefits they can provide. A structure that can change its geometric characteristics and tune its properties (stiffness and damping) to meet the mission’s requirements or different load conditions is appealing. Since the shape of an aircraft strongly affects its performance and flight dynamics, morphing technologies have always been investigated by the Aerospace industry. In particular the wings are mainly responsible for the aerodynamics loads acting on typical aircrafts in terms of lift and drag. The design of a morphing aircraft by means of smart materials is a problem that involves different disciplines. Morphing can be achieved by the use of motors or complex mechanism distributed through the wing [1], [2].

In the field of a smart technology and control structures designed for airlines, which merged into a common system will form a novel structural element, designed to improve the functional characteristics of objects flying through the interaction with the center, in which the movement takes place. The newly developed structural element, forming a structure analogous to mechatronics - a synergistic combination of control, innovative design solutions and materials, will use material and magneto-classical system is not the executive. The functional to be used as an element of the wing flaps, and its role may involve both an increase in the lift or reduce drag forces as well as influencing the active aerodynamics to reduce adverse effects such as flutter and excessive vibration and load structures, noise accompanying movement or mitigate the loss of energy necessary to move an aircraft [1], [2].

The main goal of this paper is a novel approach which will allow to gain new knowledge about the application of a magnetorheological fluid to the aircraft wing. The authors of this paper hope to do a new trend in aviation engineering thanks an application of a magnetorheological fluid in aircraft structure/ skin.

2 MAGNETORHEOLOGICAL FLUID

The increasing demands on the performance of structural systems for aeronautical and astronautical applications require a new class of structural systems. So called smart/adaptive/intelligent structures are an evolution from the composite structural materials. Piezoceramics, magnetostrictive materials, electrostrictive materials, shape memory alloys, electro-rheological and magneto-rheological fluids are families of active materials that are potentially being considered to use. These materials are essentially transformers that convert electrical or electromagnetic energy into mechanical energy and vice versa. Magnetorheological (MR) fluids, beside ferromagnetic and electrorheological fluids, belong to the non-Newtonian rheostable fluids, which are characterized by a yield point. Magnetic, ferromagnetic and electrorheological fluids are colloidal suspension of microscopic solids in the liquid carrier, and their main characteristic is rapid grouping of particles into a dense grid under the influence of an external stimulus [1].

MR fluids are composed of ferromagnetic particles of a magnetic material with a diameter of several micrometers (from 0,5 [μm] to 0,8 [μm]) and liquid carrier of low viscosity, about 0,2÷0,3 [Pa·s] [4]. Ferromagnetic particles of an MR fluid are additionally covered with a special layer enhancing their magnetic susceptibility and reducing their tendency to form aggregations. Other substances, including anti-corrosion and anti-sedimentation substances, are also added in small amount [3].

The influence of a magnetic field causes changes in physical properties of an MR fluid, and to quote one of the commonly accepted hypothesis, the molecules attract each other and combine into chains along the lines of magnetic force. Within few milliseconds there appears an increase in viscosity and stress value reaches its limit, below which the material behaves elastically. It is a reversible process. After the disappearance of an external magnetic field the liquid returns to its baseline. Changes under the influence of a magnetic field appear in less than 10 milliseconds. Magnetorheological fluids retain their properties in the temperature range of –40÷150 [°C], while the yield point value for these liquids is in the range of 50÷100 [kPa] [3].

3 CONCEPTUAL DEVELOPMENT OF SMART WING/ SKIN

The current use of multiple aerodynamics devices (such as flaps and slats) represents a simplification of the general idea behind morphing. Traditional control systems (with fixed geometry and / or location) give high aerodynamic performance over a fixed range and for a limited set of flight conditions. Outside of this range, these traditional systems can be neutral or negatively influence the aerodynamics and hence often give lower efficiency. Conventional hinged mechanisms are effective in controlling the airflow, but they are not efficient, as the hinges and other junctions usually create discontinuities in the surface, resulting in unwanted fluid dynamics phenomena [1], [2].

The intelligent structures are those which incorporate actuators and sensors that are highly integrated into the structure and have structural functionality as well as control logic, signal conditioning, and power amplification electronics. In an active (feedback) control, the strain developed in signal-conditioned and used for feedback control employing suitable control laws. The active control strategy for smart structure can be broadly classified as state-space control and distributed parameters control. A key challenge in developing a one dimensional morphing structure is the development of a useful morphing skin, defined here as a continuous layer of material that would stretch over the morphing structure and mechanism to form a smooth aerodynamics skin surface. Due to the large geometrical changes required for a span-morphing wingtip as envisioned here, metal or resin-matrix-composite skin material are suitable [1], [2].

Magnetorheological (MR) skin materials is a new development for morphing aircraft concepts created by authors of this paper. There may at first glance seem highly suited to a span-morphing wingtip: elastometric materials are ideal candidates for a morphing skin. The present research therefore focuses on the development of a magnetorehological skin with potential for use in a 1-D morphing wingtip.

The primary challenge in developing a morphing skin suitable as an aerodynamical surface is in balancing the competing goals of low in-plane actuation requirements must be low enough that a reasonable actuation system within the aircraft can stretch the skin to the desired shape and hold it for the required morphing duration. At the same time, the skin must withstand typical aerodynamics loads without deforming excessively (e.g., rippling or bowing), which would result in degradation to the aerodynamics characteristics of the aerofoil surface.

The primary phase of the morphing skin development will be fabricate the magnetorehological material that would make up the skin or face sheet. Initially, a large number of rubber will be tested for viability with a magnetorheological fluid as a smart material. A large number of silicone elastomers will be tested for viability as matrix material. Desired properties included maximum elongation well over 100%, a low stiffness to minimize actuation forces, moderate durometer to avoid having too soft a skin surface, and good working properties. Workability became a primary challenge to be overcome, as two-part elastomers with high viscosities or very shot work times would fully wet out the carbon fibre layer.

The most challenging aspect of the morphing skin to design will be the substructure. Structural requirements necessitated high out-of-plane stiffness to help support the aerodynamic pressure load while still maintaining low in-plane stiffness and high strain capability.

Recent developments in smart materials may overcome these limitations and enhance the benefits from similar design solutions. The design of a morphing aircraft by means of smart materials is a multidisciplinary problem. The challenge is to design a structure that is capable of withstanding not only the prescribed loads, but also to change its shape in order to withstand several load conditions. In order to reduce the complexity and hence increase the reliability, the actuation system, consisting of active materials, should be embedded in the structure.

Wing shape-changing concepts require actuators attached to internal mechanisms, covered with flexible/ sliding aerodynamics surfaces, together with load-transfer attachments between the skin and the skeleton. This requires a distributed array of actuators, mechanisms, and materials that slide relative to each other or skin materials that stretch. Mechanism design requirements include the range of motion, concerns about binding and friction, the effects of wing structural deformability under load, and the control of the actuator stroke under load. Actuator performance power and actuator force capability are essential to design success. The size, weight, and volume of the actuators are important metrics, as are the range of motion, bandwidth, and fail-safe behaviour. Locking is important when the wing is under load since, without locking features, the actuators must withstand full load unless the actuator works in parallel with the structural element. Morphing design may also benefit from geometrically flexible structures if the aeroelastic energy from the airstream can be used to activate the shape changing and tabs can maintain thee shape using aeroelastic control. The wealth of new technologies available to the wing designer provides intriguing design possibilities. Internal control and the strategy used to move from one wing form to another is also an important design goal.

Using an adaptive wing, whose geometry varies according to changing external aerodynamics loads, the airflow in each part of the aircraft mission profile may be optimized, resulting in an increase of aerodynamic performance during cruise.

For flight control, the system should exhibit the following main characteristics:
-relatively fast dynamics in order to allow prompt response to inputs from the remote pilot or autonomous control system. In this way, the morphing system can also be used to counteract random disturbances: for instance gusts can be particularly severe flying between buildings or closed spaces;
-capability to operate over a wide range of flight conditions, like flight speed, air temperature, and wind;
-capability of high recoverable strains;
-capability of repetitive actuators;
-low power consumption;
-high reliability, since malfunctioning may cause the loss of the aircraft.

In order to meet the above requirements and to keep the design as simple as possible, avoiding the use of sophisticated kinematics, the smart material should respond quickly to the external stimuli, should be capable of large and recoverable free strains, ideally not affected by fatigue issues, and effective in transforming the input energy into mechanical energy. The ability to work under different conditions also implies that the morphing system has to be fully controllable: ideally all the positions, between the undeformed and the fully deflected, should be reachable in order to perform different maneuvers and to counteract random disturbances. The low power consumption requirement should take into account the fact that part of the structure needs to be deformed, and the contribution of the elastic energy may be considerable with respect to the aerodynamic work.

4 CONCLUSION

In this paper, the new proposition for smart skin has been given. The concept, which seems more appropriate to meet the flight control requirements, consists of a complaint deformable trailing edge with smart material embedded into the skin.

This work explored the development of a continuous one dimensional morphing structure. For an aircraft, continuous morphing wing surfaces have the capability to improve efficiency in multiple flight regimes. However, material limitations and excessive complexity have generally prevented morphing concepts from being practical.

The research in the area of smart materials and adaptive structures has huge potential to make substantial contributions in enhancing performance, reliability of aero-mechanical systems. Significant advances have been made in the field of magnetorheological materials, in formulating techniques for modelling, simulation, health monitoring, and control of complex systems. This is a good time to start a new trend in the aviation engineering using magnetorheological fluids/ skins.

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