Design and Modelling of Spanwise Adaptive Wings for a Reconfigurable VTOL

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***Abstract*—This paper presents a novel concept and working mechanism of spanwise adaptive wings for an unmanned aircraft. The compact design of wings in the retracted configuration with a high degree of maneuverability enables the vehicle to fit in between narrow streets and confined spaces, whereas wings in extended configuration provide better gliding capability and higher (stall limits) maximum speed wherever required.**

The detailed trade studies of the spanwise adaptive wings and its mechanism has been performed. The mechanism and wing used shows improvement in reconfiguration time, robustness and technical maturity. Deployment procedure used enables a smooth and quick transition of wings. The concept design presented in the paper can be implemented with existing manufacturing expertise.

The proposed system boasts to have better performance and efficiency in terms of fuel and power requirement. With the goal to proffer a fast and compact system, this design serves as the panacea.

Keywords- deployment mechanism, reconfiguration time, spanwise adaptive wings

I. Introduction

The helicopter's high degrees of maneuverability and hover capabilities are undeniably important performance features in today's domestic and international security environment. While able to hover for hours depending on fuel levels, conventional helicopters are limited by the rotors aerodynamics to a limited top speed. On the other hand, fixed-wing planes can reach much faster speeds, but are unable to hover with a great degree of efficiency. The challenge is to merge the maneuverability desired for hover capabilities and the aerodynamics necessary to achieve greater speeds 'without unacceptable compromises in range, efficiency, useful payload or simplicity of design'.

The virtual missions created to benchmark the system include surveillance inside a city, supply drop inside a city for disaster relief management and rural operations.

The current best alternative able to perform such critical operations is the use of remotely controlled quadcopters. Though they are highly maneuverable with the greater degree of freedoms, they remain futile for the long ranged operations. Being unable to achieve higher speeds and relatively lesser efficiency with respect to the fuel required and thrust produced, it served as a benchmark and inspiration to design a compact VTOL exploitable for long ranged operations as well.

This is certainly not very first attempt of designing such a reconfigurable VTOL. The science behind this has been emerging since the dawn of world war 2. Some of the most recent examples of such VTOLs include *Harrier* and *F-35*, though all have some drawbacks making them unfit for the aforementioned operations. The compact structure with highly efficient forward flight and enduring hovering capability is designed to best suit such operations [1].

II. Background Study

The need for minimizing the weight of wing group requires a novel configuration of spanwise adaptive wings. To achieve this, various possible alternatives were considered which are inflating wings, folding and unfolding truss wings, variable sweep wings, retracting torque box design and tensairity structures wings.

A. Inflatable Wings

An inflatable wing is designed such that constant internal wing pressure is required to maintain wing shape. High stiffness is achieved with low inflation pressure by maximizing the inflated sectional moment of inertia [2]. Since the wing is constructed of a flexible fabric material, it can be stowed by folding or rolling. The outer wing (restraint) and internal baffles are constructed from high strength fibers such as Kevlar [3]. The skeleton of the wing is made of inflatable tubes, surrounded with crushable foam to provide the airfoil cross-section. The flexibility of the Inflatable Wing gives them the capability to recover from gusts and crashes. Also, it gives an opportunity to actively morph the wing for control. However, due to this flexibility either high pressure, thick wings, low aspect ratio or a combination of these factors is necessary to get enough stiffness for a certain load capability. Since wing stiffness is a function of inflation pressure, and thus aero-elastic behavior is a concern. It also means that any leak, however small, will result in the rapid depressurization of the wing and loss of structural integrity.

B. *Folding Wings*

Folding and unfolding wing structure design consists of *Primary* and *Secondary* wing structure in which *Secondary* or *Extendable* structure is connected to primary through a hinged juncture [4]. Of the many retractable wings known to the art, none have been found to be practical enough for adaptation. The main reason for this being in the structural weaknesses that existed at the junctures of the main wing or body and the secondary wing. To overcome the weaknesses materials can be strengthened with braces but the additional braces and structure are complex or heavy. Major issues with folding and unfolding wings are to provide a retractable airplane wing which is rigid, sturdy and yet light in weight. Another major challenge is to provide a means which would engage or lock the main wing and the secondary wing together such that it forms a substantially rigid structure without having abrupt ends, irregular surfaces or protrusions which would interfere with the normal air stream encountered at high speeds. Moreover, the ability to fold wings in flight is dependent on heavy and bulky conventional motors and hydraulic systems, which can be cumbersome to the aircraft.

C. *Variable-Sweep Wing*

A variable-sweep wing or swing wing is an airplane wing or set of wings, that may be swept back and then returned to its original position during flight [5]. It allows the aircraft's shape to be modified in flight and is, therefore, an example of a variable-geometry aircraft. While variable-sweep provides many advantages, particularly in the reduction of drag, compactness of structure, load-carrying ability, and the fast, low-level penetration role, the configuration imposes a considerable penalty in weight and mechanical complexity. Also, the swing mechanism itself takes up too much space inside the wing. The box of the swing wing is also heavy to carry, slower to rise or turn.

D. *Tensairity Structure Wing*

The basic principle of tensairity is to use an inflatable structure to stabilize conventional compression and tension elements. It combines an airbeam with conventional cables and struts to improve the load-bearing capacity of inflatable structures [6]. The weight of a tensairity structure is comparable to an optimized truss structure and much lighter than a simple inflatable structure for slenderness values typical in wings. Experimental tests confirm that the stiffness is much higher in tensairity compared to a corresponding conventional inflatable structure with the same internal pressure. The increased stiffness can be used to increase the span, for better performance or to increase the load bearing capacity of the wing. The lower pressure has consequences for the weight (use of lighter and cheaper materials) and the survivability. In case of a leakage it is much easier to compensate the air leakage with a small integrated pump, while still keeping structural rigidity. Since the rigid elements are placed inside the wing and thus protected by an air cushion, the tensairity wing has a good crash resistance. The ability to flex under gusts and overloads of a tensairity wing is slightly less compared to a normal inflatable wing due to the presence of the rigid compression elements.

III. Selection Method: Weighted Matrix

From analysis, 15 wing design criteria were identified and defined. The list was evaluated and the top 10 criteria were analyzed for various possible configurations using the weighted matrix method as shown in Table 1. The configurations are rated out of 5 for each criterion [7].

Table 1: Weighted decision matrix showing the various configurations ranked against the design criteria.

IV. Design Details

The proposed design of spanwise adaptive wings attempts to provide the forward flight speed equivalent to fixed-wing planes. The challenge is to reduce the weight of the wing along with increasing the range and maximum forward flight speed. The design methodology is focused on:

1. Reducing the gross takeoff weight
2. Reducing the power requirement in hover especially
3. Maximizing the forward flight speed
4. Maximizing the cruise range.

Fully retracted wings in hover configuration produce a minimum download due to the airwash of rotors [8]. During the transition, the wings are designed to have a larger span of thus giving a larger lift and stall limit at lower speeds. Such a span also provides the gliding ability for the long-range operations. The wing can be retracted back from fully extended configuration to support fast forward speed and is helpful in achieving maximum dash speed [9].

Wingspan is varied using a retracting torque box and skin covering of Vectran™. Wings are retracted in hover configuration while having the completely extended span in forward flight configuration.

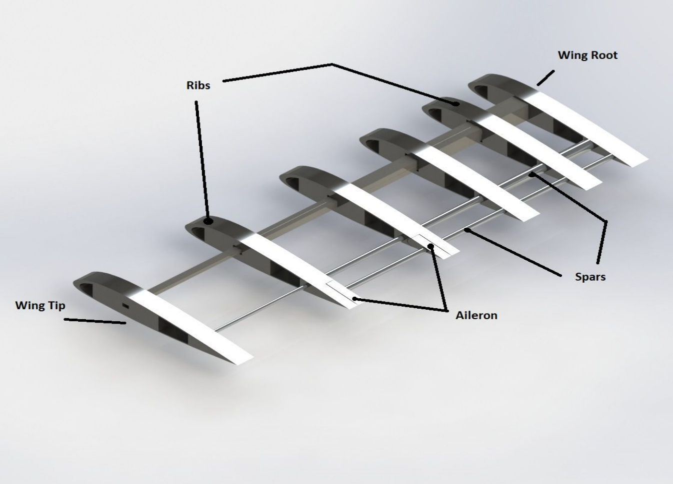

Figure 1: Retractable antenna like torque box along with rib structure of wing

The wing is mainly comprised of a single torque box, which is manufactured to run the length of the wingspan as shown in Figure 1. The torque box provides the necessary stiffness to prevent the whirl flutter instabilities, as well as to support all of the anticipated aerodynamic and structural loads during normal flight operations. A graphite-epoxy composite material is used for the construction of the torque box and ribs as it meets the high material stiffness requirements of the design while reducing the weight at the same time. Skin covering of wing structure is made up of Vectran™ [10]. Vectran™ is a high-performance multifilament yarn spun from liquid crystal polymer (LCP). It is the only commercially available melt-spun LCP fiber. Vectran™ fiber exhibits exceptional strength and rigidity. Figure 2 shows wings are made up of fabric kind material. So, to prevent sagging of fabric between the ribs, a pressure of 185-200 kPa is maintained inside the wing. To maintain this pressure the engine bleed air is used.

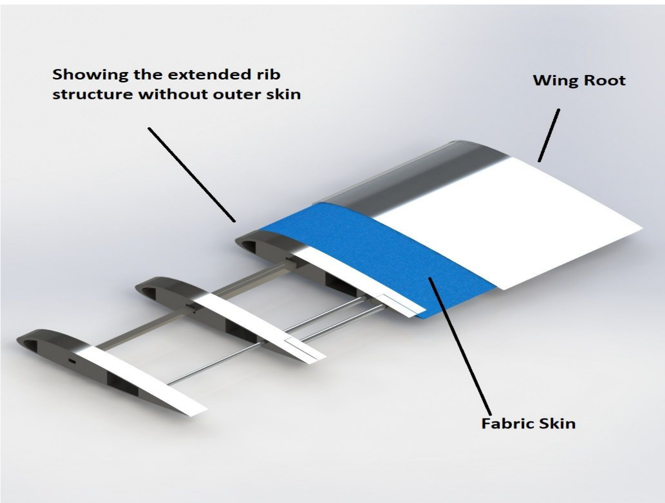

Figure 2: Internal rib structure of wing along with fabric (Vectran™) skin covering

V. Retraction Mechanism

A mechanical system is disclosed to deploy the antenna- like structure in wing's torque box and variable length rotor blade. Figure 3 shows a series of telescoping tubes nested one within the other when the antenna is in a retracted stowed position. The outermost tube is rigidly attached to the support and the inner tubes are latched in the stowed position by a caging mechanism. The antenna is driven toward a deployed position by a dual motor driven cable which is terminated in a driving tube at the lower end of the innermost tube, from whence the cable is trained about pulleys at the tops and bottoms of successively large tubes of the antenna. The cable is wound on a drum at the lower end of the antenna and coaxial therewith. During deployment of the antenna, the drum rotates, thereby reeling in the deployment cable. The initial movement of the cable causes cam releasing of the latches in the caging device. Thereafter, the antenna tubes are extended until the final deployed position of the antenna is reached. A ratchet attached to the drum shown in Figure 4 prevents reverse rotation of the drum and locks the antenna in the deployed position until the ratchet is released [11].

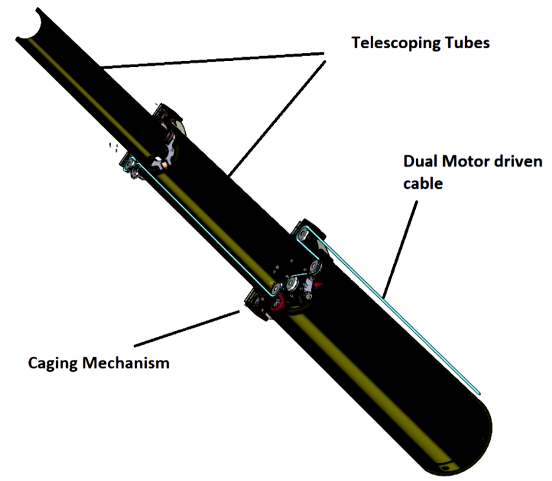

Figure 3: Extended telescopes in antenna-type retracting mechanism

The vehicle is able to reconfigure on its own using components which remain onboard the aircraft at all times. The reconfiguration is reversible and can be executed multiple times without external support as and when required.

To change the hover configuration to forward flight configuration, the wings are completely extended to the maximum span. As the vehicle gains forward speed, wings produce sufficient enough lift to sustain the forward flight without any other upward thrust providing source.

When it is required to change the vehicle from forward flight configuration to hover configuration, wings are retracted back to minimum span to provide maneuverability in hover configuration.

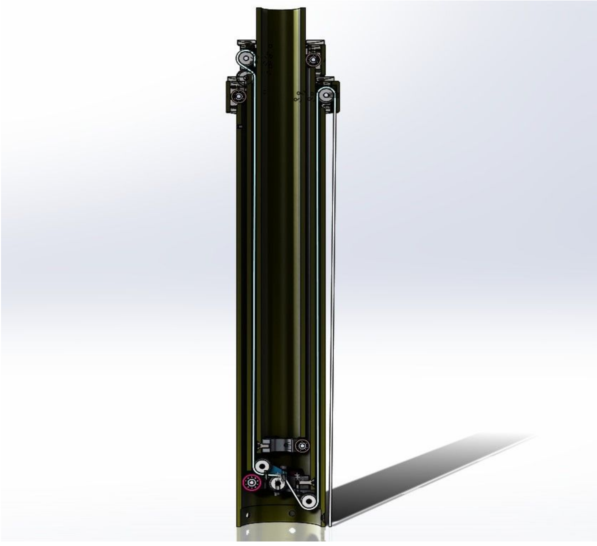

Figure 4: Retracting mechanism components inside the torque box

Wings are made up of fabric kind material so as to prevent sagging of fabric between the ribs a pressure of 185-200 KPa is maintained inside the wing. To maintain this pressure turboshaft engine bleed air can be used. The bleed air from the compressor is carried to the wing. After reaching the required pressure the valve carrying the bleed air is closed. A nitrous oxide cylinder can also be considered if engine bleed extraction is not possible in some specific engine but the cylinder does not allow the wing to be inflated and deflated multiple times.

Any minute control requirements during the lower speed phase of the transition can be handled by the swashplate mechanism of the rotor or turbojets while the control surfaces handle control during the higher speed phases of the transition.

VI. Conclusion

The presented innovative spanwise adaptive wings mechanism can provide compactness and reduce the downwash area in hover configuration while providing the same efficiency in forward flight as that of fixed wing planes. Inflating the wing with internal structure reduces weight and vibrations too. This mechanism can prove to be revolutionary for reconfigurable VTOL Aircrafts.

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