

Experimental In-Flight Rolling MAV Wing Deployment and Aerodynamic Characterization

2011-01-2648

Published
10/18/2011

Peter Coffin, Goodarz Ahmadi, Ratneshwar Jha and Piergiorgio Marzocca
Clarkson University

Copyright © 2011 SAE International

doi:10.4271/2011-01-2648

ABSTRACT

The deployment dynamics of a tape-spring style, folding MAV wing in flight are complicated and an investigation is made using wind tunnel testing. High speed photography is used to characterize the deployment motion of the wing while a force balance records six-axis aerodynamic loading of the model. An in-flight deployment of a folding wing would be advantageous after an autonomous tube launch, however the dynamics are potentially problematic due to buckling. Steady state aerodynamics of prototype tube-launch MAVs are characterized for both rigid body and compliant, rolling wings. Aerodynamic phenomena associated with the significant relative body size are identified. Wing deployments are demonstrated at four different angles-of-attack at single velocity, while an extreme case deployment is shown at a high velocity. Two-piece cylindrical shells are used to retain the wing prior to deployment and are released by hot-wire cutting of retaining lines. Three phenomena leading improper deployment are noted. Aeroelastic flutter is observed and characterized after the wing deployment at certain conditions.

INTRODUCTION

Significant advances in the size and capability of Micro Air Vehicles (MAVs) have occurred in the last 15 years. In particular, advances in the capability of compact microelectronics has allowed for the autonomous flight of MAVs. An important component of a complete MAV operation is the ability to remotely or autonomously launch the vehicle. Tube launch mechanisms have been used for the deployment of folding fin rockets and missiles [1,2,3]. Large MAVs have also been developed to launch from sonobuoy and naval gun tubes, both approximately 5 inches (12.7 cm) in diameter and having wingspans of more than 50 inches

(127 cm) [1,5]. Much smaller vehicles have been demonstrated and offer more compact transportation, wingspans less than 10 inches (25.4 cm) [5]. In addition to an autonomous launch, tube launch mechanisms offer compact and robust storage. Designing vehicles for tube launch mechanisms becomes difficult however as for space efficiency, wings should be compactly stored and only deployed after launch. At the small scales of MAV wing deployment mechanisms traditional rigid-body mechanisms become increasingly difficult to build and often involve delicate components [5,7].

At increasingly small scales, compliant mechanisms can offer reduced part counts, simplified construction and lower system mass [7]. Fully compliant, rolling or “bendable” wings have been flown and studied for their steady state aerodynamic and structural performance [8,9]. This research investigates the aerodynamics of a small tube-launched (1.5 inch, 3.81 cm diameter) MAV utilizing a fully compliant, rolling wing. At low Reynolds' numbers (less than 100,000) thin, low aspect ratio wings are desired for greatest efficiency [7]. A rolling wing is particularly well suited for this application as it is constructed from a thin carbon fiber layup and efficiently stores low aspect ratio wings. A reliable wing is constructed of a thin layup of carbon fiber in the loon of a cambered wing. The resulting cambered, thin shell behaves like a tape spring easily rolling in one direction (stored) while remaining stiff in the other (deployed), shown in [Figure 1](#). One of the first failure modes of a reliable wing is buckling, caused by aerodynamic loading [9]. Buckling in steady state aerodynamics has been analyzed [9], however buckling during the dynamic deployment has not.



Figure 1. Tape Spring Behavior, Left: Normal Deployed, Middle: Loaded, Right: Rolled

Aerodynamics associated with low Reynolds numbers are often complicated due to unsteady transition between laminar and turbulent flow. The MAV configuration for this work was taken from an earlier numerical investigation [11]. In an effort to identify characteristics of the chosen body and approximate wing size, the steady state aerodynamics were primarily studied on fixed wing models. A model was built specifically for the deployment of reliable wings, incorporating the necessary mechanisms for remote control of wing deployment. Data from a six-axis balance and tuft flow visualization is used in characterizing the aerodynamics of fixed wing models. High speed camera photography and force balance data was used in the preliminary analysis of reliable wing dynamics.

CONFIGURATIONS

RIGID WING MODELS

Two models were tested using the force balance, shown in Figure 2. The geometry of the models was identical except for the tail surface planform and airfoil as well as the inclusion of winglets on the main wing. The Model Without Winglets (MWOW) had a trapezoidal tail planform and rectangular tail airfoil cross section. The Model With Winglets (MWW) included winglets on the main wing and made use of a symmetric NACA airfoil cross section on the tail. The MWW was the primary model used for investigation in this study. The MWW winglets were easily removable and resulted in a 5% decrease in wing Aspect Ratio.

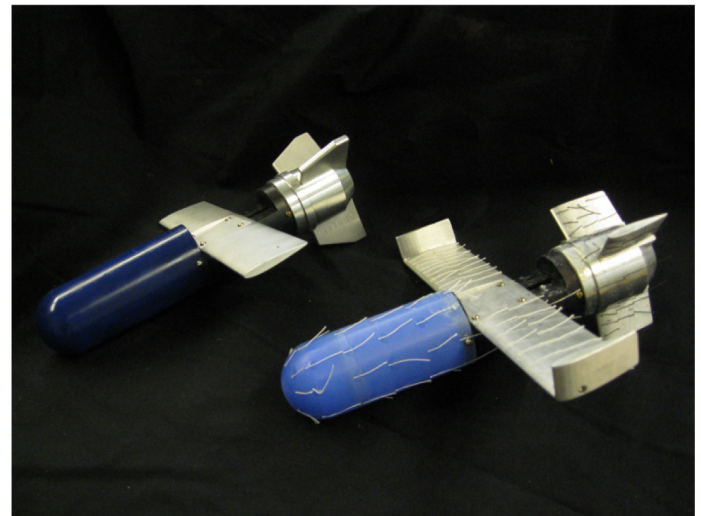


Figure 2. Two fixed wing wind tunnel models, Model Without Winglets (MWOW, left) and Model With Winglets (MWW, right)

Figure 3 shows the different configurations investigated using the MWW. The MWW was tested both with and without the body cavity filled (CF) to investigate the effects of the large cavity found above the main wing. The cavity was a result of cutting out material for the mounting of the wing near the body centerline. The cavity was filled using foam cut to the shape of the cavity, covered with tape to ensure a smooth finish. Removal of only tail surfaces was impossible due to the construction of the model, leading to a large section of the body also being removed in addition to the surfaces. The removal of the tail section for testing resulted in a significant change in fuselage length, not allowing for testing a true body-alone configuration.

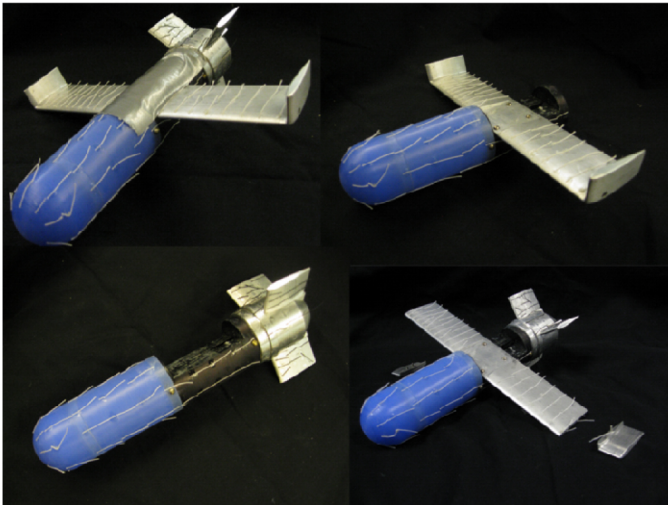


Figure 3. Tested model configurations; Cavity Filled (upper left), Tail off (upper right), Wing off (lower left), Winglets off (lower right)

DEPLOY ABLE WING CONFIGURATION

Based on earlier analysis, a configuration utilizing the maximum available wing area was desired [11]. Shown in Figure 4, the chord length of the wing was approximately twice that of the fixed wing models (0.0762 m vs. 0.0371 m), while span was roughly equal (0.2032 m vs. 0.192 in). Tail surfaces were not included on the model as their effects were not important to the analysis. The basic rectangular planform wing was chosen to provide the simplest example of a rolling wing possible. The airfoil chosen was a simple arc. Wingspan (8 inches, 0.2032 m) was the greatest value that could be packed within the desired tube. Chord was chosen as the largest value that would provide necessary space on the fuselage for future addition of tail surfaces. The necessary wing camber was calculated by comparing a simple estimate of bending moment due to aerodynamic loading with the maximum supported bending moment of a composite tape spring. The aerodynamic bending moment was calculated by assuming a constant load across the wing equal to the weight of the vehicle (0.25kg) and using simple beam theory. Maximum tape spring bending moment was calculated using the relation developed by Yee, et al. [12]. A camber of 12% of chord length was chosen as being sufficiently strong, with a factor of safety of 1.15.

The wing is mounted to the model in such a way as the camber is not constrained. Allowing for flex of the wing is important for compact rolling of the wing as a free rolling of the wing results in the camber completely flattening out. Fully constraining the mounting points will result in increased stress near the mounts. The wing is mounted by two small pads, one each at the leading and trailing edges of

the wing. The leading edge pad is mounted to the body with a pivot, axis parallel to the span direction. The trailing edge pad is mounted with a similar pivot but is also allowed to translate in the chord direction, shown in Figure 5. The pivot and slider mechanisms were manufactured into an insert constructed using stereolithography. The stereolithography insert mounted within the aluminum fuselage of the wind tunnel model.

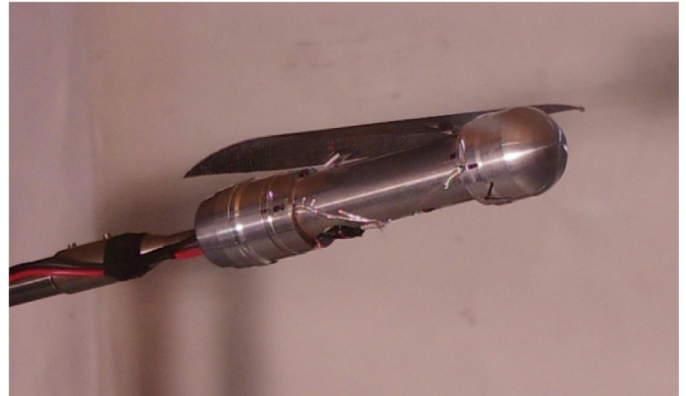


Figure 4. Deploy able Wing Model in Wind Tunnel

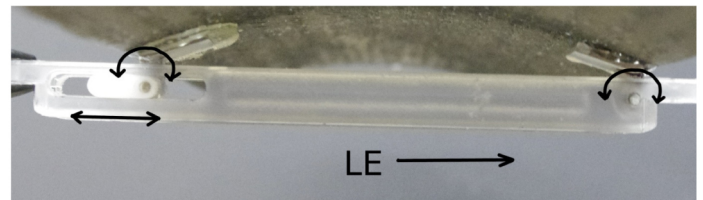


Figure 5. Wing mounting mechanism

WIND TUNNEL HARDWARE

A six-axis internal strain gauge balance was used to measure forces and moments on the wind tunnel models. The limits of the balance are 150 lbs in Normal Force, 100 lbs Side Force, 251bs Axial, 250 inch-lbs pitching moment, 180 inch-lbs yaw moment, and 200 inch-lbs in rolling moment. The balance was mounted on a two-axis model positioning system, allowing for automated movement in both pitch and yaw axes. The models were mounted to the balance via a sting as the balance was too large and models too small for it to actually fit within the models as intended. The sting consisted of an interface that fit over the balance and then tapered to a 3/8 inch diameter (9.5 mm) steel rod that fit inside the model. As the sting was mounted in the rear of the model, in its wake, it was impractical to accurately identify the loads on the sting so they could be removed from the overall measurements on the model. Figure 6 shows the model, sting, balance and balance mount in the wind tunnel.