

An Experimental Investigation of the Transient Effects Associated with Wing Deployment During Ballistic Flight

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ABSTRACT

Mortar weapons systems have existed for more than five hundred years. Though modern tube-launched rounds are far more advanced than the cannon balls used in the 15th century, the parabolic trajectory and inability to steer the object after launch remains the same. Equipping the shell with extending aerodynamic surfaces transforms the unguided round into a maneuverable munition with increased range [1] and precision [2]. The subject of this work is the experimental analysis of transient aerodynamic behavior of a transforming tube-launched unmanned aerial vehicle (UAV) during transition from a ballistic trajectory to winged flight.

Data was gathered using a series of wind tunnel experiments to determine the lift, drag, and pitching moment exerted on the prototype in various stages of wing deployment. Flight models of the design were broken down into three configurations: "round", "transforming", and "UAV". Geometrically static tests which consisted of the round and UAV models were used to determine preand post-transformation aerodynamics. Post-processing of dynamic transformation tests employed spectral analysis and appropriate signal filtering to identify and characterize the aerodynamics of the transition between static model configurations. Results indicated that complete transformation occurred within 1/3 of a second and that the prototype maintained aerodynamic stability during the entire geometric transition.

INTRODUCTION

The tube-launched UAV is a relatively new platform used to increase the portability and utility of military UAVs. These aircraft begin their missions as ballistic rounds and deploy lifting surfaces mid-flight to increase range and maneuverability. Design of tube-launched UAVs is an increasingly popular area of military research as they do not require runways and can be launched from existing equipment to fulfill rolls that range from surveillance to precision munition. Previous work has been done with both single tube [1, 3] and sonobouy [4, 5, 6] launched UAVs.

For any system that undergoes a transformation from configuration A to configuration B, there is a period when the geometry conforms to neither A nor B. On an aircraft with morphing wings, this transition period may have unique flight dynamics that are difficult to predict using only stability characteristics from modes A and B [7]. For example, transient research performed on inflatable wings demonstrated rapid changes in lift and drag during transformation (Figure 1) [8, 9].

EXPERIMENTAL DESIGN

Aerodynamic forces and moments experienced by the transforming standard-diameter design were separated into three configurations: "round", "UAV", and "transforming". "Round" referred to the design prior to transformation which represented a standard ballistically-launched round. The period during which the flight surfaces were deployed utilized the "transforming" model, which dynamically extended flight surfaces during tests. When the surfaces were completely extended, the design had reached its final stage and became a "UAV" model.



Figure 1. Previous Transforming UAV Research. The NASA Dryden I2000 with inflating wings was presented in “Aerostructural Interaction and Optimization of Inflatable Wings.”[10]

ROUND MODEL

A first set of experiments was performed to determine baseline launch geometry aerodynamics. Before transformation, the prototype design behaved as an unguided projectile in the same manner as a typical standard-diameter mortar shell. Drag was of course always present, and although there were no lift-enhancing surfaces on the round model the body was capable of generating lift and pitching moment at non-zero angles of attack [11].

UAV MODEL

The second set of experiments determined the forces experienced by the design with all lift-generating surfaces completely deployed. For this stage, the model was constructed with fixed wings attached to the body. As a UAV, the model was designed to exhibit maximum lift forces with minimal drag. Data gathered on the lift, drag, and pitching moment during this stage were important for determining the stability coefficients for future use in UAV control law development [12].

TRANSFORMING MODEL

A third model was used for gathering data during transition from ballistic projectile to UAV. The UAV model was manufactured with space to store the wings internally as well as a motorized system to release them at the desired time. The mechanism utilized an electric servo motor to pull a cable to initiate release of the wings which were held in the stowed configuration within the fuselage. Upon release, torsion springs moved the wings outward and aft through a 90° arc to the final wing rest position. The wings remained at a 0° angle of incidence relative to the body axis during the entire sweep, and were then rotated using a proprietary joint which allowed for a sudden three dimensional motion to achieve positive angle of incidence and dihedral for the wings. Initial transforming model tests involved deploying the wings with no tunnel velocity to measure the impulse generated by the moving parts in the model. To minimize undesirable flight characteristics, the transformation process was designed to occur as fast as possible. After the impulse tests were performed, the wings were deployed at the angles of attack and tunnel speeds used in the round and UAV configuration experiments.

WVU CLOSED LOOP WIND TUNNEL SETUP

All experiments were performed in WVU's closed loop subsonic wind tunnel. The 0.81 by 1.14 meter (32 by 45 inches) test section was sufficiently large to accommodate a 1:1 scale model of the standard-diameter mortar shell (Figure 2). The test stand consisted of a sting arm that connected to the tail of the model. The sting was mounted to a riser bar that ran through the tunnel floor to a three-component balance directly below the model. The riser bar was housed in a shroud that shielded it from the tunnel flow.



Figure 2. Test Section Sting Mount. The baseline model was mounted on a sting which attached to a three component balance below the test section.

As shown in Figure 3, the three-component balance consisted of three load cells. Two vertical load cells, designated Lift 1 and Lift 2, were both rated to 11.3 kilograms (25 lbf). The horizontal cell, designated Drag, was rated to one kilogram (2.2 lbf). The frame of the balance was designed to absorb the weight of the model and sting before tightening the load cells, while the load cells carried any additional forces applied to the model.

The load cells were wired via shielded cable directly into a National Instruments SCXI - 1314 front mounting terminal which was linked to the SCXI 1520 universal strain gauge module. The module was contained in a shielded National



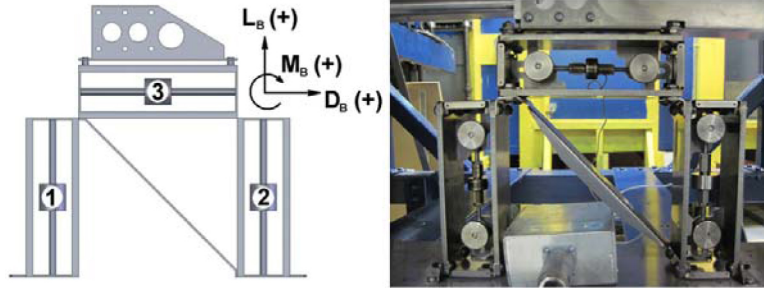


Figure 3. Three-Component Balance. The balance used three load cells to indirectly measure lift, drag, and pitching moment.

Instruments SCXI-1000 chassis which housed, powered, controlled and shielded the modules. Finally, this system connected to a National Instruments PCI 6221 desktop data acquisition card. Using LabView, a virtual instrument was created to operate the entire data acquisition (DAQ) system and view and record voltage signal output from the load cells in real time.

DATA REDUCTION

Signals taken from the load cells of the three component external balance comprised the main input signals to the data acquisition system. The three signals were initially multiplied by the inverse of the load cell interaction matrix to produce the models' lift, drag and pitching moment values. Depending upon the dominant mode of model operation in time, various methods were used to determine respective behavioral trends during fixed or transforming configurations. The steady nature of the fixed configurations allowed averaging methods to be effectively used to determine the forces and moment for untransformed and transformed states. The transient nature of the transformation process required a multi-step process which utilized spectral analysis to identify and extract the transient time period, and then appropriately filter the signal to determine the changing force and moment values. 5 Hz low pass filters were applied to all the signals to isolate their DC component and reduce mechanical and electrical noise (Figure 4).

Additional classical aerodynamic methods were finally used to reduce the model lift, drag and pitching moment to dimensionless coefficients. All lift, drag and moment coefficients were calculated using the fuselage frontal area and diameter (A_f and D_{fus} , respectively) as the characteristic geometric values, such that

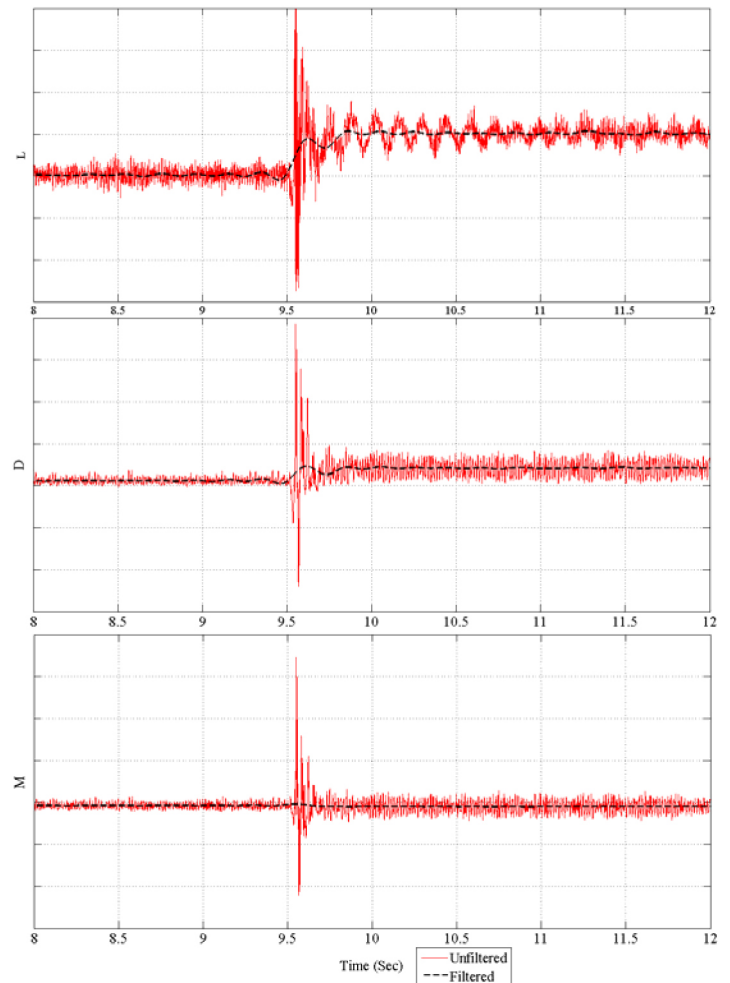


Figure 4. Data Filtering. Transient lift (L), drag (D), and pitching moment (M) signals were filtered to reduce electrical and mechanical noise.

$$C_L = \frac{L}{q_{TS} A_f}, \quad C_D = \frac{D}{q_{TS} A_f}, \quad C_M = \frac{M}{q_{TS} A_f D_{fus}} \quad (1, 2, 3)$$