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Engineering Notes

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Preliminary Flight Tests of a Hinge-Less Roll Control Effecter

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Introduction

THERE has been a growing research effort to achieve effective hinge-less flight control, spurred on by advances in fluidic control. For purposes of stealth, reduced vehicle weight, increased robustness and damage tolerance as well as compactness, hinge-less methodology is extremely attractive. Hinge-less control can be implemented through either continuous or oscillatory flow manipulation. Continuous manipulation can be achieved using blowing. Past research efforts have shown jet flaps[1,2] and circulation control[3,4] to be effective at augmenting lift and varying pitching moment. A recent study has shown that a highly deflected (normal to the surface) jet flap can match the performance of a Gurney flap using moderate jet momentum coefficients.[5] However, continuous blowing invariably requires drawing air off the engine's compressor or using shaft power to drive a compressor. Ducting is also required to route the air through its ejection path. Consequently, weight and thrust penalties can be incurred.

It would be advantageous to the designer to have the flexibility to employ a modular air-injection system that can be placed locally where control is required. The system can be configured to function as a jet flap or used for augmenting existing control effecters (forming a blown flap). Such a system would have the advantage of not requiring pneumatic lines and can be employed in flight vehicles where a pneumatic source is not present (e.g., unmanned aerial vehicles). In this Note we detail the design and implementation of a self-contained modular blower system. Blower design details are elucidated, as are verification of the blower's effectiveness as a roll control device through flight testing.

Experimental Details

Figure 1 shows design details of the blower depicted using CAD renderings as well as the manufactured component. Figure 1 also shows installation of the blower in the test aircraft's wing. The blower was designed using a three-dimensional CAD package and subsequently fabricated using a rapid prototyping facility in ABS plastic. The design drivers were low structural weight and compact dimensions. The blower was sized to fit in the selected test aircraft at 78% semispan, with a blower mounted in each wing half. Figure 1 shows the blower installed in the wing. Air was drawn into the blower off the upper surface. This location was selected for two reasons: 1) drawing air off the upper surface would provide a form of boundary-layer control through upper surface suction and 2) low observability to ground-based radar; it would be preferable to have any structural discontinuities on the wing's upper surface. The blower inlet was shrouded to aid air ingestion and for safety considerations.

A fan from a "DustBuster" was used as the air conveyance in the blower. An Astro Flight, Inc., Mighty Micro brushless motor was use to spin the fan. The motor is rated to 30,000 rpm and is designed for use with battery packs typically found on electric radio control aircraft. The blowers were powered using 10 cell packs of 2300-mAH NiMH batteries. Motor speed control is through pulse width modulation. The motor is compact, measuring just 0.023 m high and 0.025 m in diameter and is rated to 75 W.

The blower was designed so that different slot exit geometries could simply be removed and inserted. The blower slot is 94 mm wide and 2 mm high. Prior to installation in the test aircraft, the blower slot exit was surveyed using a miniature pitot static probe. Velocities were measured using a FlowKinetics™ limited liability company (LLC) FKT1DP1A-SV system. This instrument calculates the air velocity using a pitot static probe (differential pressure measurement); however, the instrument also directly measures atmospheric pressure, temperature, and relative humidity (using a detachable probe) and uses these measurements to calculate air density including effects of water vapor. Thus, the calculated velocity needs no corrections for atmospheric effects. Using data supplied by the manufacturer, the error in velocity is estimated as less then 0.8%. Study indicated that a 2-mm slot angled down at 60 deg incurred acceptable losses such that the jet exit velocities were high enough and so suitable for control.[5] The survey indicated that the jet exit velocity was uniform (within 2.5%) across the width of the slot. Figure 2 presents a summary of measured slot exit velocity vs motor rpm. As might be expected, the jet velocity varies linearly with fan revolutions per minute. The fan output (no enclosure) was also measured using the pitot probe to assess the losses associated with the blower housing. The measurements indicated that the volumetric flow rate out of the fan was three times higher than from the jet slot for comparable revolutions per minute, indicating a flow based efficiency of approximately 33%. Refinement of the blower design should increase the operational efficiency.

The aircraft model used was a $\frac{1}{3}$-scale Hangar 9 Extra 330S. The plane has a span of 2.463 m, a taper ratio of 0.51, and a wing area of 1.1515 m^2. The mean chord is 0.467 m. The aircraft mass was measured at 13.57 kg. A two-cylinder Komat'su Zenoah G800BPU two-stroke 80 cc engine rated at 7.5 hp was used (without muffler). Two radios were used (JR 10x ten channel units): one to control the aircraft and the other to control the blowers. A forward-facing Black Widow A/V BWAV200 ready-to-fly video system camera was mounted in the cockpit with real-time video feed to a ground-based recorder. The video system uses a Panasonic KX121 Color charge-coupled-device camera.

Flight-Test Result

Test flights were conducted flying standard patterns at approximately 91 m (300 ft) altitude. Each flight lasted approximately 10 min. Airspeed was monitored using an Eagle Tree Systems LLC,

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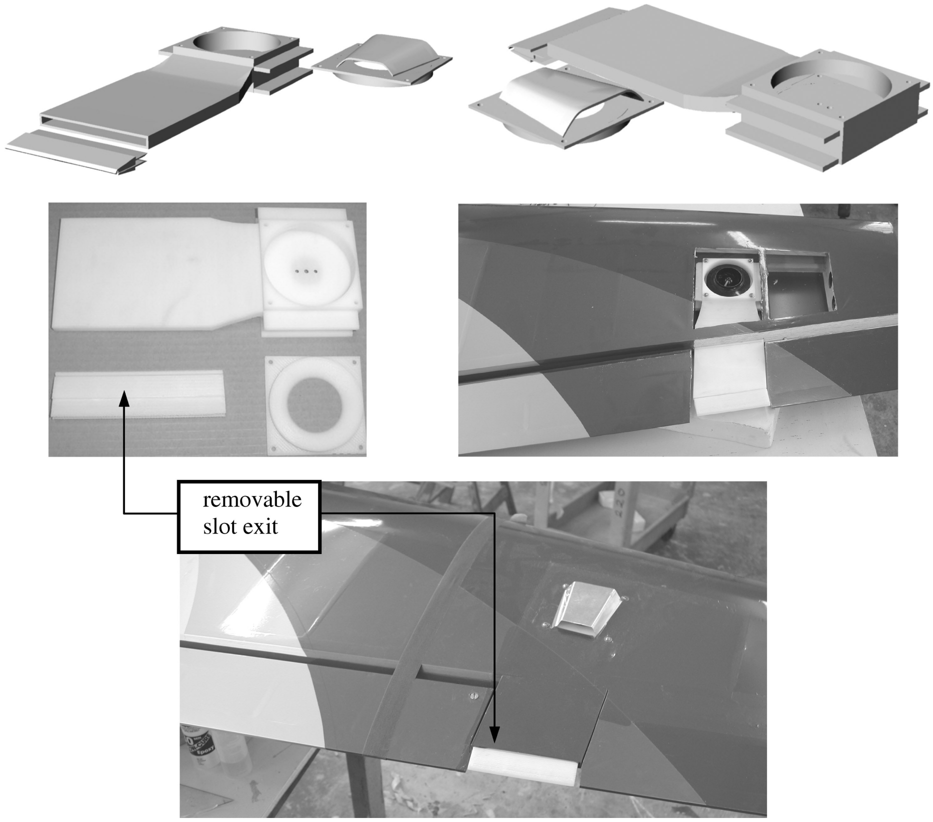

Fig. 1 Self-contained blower design details and installation.

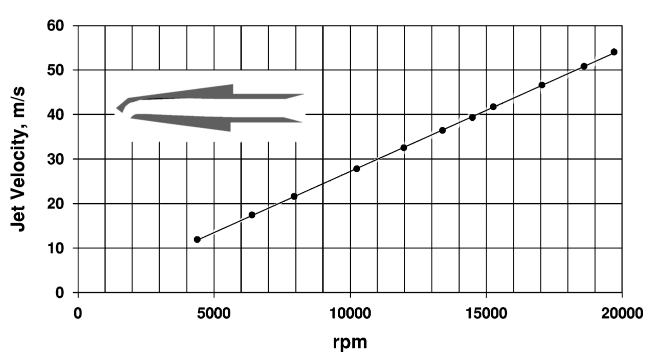

Fig. 2 Measured jet exit velocity, with 2-mm slot height. Slot exit profile is shown inset in the figure.

telemetry system encompassing a pitot mounted on the aircraft with real-time data download to a ground-based PC, where airspeed and altitude were displayed. The blowers were tested on the downwind leg. Prior to blower activation, the aircraft was pitched [once for 22.4 m/s (50 mph), twice for 29 m/s (65 mph) and three times for 38 m/s (85 mph)] to leave a visual indicator on the video record. In the first test the blower was activated to roll the aircraft from approximately horizontal to 90 deg to the left and in the second test from the horizontal to the right through 90 deg. For rolls to the left, the left-wing panel blower slot was inserted such that the jet was deflected up and the jet on the right-wing panel was deflected down, vice versa for rolls to the right.

To extract roll performance, the video was analyzed frame by frame to determine the roll history. The horizon was used as the reference for determining aircraft angle. A data summary is shown in Fig. 3. In the tests, the fans were run at maximum speed (the preliminary nature of the tests precluded installation of a fan rpm monitoring system; however, the fans could reliably be set to maximum rpm), and so the blower's jet momentum coefficient was varied using the aircraft's flight speed. A summary is presented in Table 1. The jet momentum coefficient C_μ was calculated using $C_\mu = 2A_{\mathrm{slot}}V_{\mathrm{slot}}^2/SU_\infty^2$, where A_{slot} is the blower slot exit area (both slots), V_{slot} is the average slot exit velocity, S is the wing planform area, and U_∞ is the aircraft's flight speed.

Table 1 Flight parameter summary

Flight speed, m/s	C_μ	Reynolds number (based on mean chord)
22.4	0.0038	0.704×10^6
29	0.0022	0.91×10^6
38	0.0013	1.19×10^6

The data in Fig. 3 show that despite the small extent of the blower (they amount to only 7.6% of the span) and the low jet momentum associated with the blowers they are capable of generating moments sufficient for roll control. The data show that the variation of roll angle with time has a quadratic dependence, which indicates a roll rate that is linearly dependent on time. Rolls to the left are seen to be significantly quicker than to the right, reflecting the influence of the engine torque. Although the roll rates are comparatively modest, these results reflect a preliminary small-scale installation used for proof-of-concept validation. Using greater spanwise extents of the blowers would significantly improve roll performance. The top inset in Fig. 3 shows average roll times for the three tested airspeeds. Although the scarcity of the data cautions against trend inference, it appears that increasing the airspeed increases time to roll, which can reflect the reduction in jet momentum coefficient (see Table 1). It can also be observed that the times to roll do not appear to explicitly agree with those given in the lower inset in Fig. 3. This is because of the aircraft seldom being at 0-deg roll angle at the commencement of the blower-induced roll. Thus the time for the roll was taken as that required to roll the aircraft from its existing attitude to 90 deg. Also note that the fans required approximately 2 s to "spool" up to maximum rotational velocity following the control request. This behavior is as a result of the motor controllers used.

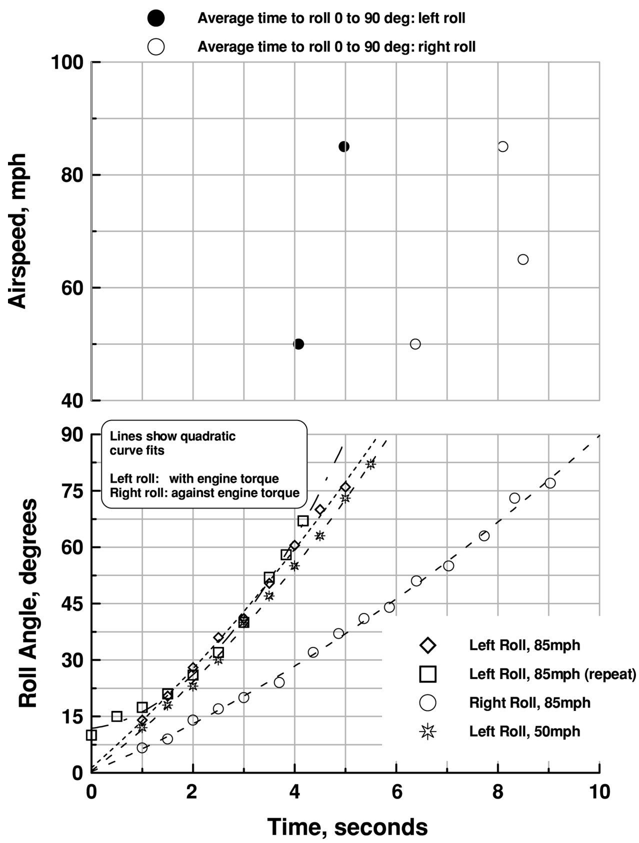

Fig. 3 Measured roll response using blowers.

Conclusions

A preliminary flight investigation into the use of modular blowers for hinge-less lateral control is detailed. Blowers were designed and then manufactured using a rapid prototyping facility. Off-the-shelf fans were used. The test aircraft was an instrumented $\frac{1}{3}$-scale Extra 330S. Video images were analyzed to assess roll performance. The data suggest that the blowers are capable of inducing rolling moments and with development can provide a reliable and "stealthy" alternative to hinged lateral flight control surfaces.

Acknowledgments

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