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Rolling Authority of a Morphing Trailing Edge System Design

D. Communier, R. M. Botez* and T. Wong

ETS, Laboratory of Applied Research in Active Controls, Avionics and AeroServoElasticity LARCASE,
1100 Notre-Dame West, Montréal, Qc,
Canada, H3C 1K3

Abstract

In order to reduce aircraft fuel consumption, the Applied Research Laboratory in Active Controls, Avionics and AeroServoElasticity (LARCASE) team at the École de Technologie Supérieure (ETS) is working on the development of morphing trailing edge technologies. To successfully develop this technology, the LARCASE laboratory can count on more than 10 years of experiences in the development of technologies related to morphing wing. The LARCASE team already did worked on SMA technologies [1], on controllers design for morphing wing [2], wind tunnel testing on morphing wing prototype [3], and on many other major projects in collaboration with industries from the aerospace sector, and with foreign universities [4]. The previous technologies developed by the LARCASE team focus on extending the laminar flow on a morphing upper surface of a wing [5]. The technology presented in this paper consists in curving the trailing edge of the wing ribs by designing slits on it (Figure 1). The slits allowed to reduce the thickness of the ribs and to keep only the neutral fiber of the ribs. This work has the effect of allowing the rib to behave as a pivot where slits were positioned. This behavior was obtained from the "compliant mechanisms" theory [6]. The flexibility of the rib was determined by the remaining neutral fiber while the amplitude of deformation was determined by the width and the depth of each slits. The fineness of the slits, and the accuracy needed to get the desired behavior from the ribs can be achieved with the use of LASER machine cutting. It was chosen to design a prototype with wood fabric in order to be build with the available equipments in the LARCASE laboratory. The LARCASE team decided to call this technology allowing curving a Morphing Trailing Edge (MTE) system. In order to validate the operation of the MTE system, wind tunnel tests were carried out to measure the aerodynamic coefficients of a wing equipped with the MTE system. The aerodynamic coefficients can be computed from the values of forces and moments measured by a Force and Torque (F/T) sensor. The F/T sensor is the Omega 160 from ATI Industrial Automation. It allowed the reading of dynamical forces with great accuracy. This F/T sensor was combined with a rotating plate that allowed to dynamically changing the angle of attack of the wing during wind tunnel tests, and whit a controller for moving control surfaces of the wing during the tests. Complex behavior as the stall of the wing could be well recorded by the F/T sensor as well as the effects of the angles of attack and control surfaces on the wing aerodynamics. A comparison of the MTE system with conventional aileron performances was made to determine if the MTE system could reduce the drag of the wing with respect to a conventional

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**E-mail address:* ruxandra.botez@etsmtl.ca

aileron system [7]. These analyses demonstrated that the MTE system produced, for the same variation of the lift coefficient, a lower drag coefficient than the aileron system.

In this paper, the roll authority of the MTE system will be analyzed to determine if the MTE system could replace a conventional aileron on the wing. More specifically, it is important to verify if the MTE system can produce the same amplitude of variation of lift coefficient as a conventional aileron. To be able to conduct this analysis, the wing is considered a rigid body as the structural study of a full wing equipped with the MTE system is not done yet. The LARCASE is equipped with the Price - Païdoussis blow down wind tunnel which allows to obtain velocities from 6 m / s to 35 m / s in its 2 ft by 3 ft section. The speeds available from this wind tunnel allow validating the roll control for low speeds corresponding to the takeoff and landing phases of the UAS-S4. The wind tunnel tests have shown that the MTE system acted as a conventional aileron moving from -25° to 25° (Figure 2).

For the roll control to be sufficient there was a need to obtain a roll rate satisfying the nondimensional roll rate equation (1) [8] where p is roll rate, b is the wing span, and V is the airspeed. The steady state roll rate is determined by the equation (2) [9]. Since the airfoil is the same for both systems, the roll damping, which is wing geometry and airfoil dependent, will be the same. The roll authority is dependent on the wing geometry and the variation of lift coefficient with the angle of the aileron $c_{l_{\delta_a}}$. The roll authority can be determined using wind tunnel test on our test wings. The measurement of the lift coefficient variation with the angle of the control surface can't be compared directly between the aileron and the MTE as the mechanism acts differently. The aileron rotates around an axis and the MTE curves along the chord. The aileron was designed to get a ratio of 1 between the angle of the servomotor and the angle of the aileron. For the MTE, the servomotor arm is directly connected to the control rod at the tip of the trailing edge in a way in which we can consider that the angle of the servomotor is the angle of deflection of the MTE. Therefore, the lift variation with the servomotor angle was measured for the both aileron and MTE [7], which allowed us to obtain the value of $c_{l_{\delta_a}}$ for both the aileron and the MTE (Figure 3). This result gives us the value for the MTE of 6.6232 /rad and the value for the aileron of 2.7196 /rad. It can therefore be found that the roll authority of the MTE is 2.435 more higher than the roll authority of the aileron. Since the MTE can reach the same lift coefficient variation than an aileron moving from -25° to 25° and the roll authority of the MTE is greater of the roll authority of the aileron, it can be concluded than the MTE can control the roll motion of an aircraft. The geometry used to analyse the roll authority of the MTE is the one of Hydra Technologies UAS-S4 given in Table 1. Using these values, the roll rate of the UAS-S4 with an MTE system can be determined. The speed used for the analysis is the minimum speed of the UAS-S4. Since the wing of the UAS-S4 is a straight tapered wing, the equation of the roll authority (3), and of the roll damping (4) with taper ratio must be used. The roll authority for the UAS-S4 would be 0.4539 /rad and the roll damping would be -0.4953 /rad if its equipped with an MTE system. This rate can be found with equation (2), by using the maximum angle for MTE system of 13°, p is equal to 105.31 °/s. Finally, the nondimensional roll rate is determined using equation (1) and is equal to 0.2079 which is almost 3 time its minimum value. To compare, with the aileron and the same calculation, we get a rate of nondimensional roll rate of 0.08543 which is just above the minimum nondimensional roll rate. Considering than the nondimensional roll rate decreases with speed to reach 0 at some speed, the MTE system gives a better margin than the aileron. For this analysis, the airfoil NACA0012 was used because of the fact that it is the airfoil used for the MTE system prototype but its not the airfoil used for the actual UAS-S4, so the previous calculation can not allow to conclude on the roll authority of the actual UAS-S4. This analysis allows us to conclude that the MTE system could completely replace the aileron on the wing.

**E-mail address:* ruxandra.botez@etsmtl.ca

$$\mathrm{pb} \,/\, 2\mathrm{V} \; > \; 0.07 \tag{1}$$

$$\mathrm{p} = -\frac{\mathrm{C}_{\mathrm{l}_{\delta_\mathrm{a}}}}{\mathrm{C}_{\mathrm{l}_\mathrm{p}}}\Delta\delta_\mathrm{a}\frac{2\mathrm{V}}{\mathrm{b}} \tag{2}$$

$$C_{l_{\delta_a}} = \frac{c_{l_{\delta_a}}C_R}{Sb}\left[(b_2^2 - b_1^2) + \frac{4(\lambda-1)}{3b}(b_2^3 - b_1^3)\right] \tag{3}$$

$$C_{l_p} = -\frac{(c_{l_\propto}+c_{do}).C_R b}{24S}[1 + 3\lambda] \tag{4}$$

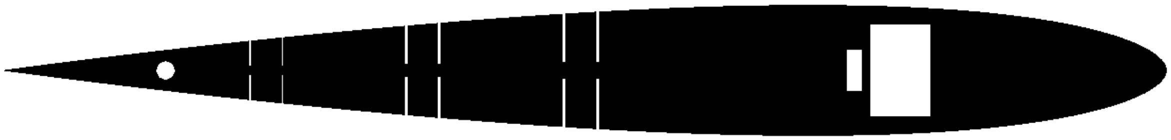

Figure 1: Morphing Trailing Edge Rib

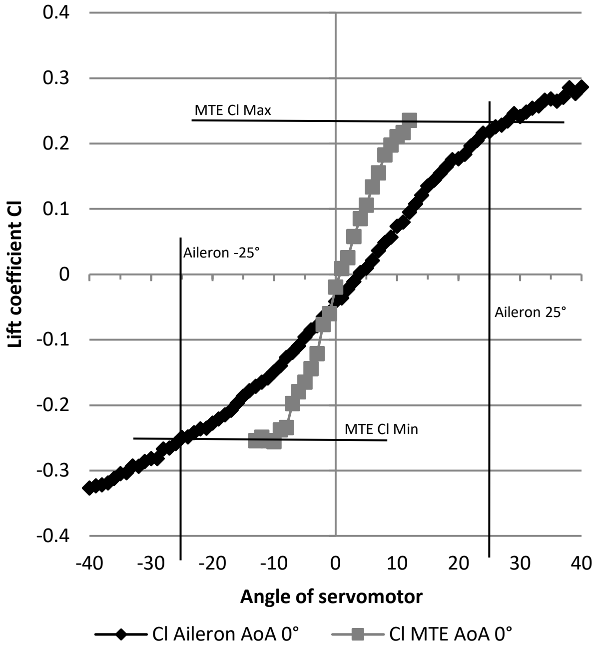

Figure 2: Comparison of lift coefficient variation with angle of servomotor for MTE and Aileron

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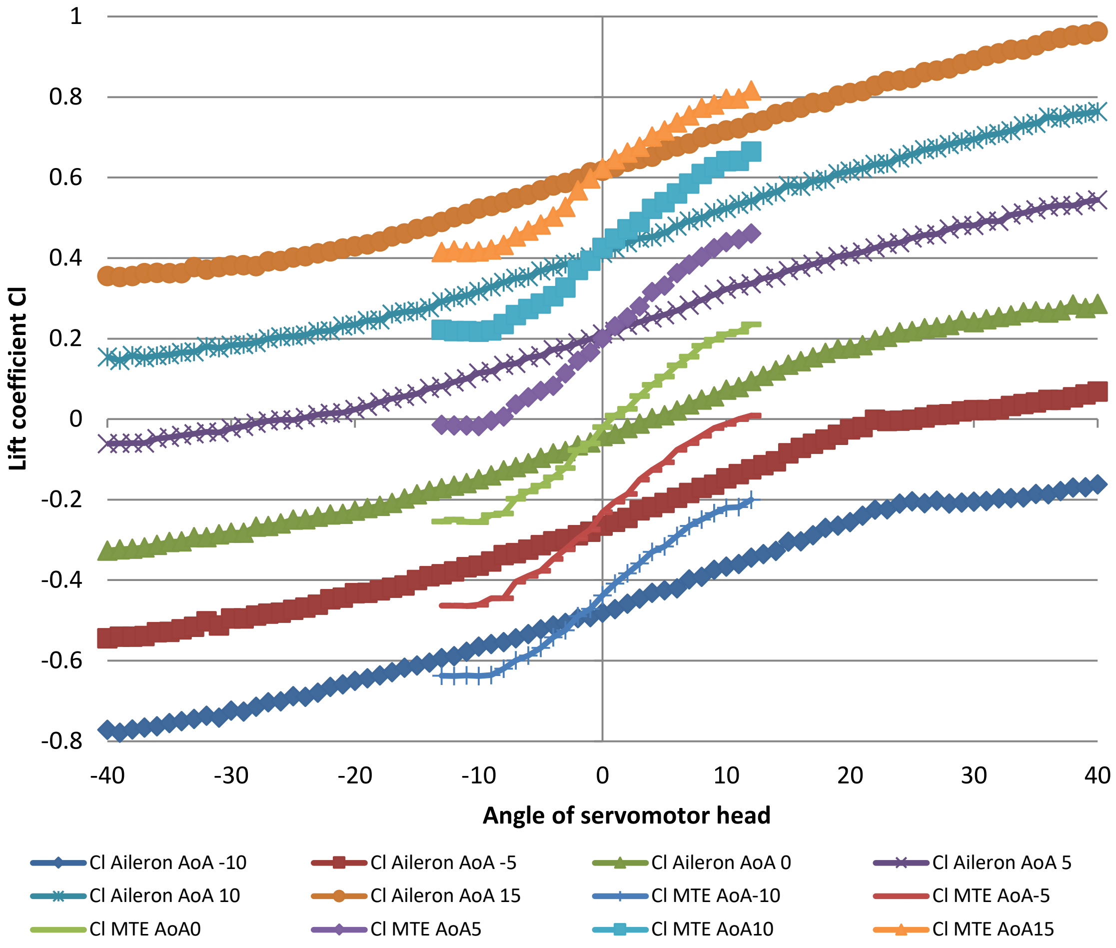

Figure 3: Lift coefficient variation with the angle of servomotor head

Table 1: Geometric data of the UAS-S4

Aircarft Speed V	18.52 m/s	End of Aileron b_2	2056.9 mm
Wing Surface S	2.9769 m²	Wing Taper Ratio λ	0.6057
Root chord C_R	656.159 mm	Airfoil Lift Slope $c_{l\alpha}$	4.5484 /rad
Wing span b	4.19 m	Airfoil Min Drag c_{do}	0.02079
Start of Aileron b_1	1504.45 mm	Airfoil	NACA0012

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**E-mail address:* ruxandra.botez@etsmtl.ca

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**E-mail address:* ruxandra.botez@etsmtl.ca