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Flight Testing a Simple Fix to Lateral Stability Deficiencies

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Small aerodynamic surfaces mounted on the trailing edges of ailerons were investigated through flight tests. These so-called canted tabs were mounted parallel to the airflow of a nonslipping aircraft but were canted outwards in such a fashion that they would create a rolling moment due to stickfree side slip. The purpose of the canted tab is to alter stickfree lateral stability. Ailerons of a single engine propeller driven aircraft were modified with canted tabs, and manned flight tests were performed. The results of the flight testing confirmed that the stickfree lateral stability can be significantly altered. The main advantage of the canted tabs may be as a simple fix to lateral stability deficiencies of existing aircraft.

Nomenclature

C_L	=	coefficient of lift of three-dimensional tab in free flow
$C_{L\alpha}$	=	slope of C_L with respect to α
c	=	chord of wing
c_a	=	chord of aileron
c_l	=	coefficient of lift of two-dimensional wing section
$c_{l\alpha}$	=	slope of c_l with respect to α
c_t	=	chord of tab
E	=	control surface chord ratio
$\boldsymbol{e}_v$	=	unit vector parallel to airflow
$\boldsymbol{e}_x$, $\boldsymbol{e}_y$, $\boldsymbol{e}_z$	=	base vector of a global Cartesian coordinate system
L	=	magnitude of lift force
$\boldsymbol{L}$	=	lift force vector
L_z^c	=	z component of lift of canted tab
L_z^r	=	z component of lift of regular tab
$\mathbf{n}$	=	normal to tab
$\mathbf{n}^c$	=	normal to canted tab
$\mathbf{n}^r$	=	normal to regular tab
q	=	dynamic pressure
S	=	planform area of tab
S^c	=	planform area of canted tab
S^r	=	planform area of regular tab
s_a	=	aileron span
s_t	=	tab span
$\boldsymbol{v}$	=	airflow vector
α	=	angle of attack
α_t	=	angle of attack of tab
α_0	=	angle of zero lift
α_{00}	=	angle of zero lift when $\delta_a = \delta_t = 0$
β	=	side slip angle
δ	=	deflection of trailing edge control surface
δ_a	=	aileron deflection relative to wing
δ_t	=	tab deflection relative to aileron
v	=	air speed
v_c, v_s	=	components of airflow vector in the chordwise and spanwise directions, respectively
ρ	=	air density
φ	=	canting angle of canted tab

I. Introduction

THERE are a number of reasons why altering lateral stability may be beneficial. Low lateral stability may result in negative spiral stability for an airplane, i.e., if left unattended the airplane will "dig" into increasingly steep turns. Lateral stability is also required to control an airplane if the primary aileron controls become inoperable. However, excess lateral stability tends to lead to Dutch roll, as well as requiring high control forces during crosswind landings.

According to the Federal Aviation Regulations (FAR) [1], FAR 23.177(b), "The static lateral stability, as shown by the tendency to raise the low wing in a sideslip, must be positive for all landing gear and flap positions"; according to FAR 23.145(c), "For all airplanes, it must be shown that the airplane is safely controllable without the use of the primary lateral control system…"; and according to FAR 23.177(d),

> In straight, steady slips…the aileron and rudder control movements and forces must increase steadily…as the angle of sideslip is increased up to the maximum appropriate to the type of airplane. At larger slip angles…the aileron and rudder control movements and forces must not reverse as the angle of sideslip is increased.

Further, for transport category airplanes, the regulations [1] state in FAR 25.177(c) that "In straight, steady sideslips, the aileron and rudder control movements and forces must be substantially proportional to the angle of sideslip in a stable sense" and in FAR 23.177(d) that "…the dihedral effect (aileron deflection opposite the corresponding rudder input) may be negative provided the divergence is gradual, easily recognized, and easily controlled by the pilot."

The canted tabs were developed primarily as a simple and cost effective alternative to complex and costly structural modifications for tailoring lateral stability characteristics, such as altering wing dihedral. In such cases, the canted tabs would be mounted rigidly on the ailerons. However, there may be further benefits in having the canted tabs adjustable so that lateral stability characteristics could be changed in flight. Such benefits could include reducing stick forces

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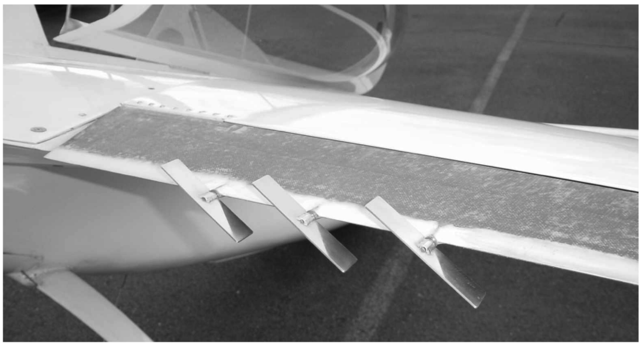

Fig. 1 Three canted tabs mounted on a VariEze amateur built aircraft.

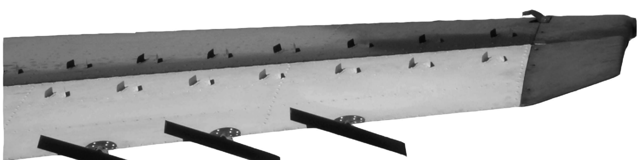

Fig. 2 Three canted tabs mounted on the right aileron of an Aermacchi AM.3 Bosbok.

for crosswind landings and increasing lateral stability for long cross-country flights or for long endurance loitering of manned or unmanned aircraft with otherwise high maneuverability and low static stability.

II. Function of Canted Tabs

The canted tabs are small aerodynamic surfaces mounted at the trailing edge of the ailerons, for example, as seen in Figs. 1 and 2. When there is no side slip, the tabs are parallel to the airflow and have little or no effect on the airflow. However, when the aircraft side slips, the canted tabs are exposed to the airflow and thus are affected by it. This creates a force on the ailerons, which will thus deflect, and the deflected ailerons will subsequently roll the aircraft. Before presenting an estimate for the effect of the canted tabs during side slips, some background from conventional trailing edge tabs will be presented.

III. Conventional Trailing Edge Tabs

Tabs hinged about an axis along the trailing edge of an aileron are rather common. These tabs may be servo controlled for trimming the aircraft, geared to the aileron to reduce or increase stick forces, or used for control of free-floating ailerons.

Figure 3 shows a cross section of a (nonswept) wing at an angle of attack α with the aileron deflected at the angle δ_a relative to the wing and the trailing edge tab deflected at the angle δ_t relative to the aileron.

The coefficient of lift of the two-dimensional wing section for arbitrary α, δ_a, and δ_t may be estimated using, for example, the classic data in Abbott and von Doenhoff [2]. In Fig. 96 of that publication, the change in angle of zero lift of the wing section for a unit change of control surface deflection is plotted versus control surface chord ratio E. An approximate two-dimensional expression is

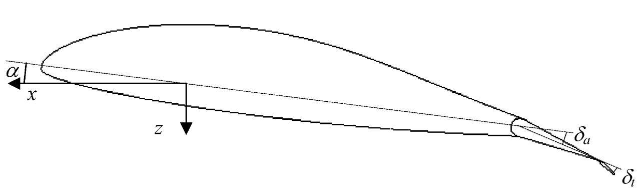

Fig. 3 Cross section of a wing with aileron and conventional trailing edge tab.

$$\frac{\partial \alpha_0}{\partial \delta} \approx \sqrt{E} \tag{1}$$

where δ, in our case, is for an aileron or a tab. The coefficient of lift of the wing section is

$$\begin{aligned} c_l = c_{l\alpha}(\alpha - \alpha_0) &= c_{l\alpha}\left[\alpha - \left(\alpha_{00} + \frac{\partial \alpha_0}{\partial \delta_a}\delta_a + \frac{\partial \alpha_0}{\partial \delta_t}\delta_t\right)\right] \\ &\approx c_{l\alpha}\left(\alpha - \alpha_{00} - \delta_a\sqrt{\frac{c_a + c_t}{c}} - \delta_t\sqrt{\frac{c_t}{c}}\right) \end{aligned} \tag{2}$$

If the aileron is free floating and controlled only by the trailing edge tab, then the aileron deflection as a function of the tab deflection is needed. This ratio, $\partial\delta_a/\partial\delta_t$, can be determined by experimental (wind tunnel), analytical (two-dimensional wing section theory, thin airfoil theory, etc.) or numerical (CFD) means. It appears that for full-span tabs

$$\frac{\partial \delta_a}{\partial \delta_t} \approx -1 \tag{3}$$

at least to the right order of magnitude. However, it naturally depends on parameters such as wing, aileron, and tab chords. The minus sign stems from the fact that as the tab deflects downwards; the free-floating aileron deflects upwards. For a free-floating aileron with a full-span tab, the two-dimensional lift coefficient may be approximated as

$$\begin{aligned} c_l &= c_l'\left[\alpha - \alpha_{00} - \left(\frac{\partial \delta_a}{\partial \delta_t}\sqrt{\frac{c_a + c_t}{c}} + \sqrt{\frac{c_t}{c}}\right)\delta_t\right] \\ &\approx c_l'\left[\alpha - \alpha_{00} + \left(\sqrt{\frac{c_a + c_t}{c}} - \sqrt{\frac{c_t}{c}}\right)\delta_t\right] \end{aligned} \tag{4}$$

Using this equation, which was derived from two-dimensional arguments, for three-dimensional flow may result in only a very rough approximation. As a note, for a tab of span s_t mounted on an aileron of span s_a,

$$\frac{\partial \delta_a}{\partial \delta_t} \approx -\frac{s_t}{s_a} \tag{5}$$

to the first approximation.

IV. Canted Trailing Edge Tabs

In this section, it will be argued that a canted tab under side slip in a certain sense is equivalent to a deflected conventional trailing edge tab under no side slip. Figure 4 may aid in the argument. When there is no side slip, the canted tabs have virtually no effect on the airflow. However, during side slip, the canted tabs get exposed to the airflow due to the spanwise component v_s of the airflow. The simplified explanation of how the canted tabs work is that they deflect the airflow during a side slip. The deflection may be either upwards or downwards, depending on the direction of side slip and the direction of tab canting. The deflected airflow leads to forces on the ailerons.

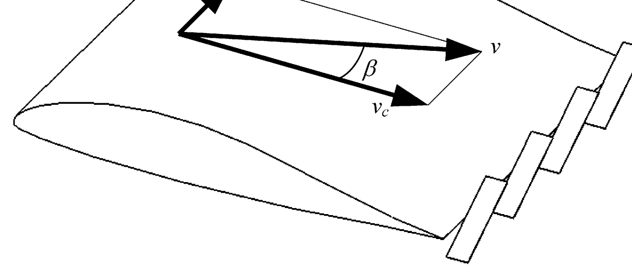

Fig. 4 Part of a wing with canted tabs.

These forces will deflect the free aileron, which will change the lift of the wing, in essence, the same as conventional trailing edge tabs on a free-floating aileron (as studied in Sec. III).

The relationship between a conventional trailing edge tab and a canted tab will be estimated using simple vector mechanics. A first approach is to consider the tabs as small lifting surfaces in free flow (unperturbed by the presence of the wing and aileron) and to relate the force on a conventional tab at some angle of attack with the force on a canted tab at a certain canting angle and side slip. If the airflow relative to the aircraft is $\boldsymbol{v} = v\boldsymbol{e}_v$, then the effective angle of attack of the tab is

$$\alpha_t = \arcsin(\boldsymbol{e}_v \cdot \boldsymbol{n}) \tag{6}$$

The magnitude of the lift on the tab may be assumed to be

$$L = qSC_{L\alpha}\alpha_t \tag{7}$$

where $q = \rho v^2/2$ is dynamic pressure. The lift force on the tab is perpendicular to the flow, and lies in the plane spanned by $\boldsymbol{n}$ and $\boldsymbol{v}$. Thus, the lift vector is parallel to the vector

$$(\boldsymbol{e}_v \times \boldsymbol{n}) \times \boldsymbol{e}_v \tag{8}$$

where $\times$ represents the vector cross product. The lift force may be written

$$\boldsymbol{L} \approx qSC_{L\alpha} \arcsin(\boldsymbol{e}_v \cdot \boldsymbol{n}) \frac{(\boldsymbol{e}_v \times \boldsymbol{n}) \times \boldsymbol{e}_v}{|(\boldsymbol{e}_v \times \boldsymbol{n}) \times \boldsymbol{e}_v|} \tag{9}$$

The normal of a conventional tab is

$$\boldsymbol{n}^r = -\boldsymbol{e}_x \sin\delta_t - \boldsymbol{e}_z \cos\delta_t \tag{10}$$

where the hinge line of the tab was assumed to be nonswept (and $\alpha = \delta_a = 0$). The normal of a canted tab, rotated by the angle φ around $\boldsymbol{e}_x$, is

$$\boldsymbol{n}^c = \boldsymbol{e}_y \sin\varphi - \boldsymbol{e}_z \cos\varphi \tag{11}$$

assuming the aileron was not deflected.

For an aircraft that is not side slipping, i.e., $\boldsymbol{v} = -v\boldsymbol{e}_x$, the z component of the force on a conventional trailing edge tab is

$$L_z^r = -qS^r C_{L\alpha}\delta_t \tag{12}$$

whereas for an aircraft in a side slip with the angle β, i.e., $\boldsymbol{v} = -v_c\boldsymbol{e}_x + v_s\boldsymbol{e}_y = v(-\cos\beta\boldsymbol{e}_x + \sin\beta\boldsymbol{e}_y)$, the z component of the force on the canted tab is

$$L_z^c = -\frac{qS^c C_{L\alpha}\beta \sin 2\varphi}{2} \tag{13}$$

Observe that the z axis is pointing downwards. Equations (12) and (13) assume that δ_t and β are small angles. These two equations provide an estimate for a relationship between the effect of a canted tab on a side slipping aircraft and the effect of a conventional trailing edge tab on an aircraft that is not side slipping. For example, the z component of the force on a 30 deg canted tab under 10 deg side slip is predicted to be the same as that on a conventional tab of the same area, deflected 4.3 deg, assuming that c_L' is the same for both tabs.

V. Preliminary Verification of the Theory

To obtain a preliminary verification, providing at least a rough estimate of the effect of the canted tabs, a simple experimental device consisting of a wing, a control surface, and trailing edge tabs was developed. The setup, which can be viewed as a simple alternative to a wind tunnel, is shown in Fig. 5. It consisted of an aluminum frame mounted to the front of an automobile and a modified half of a horizontal stabilizer from a Cessna 150, Fig. 6. The trailing edge of the control surface was equipped with three servo controlled canted tabs. The control surface was fully mass balanced by attaching a fairly long steel arm on one side. The side slip angle could be adjusted by mounting the stabilizer in different mounting holes on the aluminum frame. In this way, the side slip angle could be either -10, 0, or 10 deg, where 0 deg implies that the unperturbed airflow was perpendicular to the hinge line. The control surface deflection was recorded using a wireless displacement transducer. The automobile with the stabilizer was driven in a straight line at 18 m/s, with the tab canting angle being varied and the control surface deflection recorded. This was repeated at least twice, driving in opposite directions. Measurements were taken for each of the three side slip angles and for the tabs canted at -30, 0, and 30 deg, respectively.

Fig. 5 Preliminary experimental setup.

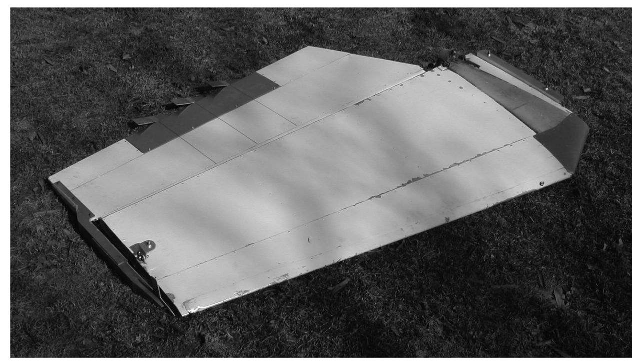

Fig. 6 Modified half of a Cessna 150 horizontal stabilizer, equipped with servo controlled canted tabs.

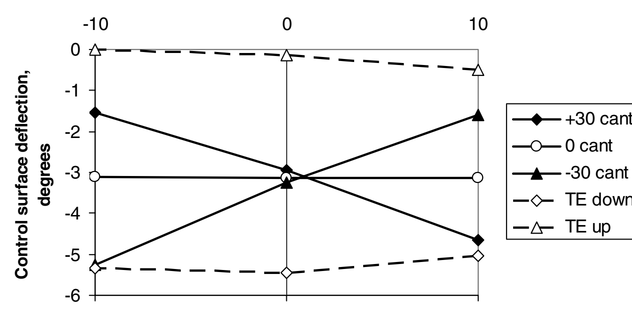

Fig. 7 Preliminary test result: deflection of free-floating control surface versus sideslip angle.

The canted tabs were then replaced with a conventional trailing edge tab with the same chord and the same total span as the three canted tabs combined. This tab was deflected trailing edge (TE) up approximately 4.3 deg ($\delta_t = -4.3$ deg). The automobile with the stabilizer was again driven in a straight line at 18 m/s, and the control surface deflection was recorded for the three different yaw angles. This tab was then replaced with a conventional trailing edge tab that was deflected trailing edge down approximately 4.3 deg ($\delta_t = 4.3$ deg), and the tests were repeated. The results are plotted in Fig. 7. The control surface free floated without any tab deflection at approximately $\delta_a = -3$ deg (marked “0 cant” in Fig. 7). The results clearly show that a positive canting angle and a positive side slip lead to a negative control surface deflection (marked "+30 cant" in Fig. 7), and vice versa. The control surface deflection due to side slip with no canting angle was negligible. The conventional trailing edge tabs deflected TE up or down were also more or less unaffected by side slip. The conventional trailing edge tab at 4.3 deg TE down had approximately the same effect on the control surface deflection as the 30 deg canted tabs under 10 deg side slips. This correlates well with the estimate at the end of Sec. IV. However, the conventional trailing edge tab deflected 4.3 deg TE up had a larger effect on the control surface deflection than the 30 deg canted tabs under 10 deg side slips. The discrepancy may be attributed to any or all of the uncertainties involved in the analytical estimate as well as in this preliminary test including road surface evenness, thickness of the trailing edge and the boundary layer of the control surface, quality of the airflow, etc. The information gained from these preliminary tests was considered sufficient to proceed and develop an installation for flight testing of a manned aircraft.

VI. Canted Tab Installation on an Aermacchi AM.3

The canted tabs were flight tested on an Aermacchi AM.3 "Bosbok" single internal combustion engine, propeller, high-wing, conventional gear (i.e., tailwheel) aircraft. The aircraft was designed for the military missions of forward air controller, reconnaissance, and light utility. The aircraft was equipped with a 320 hp Lycoming–Piaggio six-cylinder supercharged engine. The aircraft is capable of carrying a crew of two or may be configured to carry small cargo loads. The maximum takeoff weight is 3858 lbs. The aircraft is capable of very short field operations, requiring less than 1000 ft at standard day, sea level conditions. This aircraft has negative lateral stability, and it is thus well suited for testing the function of canted tabs. The Bosbok of Flight Research, Inc., in Mojave, California, was used for the manned flight testing.

Two ailerons for the Bosbok were acquired and outfitted with three carbon fiber canted tabs each. The ailerons have a 2.4 m span, the root chord is 0.62 m including a geared tab, and the tip chord is 0.44 m. Three carbon fiber canted tabs, each with 0.25 m span and 0.1 m chord, were designed and manufactured for each aileron.

The carbon fiber canted tabs were manufactured by vacuum infusion, using computer numerically controlled milled molds of high-density polyethylene. Upper and lower shells of the tabs were vacuum infused in separate molds. The layup consisted of two layers of Hexcel 282 woven carbon fiber fabric with one layer oriented in the $0/90$ deg direction and the other in the ± 45 deg direction with respect to the leading edge. The fabrics were infused with L285 epoxy mixed with H287S slow hardener from MGS Kunstharzprodukte, GmBh. After room temperature cure, a 7.94 mm diameter and 1.65 mm wall thickness 2024-T3 aluminum tube with a 32 mm long roll pin pressed perpendicular through the tube was inserted between the carbon fiber shells. The two carbon fiber shells and the aluminum tube with the roll pin were adhesively bonded with SIA E2119 epoxy adhesive from Sovereign Specialty Chemicals, Inc. After the adhesive had cured for 24 h at room temperature, the assembly was post cured by slowly ramping the temperature to 80°C, maintaining this temperature for at least 1 h, and slowly ramping down to room temperature. The tabs were then trimmed in an abrasive waterjet cutter and finally sanded by hand.

The strength of the canted tabs was checked in two ways. First, a tab was clamped between two compliant foam rubber sheets, and the aluminum axle was torqued until failure. For this test, the hollow aluminum axle was replaced by a stronger, solid axle. Multiple tests were performed, and in each case the aluminum axle failed. No indication of any failure of the carbon fiber tab was detected.

Second, the force and moment on the canted tab were estimated from dynamic pressure and equilibrium arguments. These were then verified by mounting a canted tab through a special bearing through the sun roof of an automobile and measuring the torque using a small beam type torque wrench in combination with a bracket doubling the resolution. The loads and deformations were very small for any angle of attack. The estimated factor of safety to structural failure was more than 5 for the flight speeds expected.

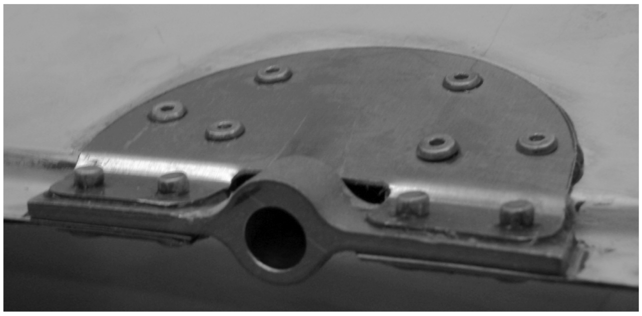

Fig. 8 Bearing block for the canted tab axle at the aileron trailing edge.

Fig. 9 Torsional test of small control surface with bearing block mounted at trailing edge.

The aluminum tubes of the canted tabs were connected to servos so that the canting angle φ could be changed in flight. The tabs were made adjustable for flight research purposes and may or may not be adjustable on a production aircraft depending on the application; for example, fixed tabs would be used to correct a lateral stability deficiency whereas adjustable tabs could be used to change lateral stability characteristics in flight. The trailing edge of the Aermacchi AM.3 ailerons had to be modified to accommodate bearing blocks for the aluminum tubes of the canted tabs. Such a modification is likely to reduce the torsional stiffness of the aileron, which is of major concern for flutter resistance. To evaluate the effect of the trailing edge modification, a control surface was modified with the trailing edge bearing block and the torsional stiffness was measured. The bearing block is shown in Fig. 8. Rather than using an aileron, a small trim tab was used for this test, shown in Fig. 9. It was torsionally tested by clamping one end in a waterjet cut bracket and clamping it to a table. Further up on the control surface, a rocking bracket was mounted. A weight was hung on the rocking bracket so that the control surface was loaded in torsion. The torsion of the control surface was measured using a digital level. Torsion of the unmodified control surface resulted in 1.7 ± 0.2 deg twist when loaded with a 0.45 kg mass hung on the rocking bracket. A cutout was then made in the trailing edge for the bearing block. The cutout resulted in a reduced torsional stiffness, and the twist of the control surface increased to 2.2 deg under the same load. The bearing block assembly, which consisted of a waterjet cut aluminum bearing block and two cover plates, was then riveted and bonded to the control surface. The twist with the bearing block mounted was 1.7 ± 0.2 deg under the same loading. The torsional stiffness for this control surface thus appeared to be regained, and flutter due to reduced torsional stiffness should not be a major concern. Possible strength reduction of the control surface was checked by increasing the load until the control surface skins buckled in torsion. There was no appreciable difference in torsional buckling load between the unmodified and the modified control surfaces. In both cases, the buckling shapes were large wavelength buckling modes of the skins not directly associated with the region affected by the trailing edge modification.

As already stated, for the flight testing the canted tabs were servo controlled. A Ray Allen T2-10A servo was mounted on the leading edge of each aileron. The aluminum tubes of the canted tabs ran through the trailing edge bearing blocks and through phenolic bearing blocks mounted on the aileron leading edge. Bell cranks were attached to the aluminum tubes and push–pull rods connected them to the servo. The installation can be seen in Fig. 2.

The modification made the ailerons tail heavy and thus possibly prone to aerodynamic flutter. The ailerons have fairly large counterbalances protruding forward of the ailerons and into the wing. These counterbalances were modified by heating them and melting lead into a cavity, as well as wrapping a lead sheet around the weights. The balancing procedure of the aircraft calls for underbalanced (tail-heavy) ailerons. The original balancing procedure was used, and the ailerons were underbalanced to the same degree. The increased size of the counterbalances may have slightly limited the maximum aileron deflections, but this was not considered critical for the present purpose of flight testing.

The electrical wires controlling the tabs were routed forward of the ailerons and the flaps and into the cockpit. The wires were connected to a box with controls for the canted tabs and indicators for monitoring their deflections. The test pilot operated the canted tabs in flight.

VII. Flight Testing

Flight testing was performed by installing the modified ailerons on the Aermacchi AM.3 Bosbok of Flight Research, Inc., Mojave, California. This aircraft has negative lateral stability, which is particularly apparent during steady heading side slips where a stick force in the "wrong" direction is required.

Flight testing of the Bosbok equipped with canted tabs was for most flights done by a test pilot and a flight test engineer. Only the first few flights, conducted to verify safety in general and flutter resistance in particular, were carried out without a flight test engineer. Test flights to investigate bank-to-bank rolls, steady heading side slip (SHSS), and spiral stability were performed.

The first flight was performed as follows: $1/3$ flaps were set for takeoff. After liftoff, the aircraft accelerated in level flight above the runway to 80 kn and then climbed to 500 ft before turning towards the flight test area. After reaching altitude, it slowed down and was trimmed for 65 kn, at which speed rapid stick raps were performed. The stick was deadbeat, i.e., there was no indication of flutter. The aircraft was then accelerated to 80 kn, and stick raps were again performed with no indication of flutter. The same was repeated at 90 kn and 100 kn with no indication of imminent flutter. All subsequent flight tests were performed at 80 kn indicated air speed (KIAS).

During five subsequent flights, bank-to-bank rolls, SHSS, and spiral stability tests were performed. Rudder deflection was measured using a tape measure attached to the right rudder pedal, and stick deflection was measured using a tape measure attached to the stick. Stick force was measured using a handheld stick force gauge. Rudder and stick deflection accuracies are believed to be approximately 2 mm, and stick force accuracy is believed to be approximately 2 N (0.5 lb). Timed 30 deg bank-to-bank rolls were performed with stick deflections measured. The results from the bank-to-bank rolls are plotted in Fig. 10. The figure shows roll response, as measured by the inverse of the time ($1/T$) from 30 deg bank in one direction to 30 deg bank in the opposite direction, versus stick deflection for different settings of the canted tabs. Negative stick deflections, with solid markers, indicate left deflections. The two lines are linear regressions of the left and right data, respectively.

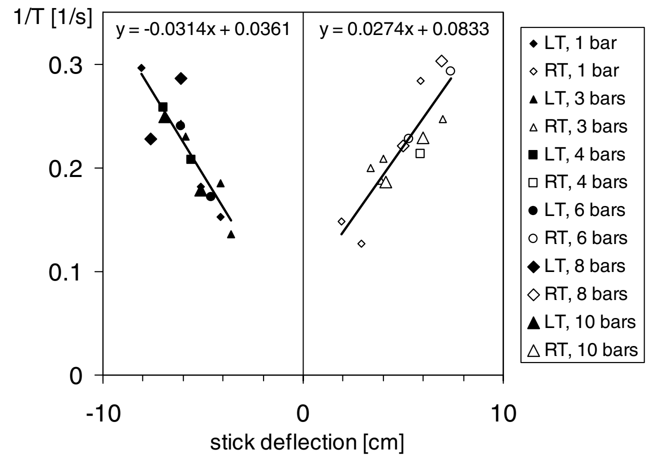

Fig. 10 Bank-to-bank rolls (30 deg) with different tab canting angles at 80 KIAS.

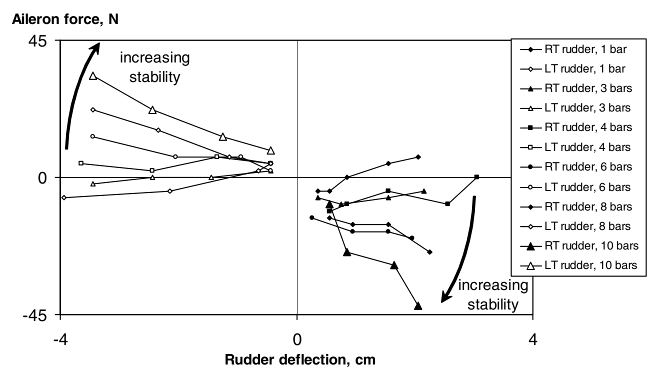

Fig. 11 Aileron force versus rudder deflection during steady heading side slip.

The canting was measured in terms of lighted "bars" on the tab controller. The bars correspond to the following canting angles: 1 bar corresponds to a 0 deg canting angle of the tabs, i.e., tabs aligned with the aileron trailing edges; 3 bars correspond to a 5.7 deg canting angle of the tabs; 4 bars correspond to a 9.1 deg canting angle of the tabs; 6 bars correspond to a 15.9 deg canting angle of the tabs; 8 bars correspond to a 22.5 deg canting angle of the tabs, and 10 bars correspond to a 29.3 deg canting angle of the tabs. The data suggest that the canting angle of the tabs has very little influence on bank-to-bank roll rates. This result, although expected, was appreciated because it indicates that the canted tabs do not adversely affect the roll control of the aircraft. However, the test pilot indicated that stick forces subjectively appeared to be slightly higher due to the presence of the canted tabs but that the increase in stick force was reduced for higher canting angles. This result was also expected. Bank-to-bank rolls were also performed with $1/3$ flap setting, yielding virtually the same results as without flaps.

Steady heading side slips were also performed at 80 KIAS and with $1/8$, $1/4$, $3/8$, and $1/2$ rudder deflections to the right and to the left. The stick force was measured as an indication of lateral stability, Fig. 11. During a steady heading side slip with a right rudder input (defined as positive), the stick force should be to the left (defined as negative) for a laterally stable aircraft. Likewise, a negative (left) rudder input should result in a positive (right) stick force. Thus, points in the first and third quadrants (upper right and lower left) in Fig. 11 indicate negative lateral stability. It is seen in Fig. 11 that with no canting angle the stick force is in the proper direction for small rudder inputs such as 1 cm. However, for larger inputs, the sign of the stick force is reversed, which indicates a laterally unstable aircraft. However, as the canting angle increased, the aircraft became more laterally stable. At 6 bars, corresponding to a 15.9 deg canting angle, the lateral stability became positive for all rudder inputs. Further increased canting angles lead to increased lateral stability as seen by the increased stick force (in the proper direction). For maximum canting (10 bars or 29.3 deg), the stick force was 33–42 N (7.5–9.5 lbs) for $1/2$ rudder deflection (approximately 3 cm). This is the main result of the present research.

Finally, spiral stability checks were performed by initiating 20 deg bank turns and then letting all controls free. The bank angle after 20 s was recorded. Spiral stability checks were performed both to the left and to the right. The results from these tests are inconclusive, at least partly due to large experimental scatter. The bank 20 s after the controls were released varied between 8 and 27 deg to the left and varied between 10 and 38 deg to the right, with no strong correlation to the tab canting angle. (The test data suggest that there may have been a slight correlation between tab canting angle and bank after 20 s, with increased canting angle leading to reduced bank angle to the left but increased bank angle to the right.) The expected result was that increased canting angle would lead to reduced bank angles in both directions or increased spiral stability. It is believed that there may have been too much friction in the control system on the particular test aircraft for the tabs to be effective for this test.

VIII. Simplified Procedure for Sizing Canted Tabs on Existing Airplane

In the following, a procedure for sizing canted tabs to an existing aircraft with lateral stability deficiencies is suggested. One or multiple conventional aileron trailing edge trim tabs are required for this procedure. The aircraft is first flown without canted tabs. It is trimmed for the airspeed, altitude, and configuration for which lateral stability modification is needed. The aileron trim tab deflection δ_{t0} is recorded. A steady heading side slip is then initiated, and the side slip angle is recorded. Stick force is measured. The aileron trim tab is then deflected until the desired stick force is obtained while maintaining the steady heading side slip. This trim tab deflection δ_{t1} is recorded.

An estimate of the size of canted tabs required to obtain the same stick force can be based on Eqs. (12) and (13). Equating these forces, $L_z^r = L_z^c$, and assuming that $C_{L\alpha}$ is the same for the canted tabs as for the conventional tabs leads to

$$S_c = \frac{2(\delta_{t1} - \delta_{t0})}{\beta \sin 2\varphi} S_r \tag{14}$$

where S_t is the total planform area of the trim tab/tabs (independent of whether there is one trim tab on each aileron or only one trim tab on the aircraft) and δ_{t0}, δ_{t1}, and β are measured in the same units (radians or degrees). A better estimate could be made if the chords of the wing, aileron, and trim tab were known. If increased lateral stability is needed, the tabs should be canted in the direction shown in Figs. 1 and 2.

There can be one or many canted tabs on each aileron. A suggestion is to use more than one canted tab because their individual size can be reduced. An aspect ratio of the trim tabs of 2–2.5 is proposed. A slightly thick trailing edge is suggested for improved effectiveness, stiffness, and robustness, at the expense of slightly increased drag.

The sizing procedure will be elucidated with an example: an airplane equipped with a trim tab of the size $S_r = 0.1\ \mathrm{m}^2$ on one aileron (and none on the other) has a lateral stability deficiency. The airplane is trimmed for the airspeed and configuration where the lateral stability needs to be increased. The trim tab deflection is $\delta_{t0} = 1$ deg. A $\beta = 4$ deg steady heading side slip is initiated. The trim tab is deflected until the desired stick force is obtained while maintaining the steady heading side slip. This requires a trim tab deflection of $\delta_{t1} = 2$ deg. The estimated total planform area of the canted tabs, canted at the angle $\varphi = 30$ deg, is

$$S_c = \frac{2(\delta_{t1} - \delta_{t0})}{\beta \sin 2\varphi} S_r = 0.058\ \mathrm{m}^2 \tag{15}$$

Three canted tabs on each aileron may be chosen (six total). Thus, the planform area of each tab will be $0.0097\ \mathrm{m}^2$. With an aspect ratio of 2.5, each tab would have the dimensions 0.156×0.062 m.

IX. Conclusions

Small canted tabs mounted on the trailing edges of ailerons were investigated. An approximate theoretical estimate of their effect on lateral stability was presented and verified with preliminary experiments. Ailerons for a single engine propeller aircraft were modified and flight tested. The flight tests showed that the canted tabs were very effective. No negative effects of the canted tabs were encountered. The laterally unstable test aircraft was transformed into a stable aircraft with the addition of the canted tabs. A simple procedure for sizing canted tabs on existing aircraft with lateral stability deficiencies was proposed. The main benefit of the canted tabs may be as a simple fix to lateral stability deficiencies, replacing complex and costly structural modifications such as changing wing dihedral or adding or modifying wingtips. It may be added that, after a short news article about the flight tests was published, a general aviation manufacturer built and flight tested canted tabs on one of their business jets. The results from these tests are at present proprietary.

As a note, looking at Fig. 2 it appears as though the aileron tip fairing of the Bosbok has the opposite effect of the canted tabs. Is there any chance that the negative lateral stability of the Bosbok is simply due to the dihedral shape of this aileron tip fairing, which is mounted to the aileron and not to the wing? Whatever the reason, the canted tabs fixed the lateral stability deficiency.

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