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Wind Tunnel Investigation of Spoiler Effectiveness on a low Aspect-Ratio Swept Wing with reflex Airfoils

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INTRODUCTION & AIM

During the development phase of a new radio-controlled aircraft at the Politecnico di Milano, characterized by a 40° sweep angle, a pronounced taper ratio, and a very low aspect ratio, it became necessary to evaluate the implementation of roll control using either conventional ailerons or spoilerons.

To support this design choice, a preliminary comparison was conducted using analytical methods (DATCOM), which are traditionally based on conventional airfoil data. However, a distinctive feature of this compact aircraft under development introduced the need to validate these preliminary estimates: the aircraft employs experimental reflex airfoils for which no prior data are available.

These factors led to the necessity of conducting wind tunnel tests in order to validate the predictions obtained from analytical methods for this class of airfoils, while simultaneously assessing roll performance. This work was also carried out to extend the conventional chordwise and spanwise ranges for spoileron placement.

The results were then evaluated through the introduction of performance indices, designed to provide the aircraft designer with sensitivity parameters related to geometry and spoiler positioning, ultimately supporting the optimization of spoiler sizing and placement on the wing during the development phase.

METHOD

The experimental campaign was conducted in a wind tunnel featuring a square test section with a side length of 2.4 m, operating at a wind velocity of 30 m/s, corresponding to an equivalent Reynolds number of 1e6.

The model was set at the centre of the test section on a 1,2 m high pylon, while the data acquisition system was installed on the wind tunnel wall at the base of the pylon.
The test model was machined from solid aluminium. The experimental campaign was carried out by installing spoilers manufactured from Plexiglas and secured using FDM 3D-printed supports at various locations along the upper surface of the right wing.
The spoilers were characterized by the following parameters: the ratio between the spoiler chord and the local wing chord, the ratio between the spoiler span and the wingspan, the geometric position along the wing, and the spoiler deflection angle.
A performance mapping of the spoiler was first conducted by maintaining a constant spoiler-to wing chord ratio, of 0.15, defined during the preliminary design phase of the RC model, while varying the spoiler starting position both in the spanwise ($\frac{b_s}{b}$ from 0.4 to 0.6) and chordwise directions ($\frac{c_s}{c}$ from 0.4 to 0.6). Subsequently, at selected locations, the investigation was extended with a sensitivity analysis by varying either the spoiler-to-wing chord ratio, the spoiler span ratio or the deflection was carried out.

RESULTS & DISCUSSION

Figure 1 illustrates the discretization used for spoiler performance mapping. The orange region represents the domain covered by DATCOM data, highlighting the extension investigated in this study, with test points moved toward the leading edge.

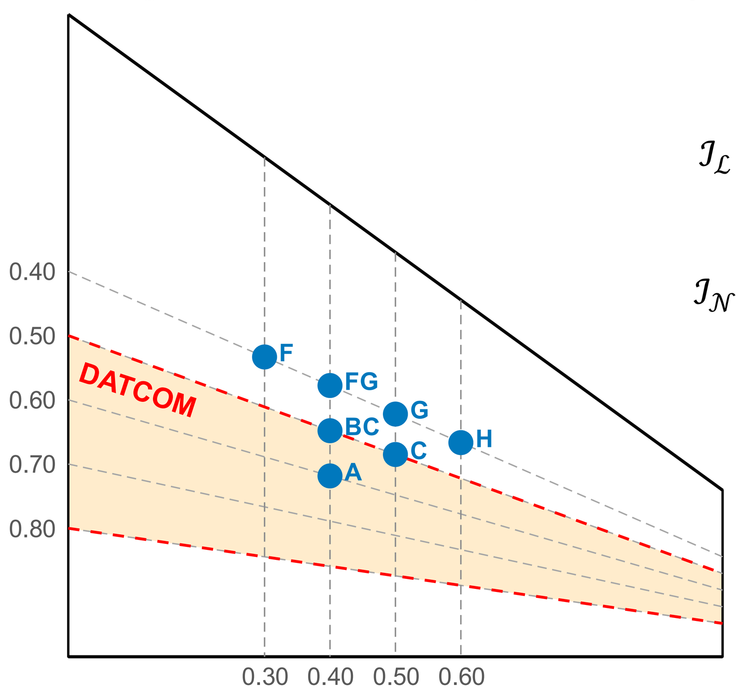

Fig.1 Test position discretisations

$$\mathcal{I}_{\mathcal{L}} = \frac{C_{\mathcal{L}}}{S_{spoiler} d_{spoiler}}$$

$$\mathcal{I}_{\mathcal{N}} = \frac{C_{\mathcal{N}}}{S_{spoiler} d_{spoiler}}$$

$$C_{\mathcal{N}} = \frac{\mathcal{N}}{0.5\rho V^2 Sb}$$

$$C_{\mathcal{L}} = \frac{\mathcal{L}}{0.5\rho V^2 Sb}$$

ρ	Air Density $[kg/m^3]$
V	Air Velocity $[m/s]$
S	Wing Surface $[m^2]$
b	Wingspan $[m]$
$S_{spoiler}$	Spoiler Surface $[m^2]$
$d_{spoiler}$	Spoiler Lever Arm $[m]$
$\mathcal{L}$	Roll Moment $[Nm]$
$\mathcal{N}$	Yaw Moment $[Nm]$
$C_{\mathcal{L}}$	Roll Moment Coefficient $[-]$
$C_{\mathcal{N}}$	Yaw Moment Coefficient $[-]$
$\mathcal{I}_{\mathcal{L}}$	Roll Performance Index $[m^{-3}]$
$\mathcal{I}_{\mathcal{N}}$	Yaw Performance Index $[m^{-3}]$

As shown in Fig. 2a, the preliminary campaign includes only three angles of attack (0°, 8°, 16°). Results are consistent with NACA/NASA findings, showing peak performance at intermediate angles of attack, followed by a decrease.
For spoileron design purposes, the effects of positioning and geometry may overlap, making it difficult to identify an optimal design strategy. For this reason, the merit indexes $\mathcal{I}_{\mathcal{L}}$ and $\mathcal{I}_{\mathcal{N}}$ were introduced to filter out the influence of the spoiler arm $d_{spoiler}$ and its surface area $S_{spoiler}$. This approach enables the identification of an optimal configuration independent of geometric scaling effects. As shown in Fig. 2a, doubling the chord (and thus the surface area) leads to a significant performance improvement. However, Fig. 2b shows that, when the indexes are introduced, a comparable performance increase, at angles of attack close to the maximum values suggested by NACA, can be achieved through a slight increase in the spoiler spanwise extension rather than in chord, while keeping the chord equal to the baseline configuration.
From a design standpoint, the results suggest that, for a given lever arm, increasing the spoileron span is more effective than increasing its chord, leading to reduced surface area and lower actuation force requirements.
Figure 3a and 3b present the mapping results at 8°, corresponding to the best-performing intermediate angle of attack. All test cases share the same spoileron configuration ($C_s/C = 0.15$, deflection 50°, $b_s/b = 0.3$. A clear performance peak is observed at position C, located beyond the conventional DATCOM applicability range.

Spoileron	Base	Span+	ΔArea	Chord+	ΔArea
Area $[m^2]$	0.0094	0.0126	+34%	0.0189	+100%

Tab.1 Total spoiler surface area variation

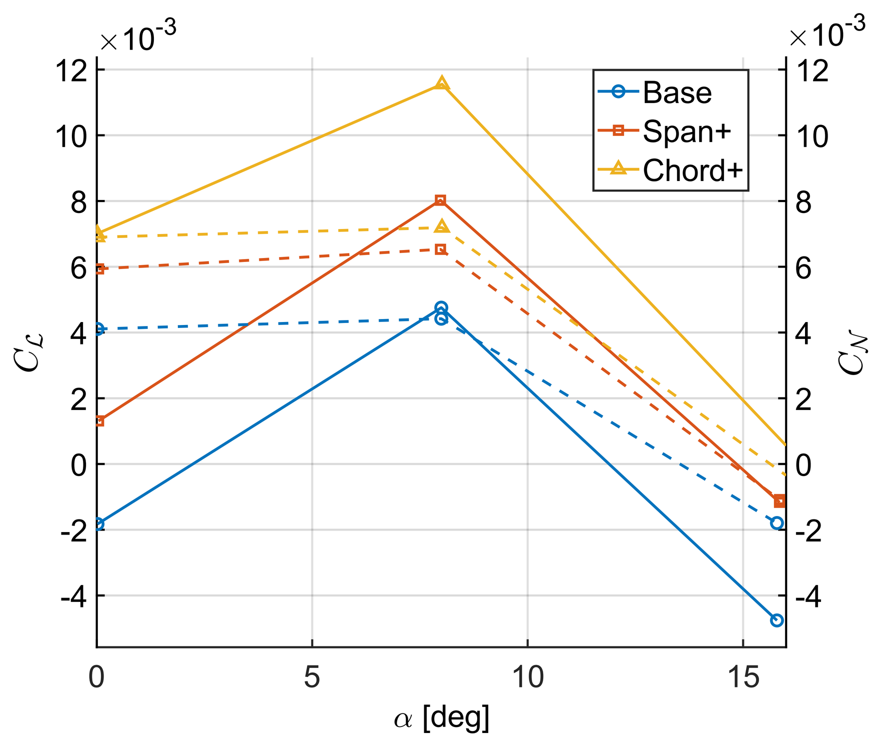

Fig.2a $C_{\mathcal{L}}$ and $C_{\mathcal{N}}$ evaluated in position H

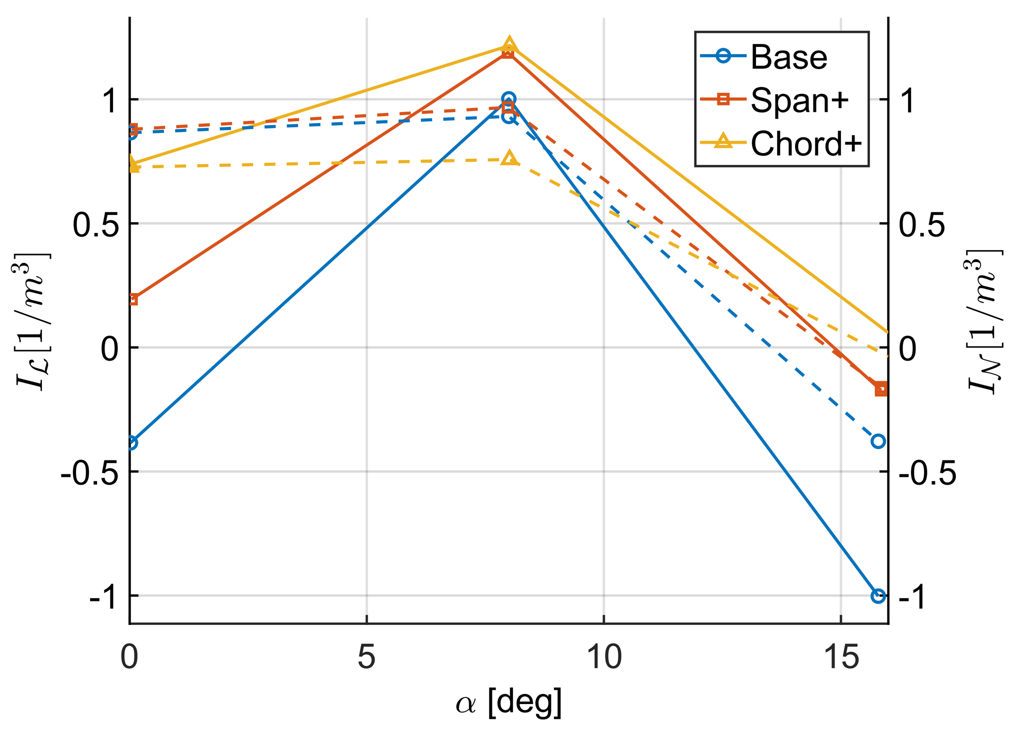

Fig.2b $\mathcal{I}_{\mathcal{L}}$ and $\mathcal{I}_{\mathcal{N}}$ evaluated in position H

The presence of a maximum at mid-span is also consistent with the predictions provided by DATCOM. However, the observed maximum is in an extended region compared to the area previously tested.

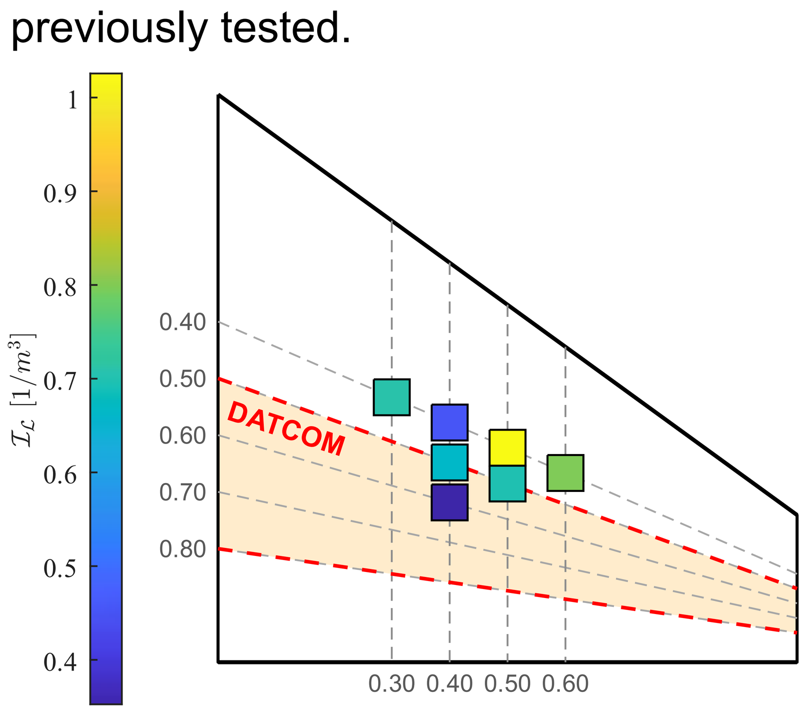

Fig.3a $\mathcal{I}_{\mathcal{L}}$ mapped at α = 8°

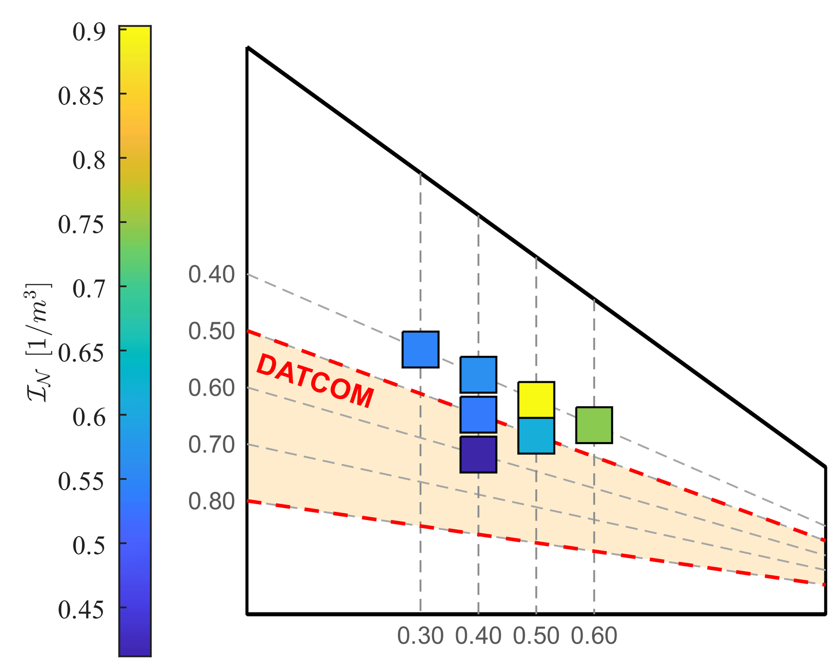

Fig.3b $\mathcal{I}_{\mathcal{N}}$ mapped at α = 8°

In terms of $C_{\mathcal{L}_{\delta s}}$ and $C_{\mathcal{N}_{\delta s}}$, an additional study was carried out at point A by varying the spoiler deflection in order to compare DATCOM predictions with the experimental results. The trend is found to be linear. For the rolling moment coefficient, discrepancies are present but remain limited, whereas the yawing moment coefficient is significantly mispredicted.

	$C_{\mathcal{L}_{\delta s}}$ [1/rad]	Error [%]	$C_{\mathcal{N}_{\delta s}}$[1/rad]	Error [%]
DATCOM	0.0177	-	0.0043	-
WTT – 0°	0.0200	+ 13.00	0.0064	+ 48.83
WTT – 10°	0.0191	+ 7.91	0.0088	+104.65

Tab.2 Comparison WT results with DATCOM prediction

CONCLUSIONS

This preliminary study, to be further expanded, shows behaviour consistent with conventional airfoils in terms of aircraft roll and yaw response. The proposed merit index $\mathcal{I}_{\mathcal{L}}$ and $\mathcal{I}_{\mathcal{N}}$ also supports an alternative design strategy, identifying the most effective parameters for spoileron sizing optimization. Based on these results, improving roll or yaw performance is more effectively achieved by increasing the span rather than the chord, thereby limiting the increase in spoileron surface area and, consequently, the required actuator force.

FUTURE WORK/ REFERENCES

Future developments of this work will include a finer discretization of the roll and yaw curves as functions of angle of attack, a more detailed analysis of the roll and yaw coefficients with respect to spoiler deflection, and an assessment of the impact on the overall aircraft lift.

«*Data on spoiler type ailerons*», John G. Lowry, NACA RM L 53124, 1953
«*Investigation of effect of span, spanwise location, and chordwise location of spoiler on lateral control characteristics of a tapered wing*», Jack Fischel and Vito Tamburello, NACA TN 1294,1947
«*USAAF stability and control DATCOM*», R. Fink, USAAF, 1978