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# Engineering Notes

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## Canard Tip Vortex Splitting in a Canard–Wing Configuration: Experimental Observations

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### Nomenclature

AR = aspect ratio
$b$ = span, m
$c$ = mean geometric chord of the wing, m
$K$ = calibration probe constant, 1/m
$L$ = stagger at the root section, m
$q_\infty$ = freestream dynamic pressure, N/m²
$T$ = gap at the root section, m
$U$ = module of the velocity at the point of measurement, m/s
$x, y, z$ = coordinate axis, see Fig. 1, m
$\alpha$ = angle of attack, deg
$\Gamma$ = circulation around the circuit defined by the instrument, m²/s
$\Lambda$ = sweep angle at one-quarter of the chord, deg
$\lambda$ = taper ratio
$\xi$ = instrument response
$\rho$ = fluid density, kg/m³

*Subscripts*
$c$ = canard
$w$ = wing

### Introduction

IN previous works the aerodynamic behavior of canard configurations was studied, both experimentally (by measuring forces[1] and pressure distributions[2]) and numerically.[3,4] For a correct numerical simulation a suitable representation of the vortex wake is necessary, as to both its position and intensity distribution. No important differences between experiments and numerical predictions arise when the canard wake does not strongly interfere with the wing surface (see, e.g., Ref. 4), but the results are not as good when this interference is strong. In this situation, a suitable numerical representation requires a deeper knowledge of the physical behavior of the canard vortex wake. This is especially true when it directly impinges on the wing, near its leading edge; in fact, in these conditions, the behavior of the vorticity field has not yet been clarified. In previous investigations[3,4] it has been shown that computational potential models may, for specific configurations, predict a splitting of the fore surface tip vortex into two parts: 1) passing over and 2) below the rear surface; recently, the possibility of this phenomenon has also been found by applying a Navier–Stokes solver to a close-coupled canard–wing configuration.[5]

In order to better understand the canard wake evolution, an experimental activity was set up; in this Note the possibility that, at certain angles of attack, the canard tip vortex might be really split at the wing leading edge into two well-defined cores, flowing along the upper and lower wing surfaces, respectively, is investigated.

### Description of the Tests and Analysis of the Results

The tests were carried out in the wind tunnel of the Department of Aerospace Engineering of Pisa, which has a circular open test section 1.1 m in diameter. Semimodels supported by a reflection plane were used. In Ref. 1 a more detailed description of the wind tunnel, the models, and the mounting scheme is reported. The adopted geometric conventions and the studied configuration (a low-canard one, with no decalage angle) are shown in Fig. 1.

In order to measure the freestream component of vorticity, a particular pressure probe was used; it is basically composed of four yaw-meters measuring the circulation around a small circuit 5 mm in diameter. The theoretical concepts underlying its operation are described by Freestone,[6] while the details regarding its construction and calibration are reported in Refs. 7 and 8. The response of the instrument is a pressure difference that, nondimensionalized with the freestream dynamic pressure, may be expressed by the relation[8]

$$\xi = K\rho U\Gamma/q_\infty \quad (1)$$

the constant $K$ depending on the probe geometry. The pressure measurements were performed by means of model 230

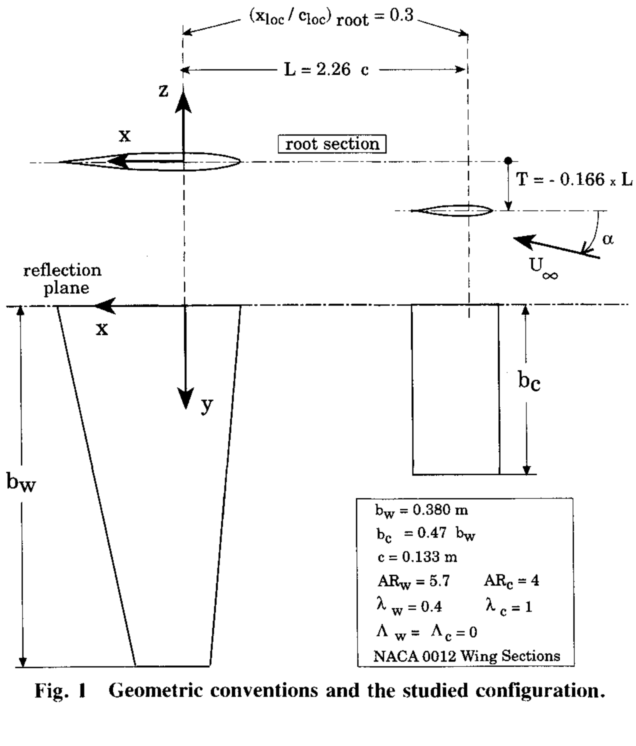


**Fig. 1 Geometric conventions and the studied configuration.**

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SETRA pressure transducers, with 0.14% full-scale accuracy; the signals were acquired with a 16 bit A/D converter.

It may be observed from Eq. (1) that the probe response $\xi$ is proportional, for a given incompressible freestream condition, to the quantity $U\Gamma$. However, it should be noted that in developed axial vortices such as that present in the wake of lifting surfaces, the tangential velocity component is small compared to the axial one, which, in turn, is of the same order as the freestream velocity[9]; therefore, the local velocity is almost constant. The response of the instrument can then be assumed to be proportional, with a reasonable approximation, to the circulation, and may then be taken as a measure of the mean vorticity inside the measurement circuit. In any case it is evident that for the purpose of the present work absolute accuracy of measurements is not necessary, the main object of the analysis being a characterization of the physical aspects of the flow.

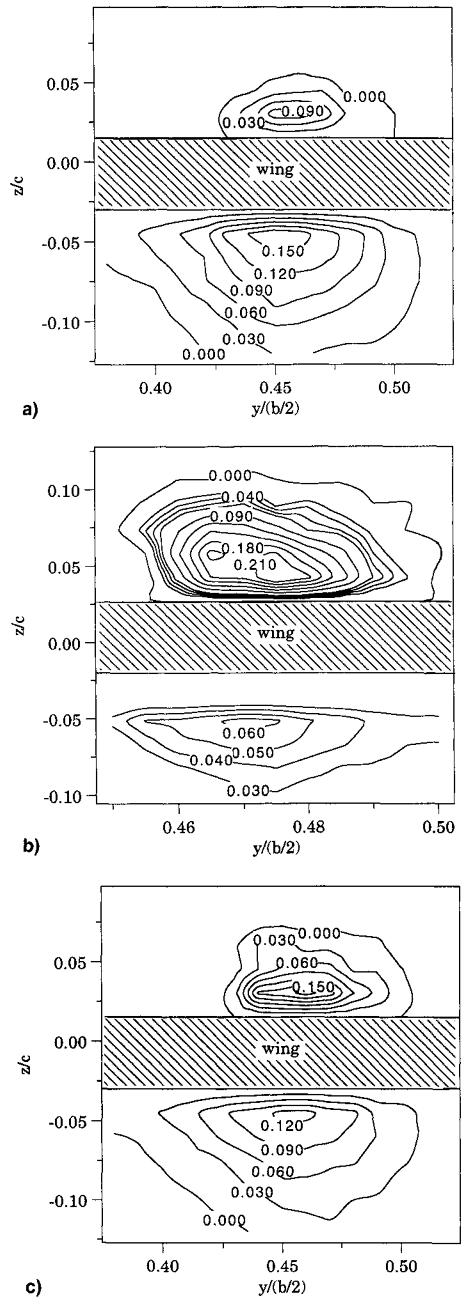


**Fig. 2 Isolines of the $\xi$ quantity at the plane $x = -0.2c$ (approximately 0.1 local chords downstream the wing leading edge). View from positive $x$ – positive value counterclockwise vorticity. $\alpha$ = a) 9, b) 10, and c) 9.5 deg.**

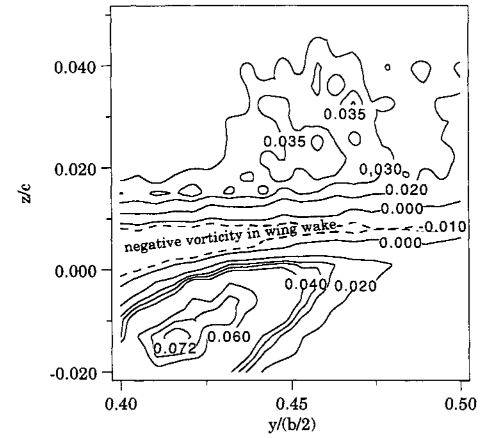


**Fig. 3 Isolines of the $\xi$ quantity at the plane $x = 0.9c - \alpha = 9.5$ deg (approximately 0.2 local chords downstream the wing trailing edge). View from positive $x$ – positive value counterclockwise vorticity.**

To study the interference effects between the canard wake and the wing, the freestream vorticity field was measured at various cross sections; in each section, measurements were carried out on a square grid of points with 2-mm-size meshes. The test velocity was approximately 25 m/s. In order to assess the physical plausibility of the tip vortex splitting, it was decided to carefully investigate whether a range of angles of attack existed, over which the switching occurred from the condition with wake passing totally below to that with wake passing totally above the wing.

The results showed that the splitting of the vortex into two parts could indeed be observed. Up to $\alpha$ slightly lower than 9 deg the canard tip vortex flowed along the lower surface of the wing, whereas, for $\alpha$ slightly higher than 10 deg it flowed along the upper surface of the wing. The transition from one flow condition to the other is of a continuous type: i.e., there is no step between the two situations. In the preceding range the canard tip vortex is split into two parts at the leading edge of the wing, flowing along the lower and the upper surfaces of the wing, respectively. The results show that progressively increasing $\alpha$ results in the progressive transition from a predominantly lower surface vortex (Fig. 2a, $\alpha$ = 9 deg), to a predominantly upper surface vortex (Fig. 2b, $\alpha$ = 10 deg). For $\alpha$ = 9.5 deg (Fig. 2c) the canard vortex splits into two comparable parts, in proximity of the wing leading edge. It is also extremely interesting to observe that downstream to the wing the two vortices are no longer similar (Fig. 3): indeed, while the lower one is still perfectly recognizable as a concentrated vorticity structure, the upper one is much more diffused. This behavior can be assumed to be typical.[8] In fact, in all the tested conditions, when the canard tip vortex flowed along the lower surface of the wing, it remained well-concentrated and defined; on the contrary, when it flowed along the upper surface, it lost its well-defined character. This difference in the physical behavior is probably due to the pressure distribution around the wing surface; indeed, the strong adverse pressure gradients existing on the upper surface greatly favor a rapid diffusion of the vortex.

## Conclusions

The splitting of the canard tip vortex in a canard–wing configuration was shown to be possible and was characterized through a simple pressure probe capable of detecting the freestream vorticity component. It was observed that, over a small range of angles of attack, depending on the gap value, the vortex could split into two parts at the wing leading edge: moreover, the part passing over the upper wing surface was more diffused and weaker than the one passing below the wing, probably due to adverse pressure gradients. It must be noted that such a high diffusion of the canard vortex may cause significant problems for the numerical prediction of the load on the wing, particularly when simple potential methods, which do not consider any diffusion effects, are used.

## Acknowledgments

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# Computational Study of a Conical Unit Aspect Ratio Wing at Supersonic Speeds

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## Nomenclature

$b$ = wingspan
$C_D$ = drag coefficient, drag/$q_\infty S$
$C_L$ = lift coefficient, lift/$q_\infty S$
$C_p$ = pressure coefficient, $p - p_\infty/q_\infty$
$M$ = Mach number
$M_N$ = component of the Mach number normal to the wing leading edge = $M_\infty \cos \Lambda \sqrt{1 + \sin^2\alpha \tan^2\Lambda}$
$p$ = pressure
$p_{t_2}/p_{t_\infty}$ = total pressure ratio
$q$ = dynamic pressure, $\frac{1}{2}\rho V^2$
$S$ = wing reference area
$V$ = velocity
$y$ = spanwise coordinate
$\alpha$ = angle of attack
$\alpha_N$ = angle of attack normal to the wing leading edge = $\tan^{-1}(\tan \alpha/\cos \Lambda)$
$\alpha_{N_{corr}}$ = angle of attack normal to the wing leading edge corrected for thickness = $\alpha_N - \delta_f$
$\delta_f$ = streamwise leading-edge flow deflection angle
$\Lambda$ = wing leading-edge sweep
$\rho$ = density

*Subscripts*

$t$ = total flow conditions (i.e., flow conditions if flow is brought to rest isentropically)
2 = flow conditions downstream of a shock wave or local flow conditions
$\infty$ = freestream flow conditions

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## Introduction

FUTURE advanced high-performance military aircraft designs will be required to have high levels of aerodynamic performance and low radar cross section for survivability. These design requirements apply to various advanced military aircraft from missiles to bombers. A well-known common geometric characteristic of all highly survivable vehicles is sharp planform edges. The design requirement of a sharp-edge planform for increased survivability integrates well with the aerodynamic design philosophy for efficient supersonic flight. The focus of the present study is to assess the utility of a general computational method that may be applied to a variety of advanced military designs over a broad Mach number range.

A literature review of the current supersonic analysis and design methods identified an Euler equation code named the Euler Marching Technique for Accurate Computation (EMTAC[1,2]) as a promising preliminary computational analysis and design tool. The literature review also identified a candidate geometry for the assessment of EMTAC. The selected geometry is a conical delta wing of unit aspect ratio shown in Fig. 1. This geometry was chosen because the wing is conical and representative of the class of geometry of interest. Experimental results for this geometry have been documented extensively.[3,4]

This study compares results from computational analysis and experimental tests. The study results are presented for $C_L$, $C_D$ (integrated from the surface $C_p$ distribution), and the

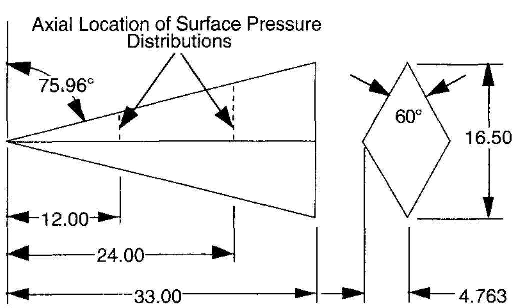


**Fig. 1 Description of geometry showing $x$ locations of the surface pressure distributions. (All dimensions are in inches.)**