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Vortex Structures on the Upper Surface of a Pointed Gothic Wing Observed at Low, Median and High Incidences

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Abstract

The purpose of the study reported in this paper is to assemble as much information as possible about the behaviour of vortex structures, in particular at very low incidences, but also, briefly, at median and high incidences on the upper surface of pointed gothic wings of different apex angles. The results highlight the starting point and subsequent progressive development of large vortex structures which, at mean incidences, will become concentrated and stable but undergo transformation from structures of a flow with raised edges to those with the standard vortex tube behavioral properties.

Keywords: Vortex structures; Apex angles; Wings

Notations

θ_, m: preferential angle associated with the whole numbers l and m

ℓ and m: whole numbers such as m > 0 and ℓ ≥ m

β: apex angle

C_o: height of wing

h: height of cone

R: radius of the circular base of the cone

i: incidence

V_o: speed of the flow at infinite up stream

Re: Reynolds number

α1: the main or interior inter vortex angle for wings

α2: the secondary or exterior intervortex angle for wings.

Introduction

Very much an impressive number of studies have been done to date into d wings, ogival wings, cones furthermore into pretty much straightforward thin bodies framed from blends of such segments; the discoveries have managed as much with the improvement of estimated hypotheses especially those by Jones as with the meaning of models pointing out vortex lift by unit range.

Visualizations of hyper lifting vortex structures, essentially those did by Werle [1-7], the investigation of weight and pace fields made by these vortices, with or without breakdown – outstandingly the examination by Solignac [8-11] –also give truly exceptional studies that are the standard works in their fields.

Effectively portrayed completely in such papers as, for instance, those by Werle, Solignac and Stahl [12-16], these discoveries offer today whole an exhaustive information of the properties of different sorts of thin bodies.

Nonetheless, given that the character of the majority of the viewpoints alluded to stays exact and constrained to either level of incidence or to a numeric range [17-19], the way lies open, beginning from exploratory information and different components of analysis [20], for new endeavors to be embraced to analyze the basic issues identified with the position of vortices made by such thin bodies.

A substantial number of photographic visualizations, concerning vortex streams created on the upper surface of delta or ogival wings and cones, have been done at the valenciennes university (France) laboratory [21,22] in such a path as to give a superior understanding of the advancement and situating of vortex structures at low and mean rate as well as at high frequency.

These visualizations have empowered need to be agreed to the study of illustrations of the most basic molded area, i.e. delta and ogival wings.

The results got in these two cases, completely depicted in past articles and papers, may be recognized to have astounding straightforwardness and thus pass on the major nature of these studies.

The inter vortex points have been found, under trial conditions, to have a special nature along these lines underlining a basic rakish characterization of the relative positions of single or twofold v.

Vortex Structures of Pointed Gothic Wing

Geometrical description

The profile under investigation in the wind tunnel is of pointed gothic wing having an apex angle β=52° and a chord C_o=240 mm. It is 1 mm thick.

Analysis of the results

The advancement of the vortex phenomena was followed regarding that parameter which applies the best impact on them, specifically the plot of occurrence of the setup in connection to the stream. The visualizations were done at an upstream speed of stream of 3 m/s.

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An Indication of the Primary Phenomena Occurring at Low and Mean Rates

1. i=0° : the stream is uniform on the upper side of the wing. The limit layer is watched yet there is non-stream partition up 'til now.

2. i=2°, i=5° :the upstream stream skirts around the main edges of the profile. Three zones get to be composed: a focal zone and two outer ones. The hyper lifting vortices coming about because of the detachment of the limit layer start to show up as progressively composed struct.

3. i=8° :the main and secondary vortices are clearly detected and have now become individualized, concentrated and separated from boundary layer. The central zone is visualized. There is fading out.

4. i=10°, i=15°, i=20° : the vortices increment in quality. Both the vortex stream and the bearing of the turn of the vortices are plainly seen. At that point focal zone has vanished. The vicinity of tertiary vortices is to be noted in spite of the fact that they are to a great degree hard to envision. There is no breakdown so.

5. i=25°: the breakdown phenomenon makes its appearance. The main vortices are breaking down a long way downstream from the profile: in fact, a more diffused mass of smoke is observed in this zone. The secondary vortices have broken down upstream from the trailing edge; as for the tertiary ones, which are difficult to observe because of their positioning at the edge of the boundary layer, it seems that they break down in the area close to the apex and coil around the main and secondary vortices. Once the secondary vortices have broken down, they also coil around the main ones. The asymmetry of the breakdown point of the main and secondary vortices is to be noted.

6. i=30° : the tertiary vortices have now totally vanished. The auxiliary ones are separating in the range of the trailing edge of the profile.

7.i=40°: the optional vortices separate close to the pinnacle though the purpose of breakdown of the principle ones has progressed to a third of the path along the harmony. A sudden extension at the center of the principle vortices is still perceptible, took after by an unsteady zone demonstrating truly significant turbulent.

NB: the position of the breakdown point is estimated on the basis of a main reading of the respective breakdown points of the right-hand and left-hand main vortices.

8. i=45° : the principle vortices separate at the fore quarter of the harmony; the optional ones are consumed by the primary vortices at the summit and no more unmistakable

9. i=50° : an aggregate breakdown of the vortices happens at the summit. Exceptional turbulence is seen at about the trailing edge

A Wing with an Apex Angle where β=50°(NP) (Figure 1)

By way of example, a view of one of the shapes obtained at very low incidence {i.e. i=4°} is examined. Subsequently, in the following pages, other views will be briefly scanned which describe the stages of the evolution of vortex structures. On the two enlarged photographs reproduced here {Views n° 1 and n° 2}, the following traits have been observed:

- at an extremely low incidence, e.g. where **i**=2°, the smoke trails envelop the upper surface without becoming concentrated around a vortex. One of the essential facts seems to be that the edges of the flow in the area close to the apex do not coincide with the leading edges of the wing. This reality appears to be linked to the non privileged and widely spaced value of the two privileged angles (45° and 54.7°) closest to the apex angle (β=50°).

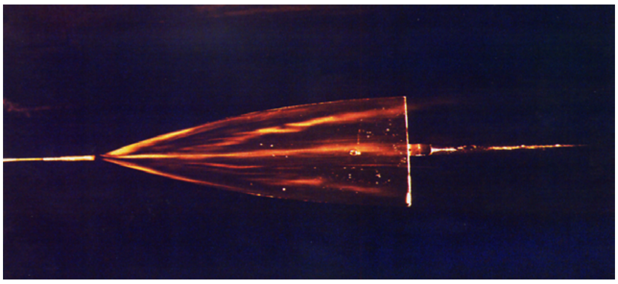

Figure 1: View n° 1: β = 50° i = 4°.

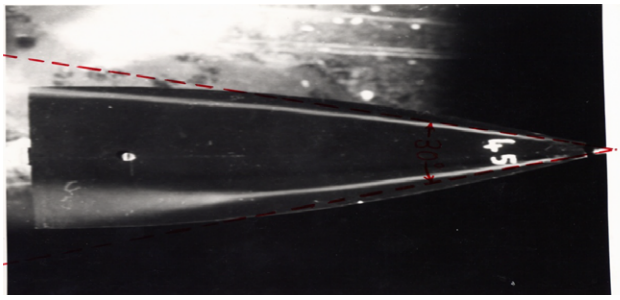

Figure 2: II.2View n° 2 – View of the upper surface : β=45° i=30° α1=30° α2=20.7°

- everything happens as if, at least in the proximity of the apex, the edges of the flow are already taking on the behavioral properties of vortex structures which refuse to form a non privileged angle.

- moreover, a particularly important enlarged photograph of an area of the wing close to the apex reveals that the initial tangents of the smoke flow are formed at 45°. Two inflections are then detected, one on each edge of the flow, which reduces the angle to one of 35.3°, i.e. an inferior privileged angle before, further downstream, the edges of the flow will at last, approximately, hug the wing's leading edges (Figure 2).

At median incidences, the formation is noted of two vortex structures separated by a non vortex flow space. Therefore, from 28° to 30°, is observed the beginning of the vortex breakdown, the flow of which rises from downstream to the apex. The vortex couple forms an angle of 30° which rotates in the opposite direction as shown in the figure below.

At high incidences, the phenomenon is noted of the vortex breakdown which ascends toward the apex while retaining a privileged angle and also sometimes the pulsation phenomenon makes its appearance. These observations are equally applicable to the process of using solar panels for the drying of fruit such as prunes, mangoes, bananas and mushrooms. The fusion of vortex structures is observed at angles over 30° (Figure 3).

The vortex structures close to the wing's leading edges

N_1 main vortex structures

N_2 secondary vortex structures

S_1 first breakaway

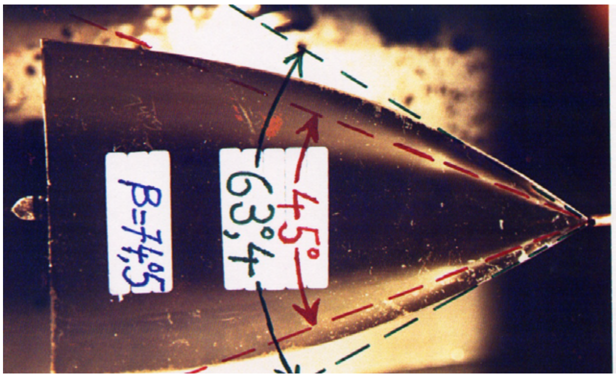

Figure 3: View n° 3 – View of the upper surface: β=74.5° i=40° α1=45° α2=63.4°.

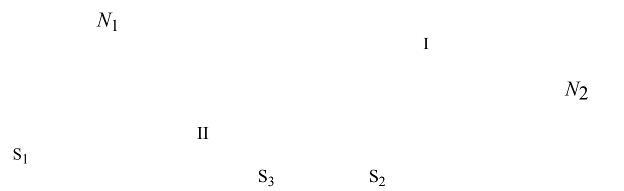

Figure 4: Vortex structures close to the wing's leading edges.

S_2 second breakaway

S_3 third breakaway (Figure 4)

The secondary vortex (II) flows in an opposite direction to that of the main one (I). As the structures are located on the upper surface of the wing, between S_1 and S_2, it is very difficult to visualize them by smoke trails because their rotational forces, according to Solignac et al., are from 3 to 5 times weaker than the main ones.

Comparison with vortex structures formed on the upper surface of thin gothic wings

The results of the study of the behavior of vortex structures on the upper surface of gothic wings [23] can be compared with the findings which can be obtained through another examination of the photographs published by Werle [6]. The figures numbered 11a, 11c and 11e in that publication reveal that, for the apex angle β, those structures can easily be calculated from the constituents E {namely, the relationship between the median chord at the edges of the flow and the parabolic shape of the leading edges}, each of which being individually and in the order mentioned 37°, 56.4° and 72.1° as indicated by H. WERLE [Private communication].

Conclusion

The progressive evolution from elementary vortices of the sheared flow before breakdown towards a particularly stable vortex system, wherein spatial positioning reveals an original organization, still remains today an enigma. As regards those gothic wings studied, which have included apex angles over a very wide range, the major results from visualization's – the latter made possible by producing smoke streams at the apex of those wings – may be resumed thus :

- if the angle between the leading edge at their point of intersection (apex angle) β is a preferential one of the first grouping (i.e. 20.7°; 26.6°; 30°; 35.3°; 45°), only two curvilinear vortices are formed and these are to be found above the wing starting from the apex and thereby constituting a preferential angle between them at the apex point.

- however, where the apex angle β is either a non preferential one, or a preferential angle of the second group (i.e. 54.7°; 63.4°), four vortices are observed, the two interior of which form between them a preferential angle α_1, while the two exterior vortices form between them another preferential angle α_2.

For example, above the wing having an apex angle β of 52°, the interior vortices create an angle $\boldsymbol{\alpha}_1$ of 35.3° {= θ_{lm} : this corresponds with l=m=1} whilst the exterior vortices also create a preferential angle, immediately inferior to the angle β, being an angle α_2 of 45° {corresponding with l=m=1}. The angle (or angles) between vortices is (or are) constant, either throughout the range of incidences – i.e. from the first appearance of the vortices up to their breakdown – or at a maximum of two or three levels within the range.

However, it is important to remember that several of these preferential angles, either separately or in groups of two or three, are equally to be found in the widely accepted.

Standard theories of hydrodynamics and aerodynamics such as those pertaining to the wake of ships and to aerodynamic drag.

The curve α=F(β) describes, for one of the angles of incidences studied, the totally discontinuous evolution of intervortex angles in relation to β.

One of the central ideas of this present paper is the following: the leading edge of the wing is at the same time a line along which the borderline layer of flow is especially not very thick and this is because the leading edge is more often than not very close to the breakdown line, or to the partitioning line along which the flow is divided between currents on the lower and upper surfaces. On the other hand, this same leading edge is equally a line along which the speed is very high at the boundary of the borderline layer. This is a result of the narrowing of thin fluid streams associated with the sharp curvature of the wall.

A leading edge is therefore a line around which the transverse variation rate of speed is especially high and where, consequently, are to be found a concentration of very high values of the module of the vortex vector whose direction should, in a stationary flow before breakdown, coincide with that of the leading edge.

Therefore, where the two leading edges of one and the same gothic delta wing, or the two wings of a subsonic aircraft, or of a ship fitted with a lifting wing, are to be found coupled following one of the angles ensuring the mutual equilibrium of two vortex structures, it may be thought that these structures eliminate the breakdown, vibration and noise… and, in consequence, that the wake, deriving from such a borderline layer, will also be stable, as non divergent as possible and will lead to a reduced value of Cx.

The most spectacular properties of preferential angles systems are perhaps, even more so, the particular phenomena that can be observed above cones of various angles at their summit.

Hydrodynamic and aerodynamic phenomena are rich in preferential angles, the theory of which has, over the years, been fully elaborated. This is the case found in the very subtle and elegant theory proposed by Lord Kelvin [24] and Froude [25] concerning the wake of ships, described in particular in the works of Lamb [26] and Lighthill

[27]. In such wakes, the crests of waves, in a triangular curvilinear form, will in fact each disappear at two counter-flow points, the alignment of which, along two right-hand sides, determines a total span of the wake at twice 19.4° here and there of the axis of the wake, axis with which the counter-flow tangents, associated with the crests, form an angle of 54.7° while also forming with each corresponding edge of the wake an angle of 35.3° {i.e. 54.7° minus 19.4°}.

$\theta_{3.2}=\theta_{2.2}=\theta_{8.8}$

(54.7°=35.3° + 19.4°).

The link between the wake of a ship, being the result of the combination of bi-dimensional surface waves shed in various directions, and the phenomena, described above in relation to the wake of a ship and to aerodynamic drag, may appear at first sight to be very mysterious.

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