PARTICULARITIES OF THE INTERACTION BETWEEN THE AIRCRAFT WAKE VORTICES AND THE ATMOSPHERIC BOUNDARY LAYER

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Abstract: *The most important consequence of aircraft wake vortex is the risk of aerial accidents as another aircraft can come across the wake left behind by the preceding one. This occurs more frequently during the take-off/landing phases when the wake vortex interaction phenomena could enhance the intensity of the wake vortex. Modern airports are faced with the optimization problem of the aerial traffic so as to allow maximum aircraft turnover without thus endangering them in any way. A wake reduction method is represented by acceleration of the instability mechanisms which develop in wake vortex. In this paper will be studied the wake's interaction with the atmospheric boundary layer in the proximity of airports in order to highlight the turbulent instability mechanisms. Positioning and dimensions of the airport infrastructure can modify the atmospheric boundary layer and will lead to a decomposition of the wake vortex.*

Keywords: *wake vortex; instability mechanism; boundary layer.*

1. INTRODUCTION

When a plane is flying, there is a high pressure below the wings and a low pressure over them. So at the extremity of the wings, there is an air flow from the high pressure to the low pressure [1]. This flow has circular movement and that's why some vortices are created. We call them wake vortices: two contra-rotating vortices which have the same radius and the same intensity (figure 1).

Figure 1: The origin of wake vortices

This phenomenon is particularly dangerous in an airport because the vortices generated have a high intensity and that could lead to crashes when a plane is about to land or to take off [4]. There are a lot of researches ongoing about wake vortexes because of the several issues related to it [5].

First of all, it is a great source of drag, representing approximately one third of it. In the current economical context, both aeronautical manufacturers and airline companies look for solutions in order to get lower flying costs. Even a small decrease in drag would allow billions of litters of fuel economy each year.

But the main issue with vortexes is the incidents that can happen when a plane flies through it. If the plane is too light compared to the vortex, it will experience a rolling motion, sometimes surprising the pilot and creating dangerous situations [5].

Around airports, at takeoff or landing, when several planes have to follow each other, this problem is frequent. In order to minimize the amount of accidents, the 'Federal Aviation Administration' put minimal distances between each planes depending on their sizes in 1970.

Several accidents still occurred years after, and not only small planes but also medium-sized ones like an Airbus A300-600 on November 12th2001, which lost its rudder due to an excessive force applied on it by a wake vortex [6].

Our work will be split in several stages. The very first one is to generate a laminar boundary layer on a surface with a side wind. Then, we will insert an obstacle which represents an airport building in order to disturb the boundary layer and generate a turbulent boundary layer [7]. Next, we will generate vortexes and look at their evolution without a side wind [9].

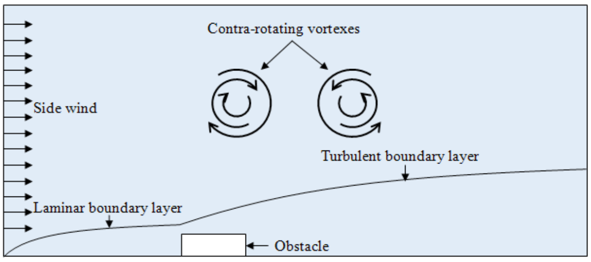

Figure 2: The wake vortex in boundary layer effect

This will allow us to predict their behavior in the final stage and adapt the geometry of our simulation [2]. And finally, we will overlay the two cases in order to look at the interactions between a turbulent boundary layer and a pair of contra-rotating vortexes (figure 2).

2. BOUNDARY LAYER

A fluid flowing along a surface leaves a layer on the surface [8], which becomes attached to it, wetting it in the case of water for example. This is called the ‘no slip condition’. Alongside with the effect of viscosity, the flow along the surface will have a specific speed field [10].

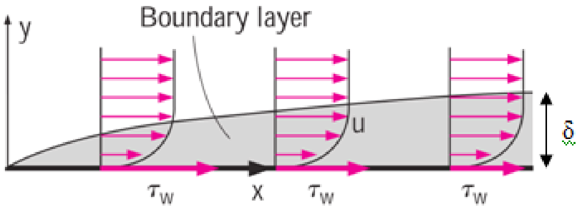

Figure 3: Boundary layer

Figure 3 shows a laminar boundary layer on a horizontal plate for a flow along the x axis, where δ is the height of the boundary layer, distance at which the speed of the fluid is equal to 99% of the initial fluid speed.

We can see that the value of δ increases with the distance to the starting point of the plate. Over a certain distance, the value of δ becomes too important and instabilities appear, leading the laminar boundary layer to a turbulent state [3].

The first case we will study is a laminar boundary layer over a surface. The geometry will consist of a rectangle with $L_x = 1\,m$, $L_y = 1\,m$, $d_x = 0.02$ and $n_y = 100$ with a successive grading ratio of 1.033 in order to make the cells smaller near the surface. The total amount of cells is 5000. A velocity inlet at the left side will simulate the presence of wind at a speed of $1\,m/s$.The bottom boundary will be a Wall, the upper boundary Symmetry, and finally the outlet will be at the right side. After 466 iterations the simulation converged with very little residuals. We can now proceed to analyze the results.

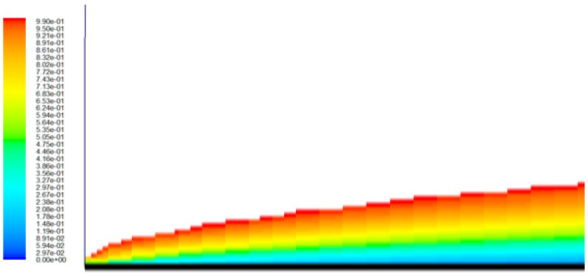

Figure 4: X velocity for a boundary layer

First we will look at the shape of the boundary layer. To do so, we have to look at the longitudinal speed field at the beginning of the surface. In figure 4 the scale on the y axis has been modified in order to make it easier to see the thin boundary layer [2]. Then, we will look at the speed field near the end of the plate.

In this second case, we will insert an object within the boundary layer, simulating a building, and perturbing the laminar boundary layer [3]. This will result in a turbulent boundary layer being generated. Finding the right mesh in order to do this was the main difficulty here, because the cells around the object had to be small enough in order to see the influence of the boundary layer, but not too small in order reduce computing time [8].

We even came up with cases that would converge while being physically wrong, due to a particular mesh disposition.

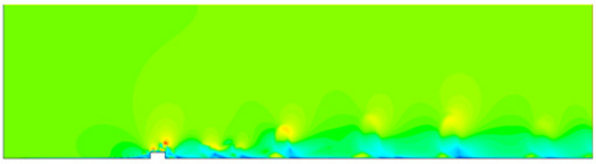

Figure 5: Velocity magnitude after 6000 iterations

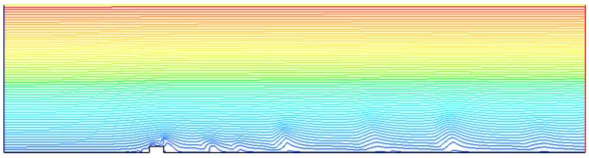

Figure 6: Streamlines within the turbulent boundary layer

We then iterate our case for a large amount of time. This is necessary because else there would be little to no turbulences generated. After 6000 iterations, we obtain the speed field on figure 5. The streamlines are presented in figure 6. We can see there are turbulences on the right side of the object, and their growth in size corresponds to that of a turbulent boundary layer.

3. WAKE VORTEX SIMULATION

Our goal here is to look at the evolution of a pair of vortexes. To do so, we could make a large rectangular mesh with symmetry boundaries and generate the vortexes in the middle.

We will use to the left and right sides of the domain the symmetry boundaries and the upper and down edges will have periodic boundaries.

The mesh is therefore a rectangle, with $L_x = 15\ m$, $L_y = 5\ m$ and $d_x = d_y = 0.05$, $n_x = 300$, $n_y = 100$ and the total amount of cells is 30,000. The origin being in the left bottom corner, the center of the first vortex will be at coordinates $Xc_1 = 6\ m$ and $Yc_1 = 3\ m$, and the center of the second vortex will be at coordinates $Xc_2 = 9\ m$ and $Yc_2 = 3\ m$.

The core radius of both vortexes will be $r_0 = 0.2\ m$ and the circulation contained in the vortex will be $\Gamma = 10\ m^2/s$.

The dimensions used here were chosen arbitrarily because we just want to watch the evolution of any pair of contra-rotating vortexes. Figure 7 shows the streamlines after we've generated the vortexes.

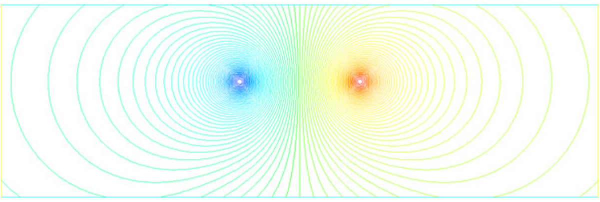

Figure 7: Streamlines showing the two generated vortexes

Running an unsteady simulation, we follow the evolution of this pair of vortexes every second for six seconds. What we were able to see is that they move, going downwards, and their centers reach the bottom of the mesh between $T = 5\ s$ and $T = 6\ s$. So they have an approximate descending velocity of $V_d = 0.5\ m/s$ (figure8).

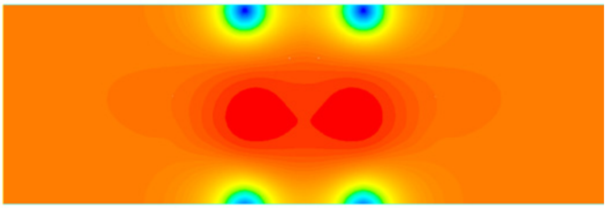

Figure 8: Static pressure at T = 6 s, showing the center of the vortexes after reaching the bottom of the mesh

We can verify the results we have obtained through simulations for the descending velocity using the next equation: $V_d = \frac{\Gamma}{2\pi b}$

In this formula, V_d is the descending velocity, Γ is the circulation within the vortex, and b is the distance between the two vortexes [11]. With the values we have chosen to generate the pair of vortexes with, we find a value for the descending velocity $V_d = 0.531\ m/s$, which verifies the results of the simulation.

4. WAKE VORTEX IN GROUND EFFECT

In order to study the evolution of a pair of vortexes near a wall, we will use the same mesh as in the previous section. The only thing we need to change are the boundary conditions, putting symmetries everywhere except at the bottom which will be a wall [12]. Running an unsteady simulation with 0.1 seconds time steps, we capture an image every 10 time steps, and then compare them (figure 9).

On figure 9 we can see that the vortexes separate when approaching the wall. If we make a graph out of their positions (figure 11), it would look like the theoretical one presented in figure 10.Their trajectory look like an inverse function, first going down almost vertically, and then continuing along the wall asymptotically.

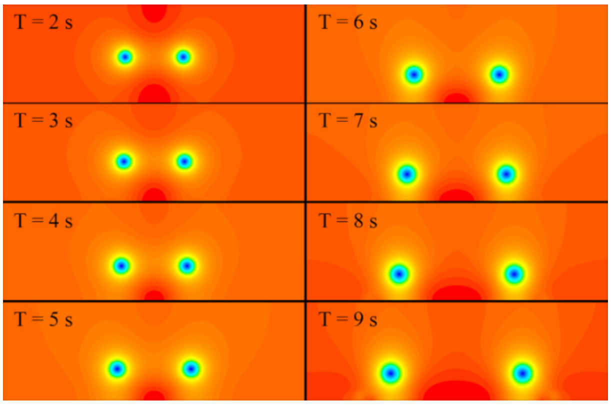

Figure 9: Position of the centers of the vortexes shown by static pressure

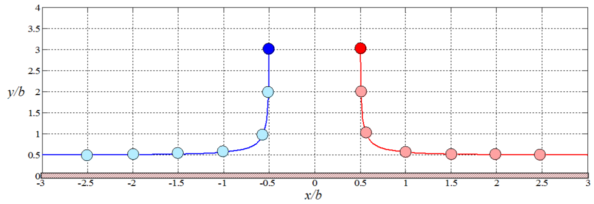

Figure 10: Graph showing the trajectory of the centers of the vortexes

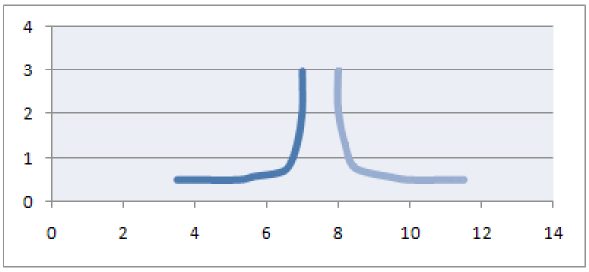

Figure 11: Graph showing the calculated trajectory of the centers of the vortexes

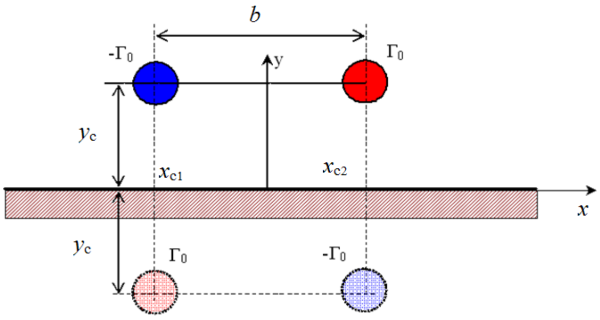

Figure 12: Representation of the “mirror” effect created by the wall

The reason of this particular trajectory is that the wall acts a little like a “mirror” for the vortexes. This is explained in figure 12, where the two contra rotating vortexes approaching the wall begin to interact with two other vortexes. The blue vortex rotating clockwise, its image will be a counter-clockwise vortex, leading it to the left following the same rules as of the two initial vortexes. The same happens with the red vortex on the right side.

5. WAKE VORTEX IN BOUNDARY EFFECT

For this final step, the idea is to overlay the vortexes and the turbulent boundary layer. Doing it in a single stage is the first approach, but we’ll quickly see that it will not work.

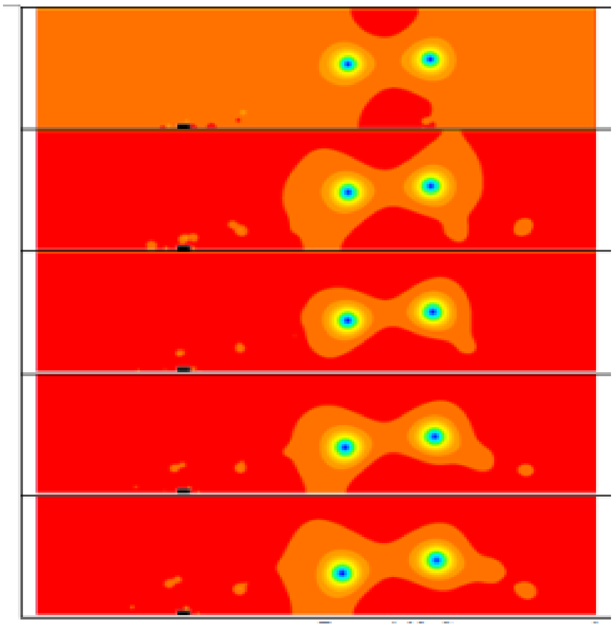

Figure 13: Static pressure for a pair of vortexes near turbulent eddies

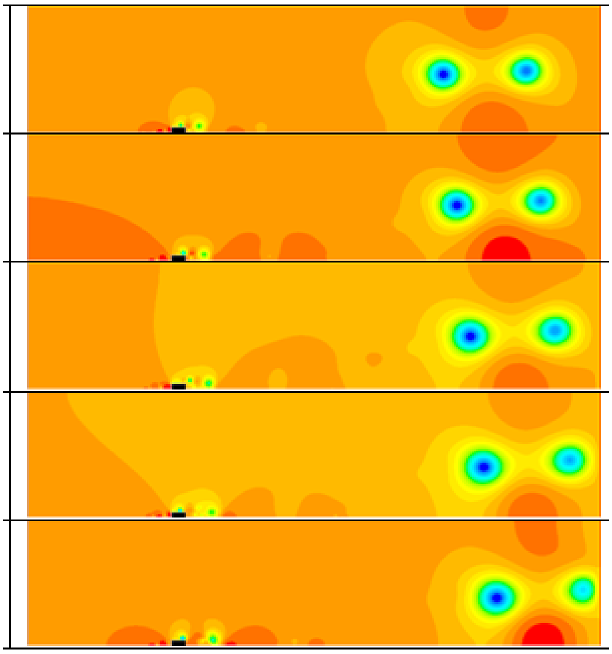

Figure 14: Static pressure for a pair of vortexes with a side wind

This is because we have to find an equilibrium between three times: the time needed for the vortexes to reach the ground t_d , the time before a turbulent boundary layer is formed t_f, and the time before the vortexes are pushed out of the simulation by the windt_v. In this case it is impossible, because $t_f > t_v$, so even if we increase the strength of the vortexes to reduce t_d, they will never meet a turbulent boundary layer.

We chose a value for $\Gamma = 50$, this way the descending speed $V_d = \frac{\Gamma}{2\pi b} = 2.65\ m/s$ which, compared to the side wind speed of $5\ m/s$, makes it possible for the pair of vortexes to get near the ground before exiting the mesh.

However, it still did not let us enough time to study the vortexes. They got close to the turbulences, but their interactions can’t clearly be seen because of the proximity of the pressure outlet which makes the results false.

Raising the value for Γ would speed up the process, but it would also increase the difference of intensity between the vortexes and the turbulences, making the output useless (figure 13 and 14).

CONCLUSIONS

In this study we have emphasized how we can create some turbulence thanks to a building of an airport. This turbulence can weaken a vortex contrary to the ground which, when the vortex touches it, increases the strength of this vortex. Moreover a small building is more effective than a big one to weaken a vortex.

So we can reduce the life expectancy of the wake vortices created by the planes thanks to the building of the airport. So it is important to have some building not too far to the landing runway in order to make sure that there is some turbulence and that the vortices are weakened quickly. Thus we can reduce the delay between to plane.

This study has shown that using the building of an airport is really a solution to reduce the life expectancy of vortices. But know it could be interesting to work on the disposition and the form of these building to find the best way to improve the security in an airport.

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