

## IDENTIFICATION OF VORTEX STRUCTURES IN DYNAMICSTUDIO SOFTWARE

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### 1) Introduction

Identification of vortex structures from experimentally gained velocity field is topical problem for last decades. Optimal identification method should detect vortex and its generation, evolution, interaction and decay both in time and in space. Since there is no exact definition of vortex structure, this task for any identification method is very difficult and results are not very often representative.

Very often identification methods are using vorticity. However, it has been shown by many authors that vorticity is not convenient for identification of vortices as it cannot distinguish between pure shearing motions and the swirling motion of a vortex.

At that time, the most popular methods for vortex identification are based on the analysis of the velocity-gradient tensor  $J=S+\Omega$  and its symmetrical and antisymmetrical parts ( $S$  strain rate tensor,  $\Omega$  vorticity tensor). But even these methods are not wholly appropriate, unlike some special methods as triple decomposition [2].

Below it will be shown some common methods that are present in DynamicStudio and are used for preliminary identification. As an experiment velocity field is used plasma actuator generated field from previous study [1].

### 2) Description of identification methods

This PIV software can calculate from a vector map scalar derivatives as vorticity, lambda 2, swirling strength and 2<sup>nd</sup> invariant that can be used for vortex identification.

Vectors in vector map are located in discrete position, then velocity gradients are calculated by comparing neighbour vectors to one another. For this purpose, a central difference scheme is used:

$$\frac{\partial U}{\partial x(m,n)}_{central} \cong \frac{U_{m+1,n} - U_{m-1,n}}{X_{m+1,n} - X_{m-1,n}} = \frac{U_{m+1,n} - U_{m-1,n}}{2\Delta X}$$

where the gradient of velocity component  $U$  in the  $x$ -direction is at the point  $(m,n)$ . The result corresponds to the slope of a 2<sup>nd</sup> order polynomial. But if only one neighbour vector is present, forward or backward schemes have to be used. Then the result

corresponds to the slope of 1<sup>st</sup> order polynomial. By these schemes gradients  $\frac{\partial U}{\partial x}$ ,  $\frac{\partial V}{\partial x}$ ,  $\frac{\partial W}{\partial x}$ ,  $\frac{\partial U}{\partial y}$ ,  $\frac{\partial V}{\partial y}$  and  $\frac{\partial W}{\partial y}$  can be calculated.

Vorticity is defined for 2D as follows:  $\omega_z = \left( \frac{\partial V}{\partial x} - \frac{\partial U}{\partial y} \right)$ . Other identification schemes are based on velocity gradient tensor  $J$ .

The idea of lambda 2 vortex criterion is splitting velocity gradient tensor  $J$  in a symmetric and an antisymmetric parts. Tensor  $J$  is defined as:  $J = \nabla U$  and  $S = \frac{1}{2}(J + J^T)$ ,  $R = \frac{1}{2}(J - J^T)$ . The second step is to calculate eigen-value of tensor  $S^2 + R^2$ . This tensor is real and symmetric therefore all 3 eigen-values are real and can be ordered in position

$\lambda_1 \geq \lambda_2 \geq \lambda_3$ . The vortex criterion is then: if the investigation point is a part of vortex, eigen-value  $\lambda_2$  of  $(S^2+R^2)$  must be lower than zero.

Swirling strength is defined as the imaginary part of the complex eigen-value of the velocity gradient tensor. For planar data the gradients in the z-direction are set to zero so

$$\lambda_{ci}^2 = \frac{1}{4} \left( \frac{\partial U}{\partial x} \right)^2 + \frac{1}{4} \left( \frac{\partial V}{\partial y} \right)^2 - \frac{1}{2} \frac{\partial U}{\partial x} \frac{\partial V}{\partial y} + \frac{\partial V}{\partial x} \frac{\partial U}{\partial y}$$

the square of the imaginary part represents the swirling strength. Note that eigen-value will be complex only if this parameter is negative. As with  $\lambda_2$  criterion, local minima of  $\lambda_{ci}^2$  can be used for identification of vortex core.

The second invariant Q of the velocity gradient tensor J for 2D can be expressed as  $Q = \frac{\partial U}{\partial x} \frac{\partial V}{\partial y} - \frac{\partial V}{\partial x} \frac{\partial U}{\partial y}$ . Points located inside a vortex have positive value of second invariant Q, negative values indicate the area where shear is present.

### 3) Results

Velocity vector map of plasma actuator vicinity was used for illustration of different identification methods results. The plasma actuator was set to operation cycle of amplitude modulation with parameters 3Hz and 30 % [1]. Every identification methods are compared to each other and two different ways of display are shown; direct display in DynamicStudio and display of scalar derivatives using graphic software Tecplot.

All four methods can detect the vortex core in the same position of vector map with, of course, different maximum or minimum value of scalar quantity. However, the distribution of scalar value in the vicinity of vortex is not identical for all methods and it is difficult to say which one shows reality more precisely. In terms of comparison DantecStudio and Tecplot displays, various levels of scalar quantity differ and have different smoothness. The DynamicStudio software obviously contains smoothing algorithm therefore the results are not exact correct. Using these methods it is suitable to suppress the output positive/negative quantity to gain only the area of vorticity without shear areas.

### 4) Conclusions

Vorticity is not convenient method for vortex identification because one cannot distinguish between area of vorticity and area of shear. The remaining three methods give similar results, but not exactly the same. Post-processing in Matlab or some graphic software seems to be more useful. But the best way will be to use identification method based on triple-decomposition of tensor J and to perform an analysis of vortex flow using this tool in time and in space.

### 5) Acknowledgement

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### 6) References

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