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# DIPOLE APPROXIMATION IN THE CALCULATION OF THE PERTURBED VELOCITIES

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In this article we consider one of the approaches aimed at reducing time of calculation of aerodynamic characteristics of the studied objects using discrete vortex method. Also, accuracy assessment of calculation of aerodynamic characteristics was performed.

Analysis of the obtained dependences allows us to make a conclusion that the considered approach to the calculation of the functions of the mutual influence on the stages of formation of the system of linear algebraic equations, position of vortex sheet nodes as well as aerodynamic loads reduces hardware costs about three times, with a relative error of less than 4%.

**Keywords:** discrete vortex method, dipole approximation

## 1. Introduction

The efficiency of numerical methods for solving numerical aerodynamics problems depends on the entry requirements to the software and computer resources.

The modern level of computing technology allows solving effectively a wide range of numerical aerodynamics problems. However, in case of solving problems in nonlinear stationary and non-stationary setting there are significant problems related, first of all, with large duration of the calculation of the aerodynamic characteristics of a studied body that significantly complicates the solution of retrieval problems and reduces the efficiency of performance. Development and implementation of measures that aimed to reduce the requirements for software with available computing resources is an important task, it requires an analysis of all phases of the numerical modeling and computational algorithms.

Figure 1 shows the possible ways to improve the effectiveness of computational experiment:

– computing technology performance improvement (extensive way);
– analysis of the problems with the rational combination of numerical methods of research and engineering methods;
– rational mapping of the studied object, taking into account the particular features of the numerical method (quadrature with higher convergence rate, accounting of the results of the research on the methodology of calculation, etc.);
– optimization of algorithms of calculation (minimization of computational procedures, rational construction of software modules, etc.).

The most important of these approaches are:

– rationalization of calculation of mutual influence functions at the stage of the formation of system of linear algebraic equations (SLAE) matrix;
– calculation of the spatial position of the vortex sheet that descended from the surface of the studied body;
– calculation of the aerodynamic loads.

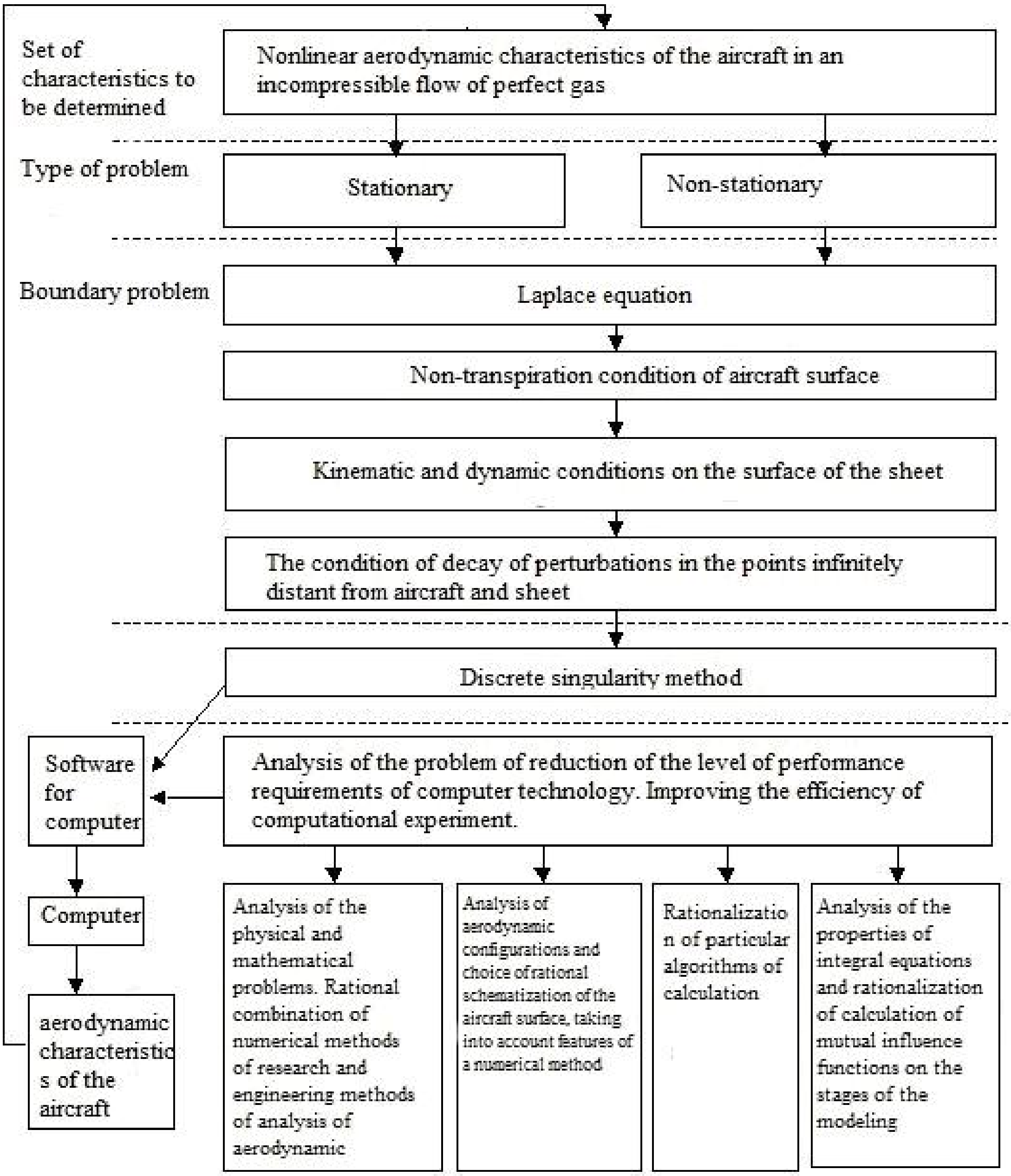


*Figure 1.* Ways of improving the efficiency of numerical experiment

## 2. Problem solving

From the assumption that the vortex frame through which describes the configuration of the body and the vortex sheet that descended from it, at a distance $R$, significantly exceeding its perimeter $P$, creates a dipole field with an intensity $\vec{d} = \vec{n}\Gamma S$, that is estimated by the module of the potential difference of flat panel the dipole potential:

$$\delta \le d\left(\frac{P}{R}\right)^2 . \tag{1}$$

This assessment allows you to make an assumption about the rationality of the use of approximation formulas for calculation of functions of mutual influence at minor ratios $P/R$.

The results of studies on the proposed method of calculation showed that at $0 \le P/R < 3$ it is expedient to use the dipole approximation to calculate the coefficients of the SLAE matrix and also aerodynamic loads, of the calculation of the spatial position of the vortex sheet. At the same time the accuracy of the calculation results are not worse than $0 \le P/R \le 1{,}5$. In the case when $\frac{P}{R} > 1$ it is recommended to conduct a double-precision calculation.

### 2.1. Checking the efficiency of the methods of calculation

Figure 2 shows the dependence of the calculating error $\delta(\bar{r})$ of SLAE matrix coefficients with the dipole approximation in comparison with the calculation performed with double precision, from the distance $\bar{r}$ to the vortex frame:

$$\delta = \frac{|w_2 - w_Д|}{w_2}, \tag{2}$$

where $w_2$ and $w_д$ - coefficients of the SLAE, calculated with double precision and using the dipole approximation.

The distance from an arbitrary point in space to the vortex frame is presented in relative units:

$$\bar{r} = \frac{r}{l}, \tag{3}$$

where $l$ - length of the perimeter of the vortex frame.

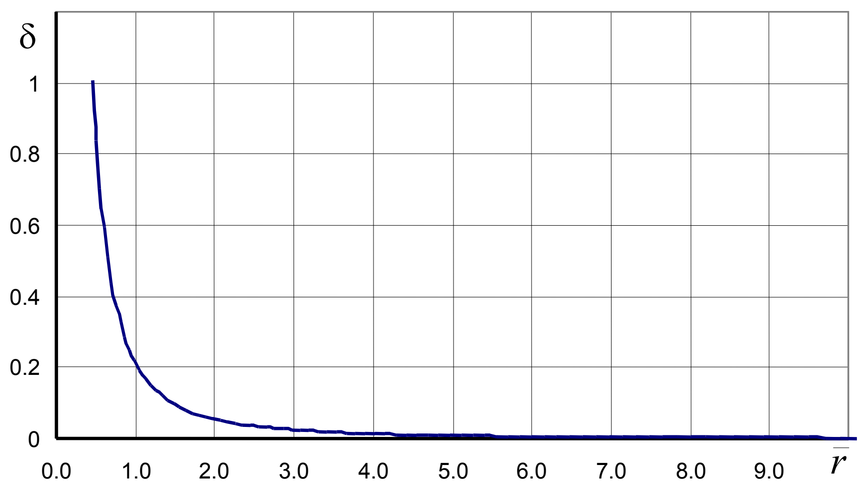


*Figure 2.* Dependence of the calculating error of SLAE matrix coefficients with the dipole approximation in comparison with the calculation

Dependence analysis $\delta(\bar{r})$ allows us to make a conclusion that at a distance from the computational point to the vortex frame $\bar{r} \ge 3$ calculating error is $\delta \le 5\%$.

### 2.2. Validation of the obtained results

For the validation of the obtained results of calculation of aerodynamic characteristics using the dipole approximation, numerical experiment with use of mathematical model of a rectangular wing was performed ($\lambda = 5$, $\alpha = 10^\circ$), the results of which were compared with those obtained by traditional methods that being used in discrete vortex method (DVM) [1].

Figure 3 shows the relative rate of calculation $\overline{T}$ of one pitch on the non-dimensional time, which was estimated using the expression:

$$\overline{T} = \frac{T_1}{T_2}, \tag{4}$$

where $T_1$ - rate of calculation using the dipole approximation, $T_2$ - rate of calculation according to adopted methods in DVM.

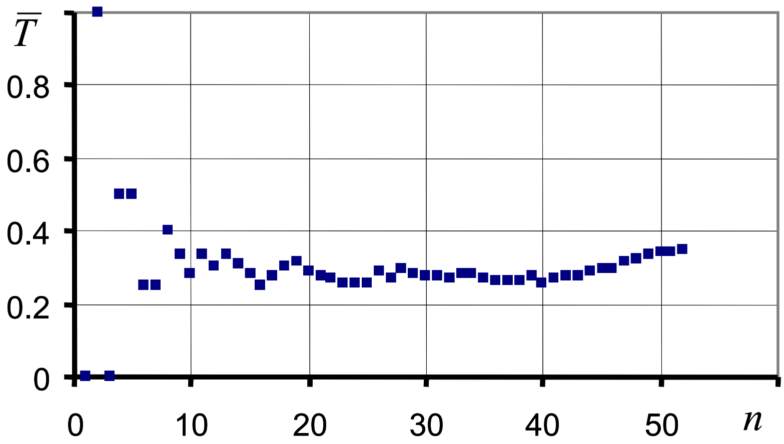


*Figure 3.* Relative rate of calculation depending on the pitch (on the non-dimensional time)

You can see that the rate of calculation using the dipole approximation, about 3 times higher than the rate for the calculation methods adopted in DVM.

The estimation error of the calculation of aerodynamic characteristics was performed. Figure 4 shows the dependence of the calculating error $\delta_{Cy_a}$ on the pitch on the non-dimensional time $n$, which was estimated by the formula:

$$\delta_{Cya} = \frac{|c_{ya2} - c_{ya1}|}{c_{ya1}}. \tag{5}$$

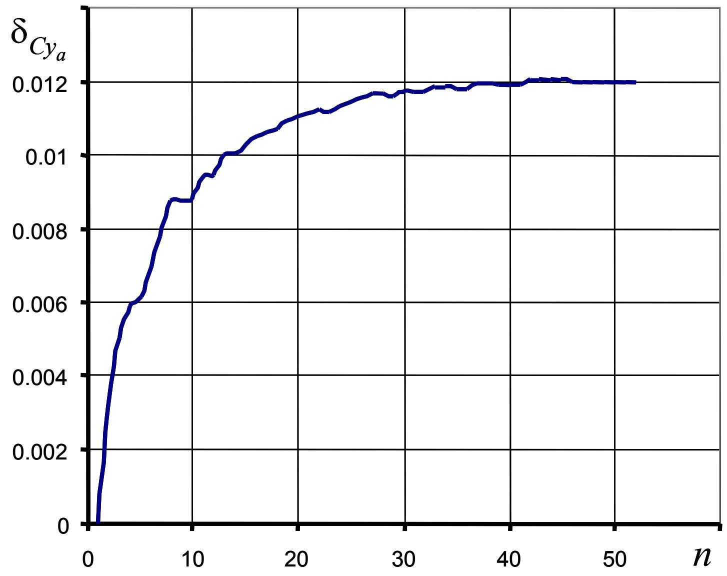


*Figure 4.* Dependence of the calculating error on the pitch
(on the non-dimensional time)

Analysis of dependence (Figure 4) shows that the calculating error of aerodynamic loads does not exceed 1.2%, which is quite acceptable for problems of this kind.

Figure 5 shows the dependence of the relative number of vortex frames for which elements of the SLAE matrix was calculated with double, single precision, as well as using the dipole approximation.

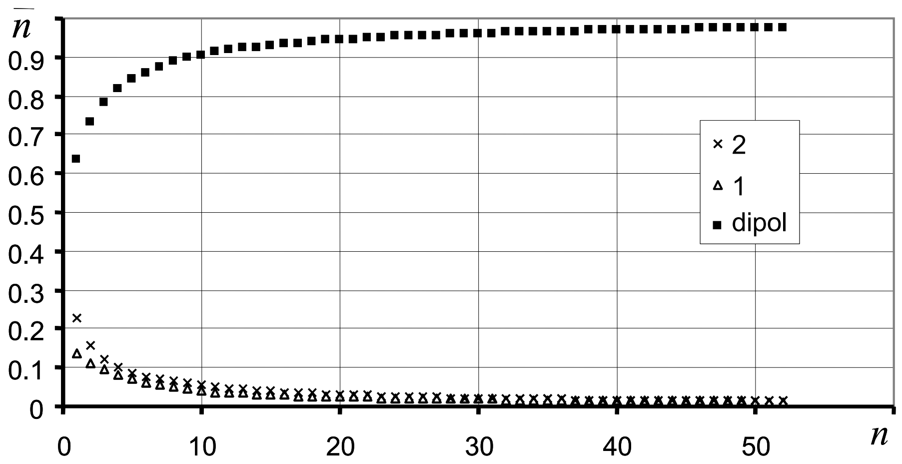


*Figure 5.* Dependencies of the relative number of vortex frames on the pitch
(1 - single precision; 2 - double precision)

Figures 6 and 7 shows similar dependencies for a rectangular wing ($\lambda = 5$, $\alpha = 60^{\circ}$).

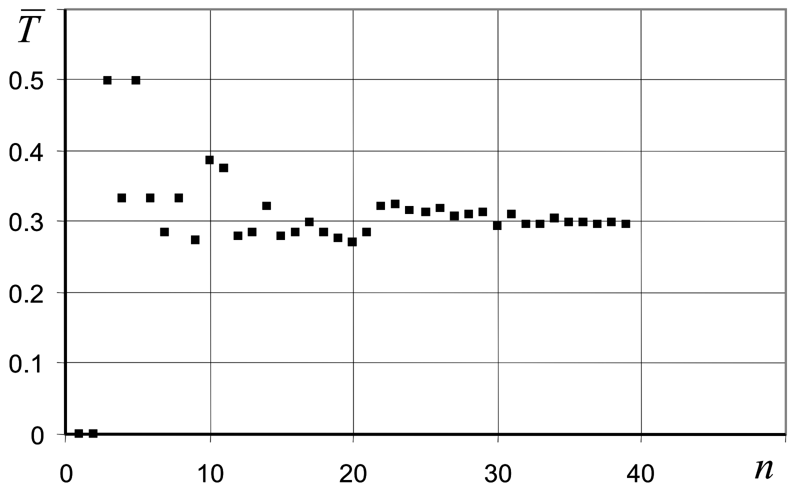


*Figure 6.* The relative rate of calculation of characteristics of rectangular wing depending on the pitch (on the non-dimensional time)

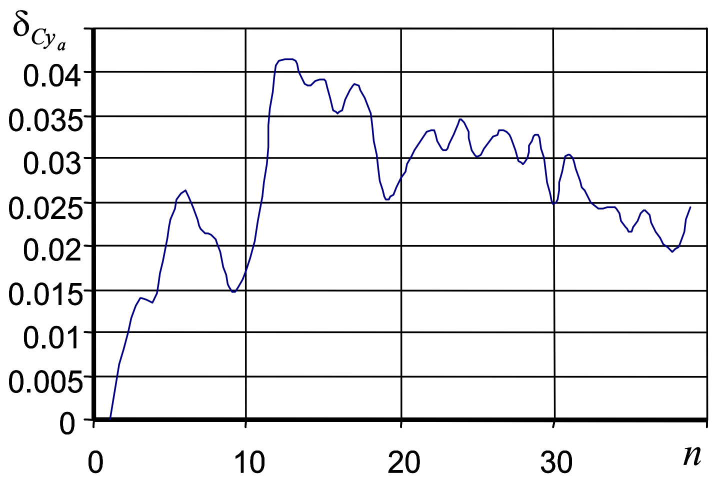


*Figure 7.* Dependence of the calculating error of the parameters of a rectangular wing on the pitch (on the non-dimensional time)

## 3. Conclusion

The considered approach of determining aerodynamic characteristics of studied objects by using discrete vortex method reduces the calculation time. The estimates calculating error of aerodynamic characteristics do not exceed 1.2%, which is quite acceptable for problems of this kind.

The analysis of the submitted dependences allows us to make a conclusion that the considered approach to the calculation of the functions of the mutual influence on the stages of SLAE formation, position of vortex sheet nodes as well as aerodynamic loads reduces hardware costs about three times, with a relative error of less than 4%.

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