Results from numerical study of the velocity field characteristics of jet flow in the work zone of small aerodynamic tunnel, by using LES method

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Резултати от числено изследване на характеристиките на скоростно поле на струйно течение в работния участък на малък аеродинамичен тунел, чрез CFD метода LES: *Представената публикацията е продължение на: „Изграждане на модел за числено изследване на характеристиките на скоростно поле на струйно течение в работния участък на малък аеродинамичен тунел, чрез CFD метода LES“. Тук са представени резултатите от проведеното числено изследване на разпределението на скоростното поле на струйното течение в работната зона на аеродинамичния тунел (АДТ) на Технически университет София. Както бе споменато, численото изследване се базира на методите на изчислителната динамика на флуидите (CFD), като използваният метод за решаване на системата частни диференциални уравнения на Навие - Стокс е „Метода на крупните вихри“ - LES (Large Eddie Simulation). При този подход, едромащабните турбулентни вихри на течението се изчисляват директно, а малките предварително филтрирани вихри се моделират чрез широко използвания модел на Смагорински. LES метода е добре приложим при моделиране на струйни течения, като предоставя значителна точност и детайлност на резултатите при сравнително ниска стойност на изчислителните итерации. Получените резултати, базирани на директно измерени начални и гранични условия, охарактеризират адекватно параметрите на струйното течение в работната област и дават възможност за разработване на виртуален модел на изследваното съоръжение.*

Key words: *Aerodynamic Tunnels (Wind Tunnels), Velocity Field Modeling, CFD, LES method*

INTRODUCTION

The current paper continues the work, revealed in: *“Ivanov, M., Mijorski, S., “Model build up for numerical study of the velocity field characteristics of jet flow in the work zone of small aerodynamic tunnel, by using LES method”, Submitted for publishing in: Proceedings of “International Scientific Conference in Ruse – 2014”, October, 2014”*, by presenting the achieved numerical results.

INITIAL FLOW PARAMETERS

As it was shown, the inlet non-uniform velocity field was derived by a network of 176 measurement points, located at the ADT nozzle outlet. The assigned values of each of them are shown in Table 1. The average value of the measured velocity is 30 m/s. The blue boxes show the location of the monitoring points 35, 46, 131 and 142, which surround the work zone of the ADT, while the green ones (88 and 89), indicate the center of the analyzed zone.

Table 1. Non-uniform velocity field values at the ADT Nozzle

Z, [mm]	***Velocity [m/s]***															
500	0	0	3,54	19,9	20,5	20,2	20,2	25,1	26,1	28,4	29,9	30,9	31,5	25,9	0	0
450	23,3	30,8	30,7	30,7	30,7	30,7	30,7	30,7	30,6	30,4	30,6	30,8	31	31,2	31,4	13,3
400	18,6	30,7	30,5	30,6	30,6	30,7	30,6	30,5	30,4	30,3	30,2	30,4	30,7	31	29	23,5
350	30,1	30,5	30,2	30,3	30,3	30,5	30,5	30,3	30,2	30,1	30	30,1	30,5	30,9	28,8	22,6
300	26,6	30,5	30,2	30,3	30,3	30,5	30,6	30,5	30,4	30,2	30,2	30,2	30,6	31	28,8	24,2
250	28,1	30,4	30,2	30,2	30,3	30,5	30,5	30,4	30,5	30,3	30,3	30,3	30,6	30,9	28,7	27,3
200	18	30,4	30,3	30,3	30,4	30,5	30,6	30,7	30,6	30,5	30,4	30,4	30,6	30,9	29	27,3
150	15,7	30,2	30,3	30,2	30,4	30,5	30,5	30,6	30,7	30,5	30,4	30,5	30,7	30,9	29,1	27,8
100	4,81	30,6	30,4	30,4	30,6	30,7	30,7	30,7	30,9	30,6	30,6	30,8	30,7	30,8	29,2	10,6
50	6,53	30,8	30,6	30,6	30,7	30,8	30,7	30,9	31	30,9	30,8	30,9	30,9	31	31,1	26,7
0	0	0	16,4	31	31,1	31	30,6	27,8	27,5	26,2	24,9	16,6	14,9	6,92	0	0
Y, [mm]	**0**	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**550**	**600**	**650**	**700**	**750**

The same network of points, used for conducting the experimental measurements, was repeatedly placed every 10 cm in X direction along with flow direction (with additional monitoring grid at 0 and 5 cm away of the nozzle outlet). In that manner the velocity field was monitored during the simulation, providing better discrete image of the velocity fluctuations at the selected numerical domain locations. The exact situation of the monitoring point networks are shown on Figure 1.

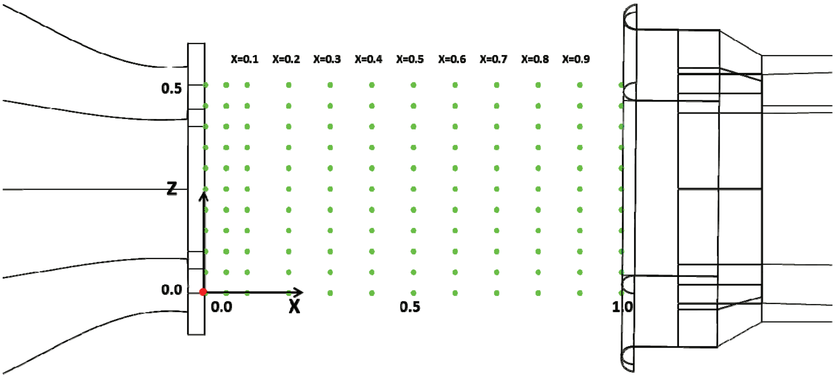

Figure 1. Monitoring point network locations in X direction of the ADT work area

NUMERICAL RESULTS

The simulation was performed on server machine with 16 parallel processors and the run time was approximately 48 hours for the entire case. The time step was 0.0002 seconds, in total of 5000 steps in time. The resultant simulated time was 1 second. In order to capture the overall performance of the ADT at the work area, a field averaging function was applied for the last 0.5 sec of the simulated time.

The visualization was performed by the "*ParaView*" post-processing software. Figure 2 shows the mean velocity distribution in X direction at 3 distinctive section planes X = 0 m, X = 0.5 m and X = 1.0 m. The presented velocity plots are based on the averaged flow field.

The numerical results suggest relatively high degree of homogeneity of the mean velocity field, as it is observed during the experimental measurements, published in [4, 5]. At 0.5 m from the nozzle outlet in X direction, which corresponds to the centre of the work area of ADT, the monitored velocity field was still comparatively homogeneous. But, at 1.0 m distance in X direction, which is at the end of the work area, a significant velocity drop was observed in the numerical results. This velocity drop is also documented in the experimental measurements [4, 5].

Figure 3 shows the mean velocity plot at the middle of the ADT work zone, at section plane Y = 0.35 m. The high level of velocity field homogeneity was observed again. Further, to this velocity plot illustration, it can be found again the mentioned velocity drop at the vicinity of the ADT collector.

In addition to the velocity plots, there are presented the instantaneous velocity streamlines at section plane Y = 0.35 m (see Figure 4). At this illustration, it can be observed the cutting effects of the collector over the ADT jet flow. These numerical results show a flow separation in the vicinity of the collector, which causes disturbances in the ADT work zone.

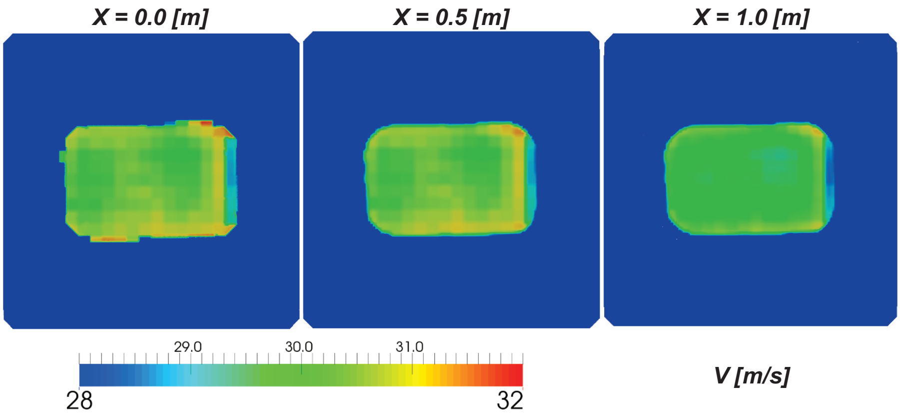

Figure 2. Mean velocity plots in X direction

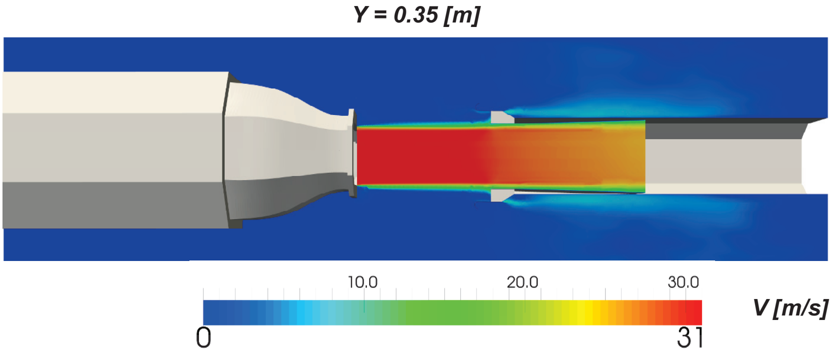

Figure 3. Mean velocity plot in Y direction

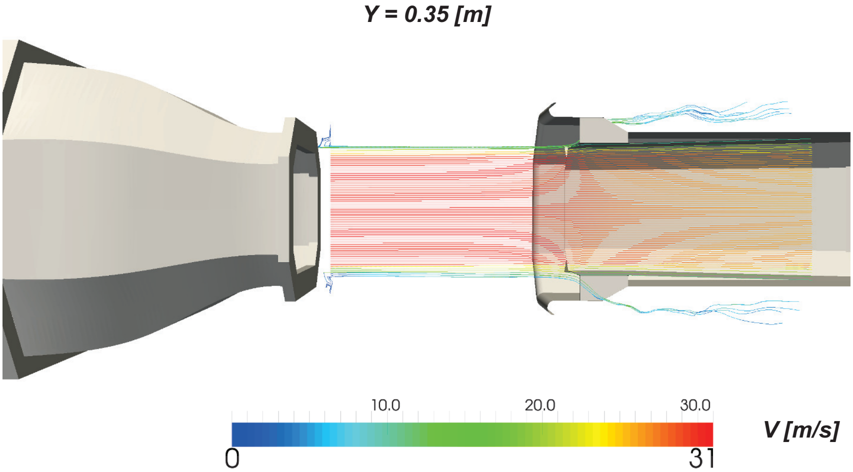

Figure 4. Instantaneous velocity streamlines in Y direction

ANALYSES OF THE RESULTS

For further analyses of the numerical results, a discreet illustration at the six characteristic locations of the ADT work zone is presented on Figure 5. The figure follows the flow development monitored at the boundaries and the center of the ADT work area, along the jet flow direction. Clearly, the numerical results suggested significant velocity drop ahead of the nozzle outlet at distance 0.8 m. Up to this section, the monitored results illustrated homogeneity of the jet flow. After passing 0.8 m till the end of the work area at 1.0 m, the velocity drop at the center reached approximately 0.8 m/s, while at the boundary corners of the work zone it was between 0.3 - 0.5 m/s.

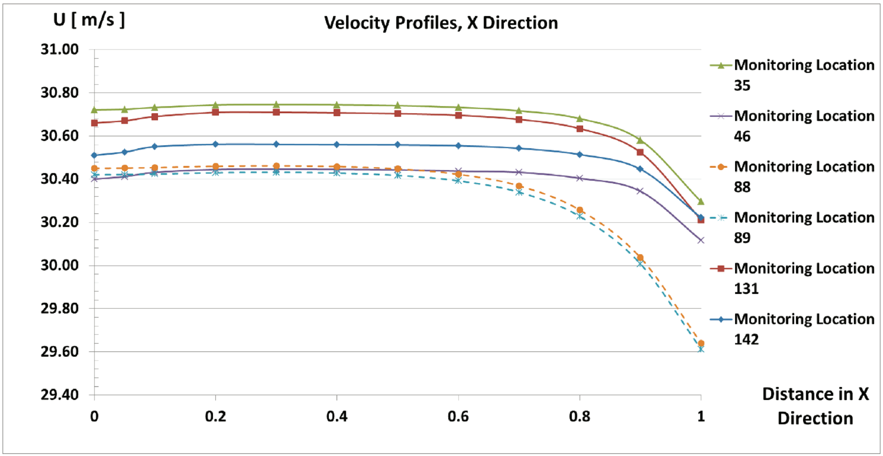

Figure 5. Work zone velocity profiles distribution in X direction

MODEL LIMITATIONS

As part of the presented study, several limitations of the numerical model were pointed out:

- Nevertheless of the high refinement level of the numerical discretization in the presented case, there is a need for grid independent solution study, which was not yet performed. This study will make possible the analyses of the effects of the local surface refinements over the velocity and pressure field characteristics;
- The performed simulation was based on isothermal conditions. That means that, from the set of the partial differential equations of the model, the energy equation was excluded;
- The selected numerical algorithm scheme PIMPLE, for connection of the velocity and pressure fields, was optimised for fast solution with large steps in the time. It is possible that, by applying different numerical scheme, the accuracy of the solution to be improved.
- The operational parameters of the selected Smagorinsky sub-grid scale model of the LES method may needed further analyses, in order to be optimised for the presented case study.

CONCLUSION

● Precise numerical model of the work zone of the small air dynamic tunnel at Technical University – Sofia was proposed and constructed within the “*Open FOAM Version: 2.2*” software package.

● Numerical simulations of the ADT's jet flow in the work zone was performed. For initial and boundary conditions was used the data from previously conducted experimental measurements of the jet flow parameters.

● Analyses of the velocity field characteristics in the ADT work area was performed by visualization and simple descriptive methods.

● The presented results described adequately the real operating conditions in the ADT's work zone area. The high level of homogeneity in the flow velocity distribution, which was suggested in previous studies, was confirmed. Numerical results also showed the sufficient velocity drop in the centre of the jet flow, which will be further analysed.

● Several limitations of the developed numerical model have been pointed out and analyzed for future model improvements.

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This paper has been reviewed.