Unsteady numerical simulation of electrostatic spray-painting processes with moving atomizer

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1. Introduction

In recent years numerical simulation of spray painting for the automotive industry, especially using high-speed rotary bells and electrostatically supported methods, has been performed by means of the CFD (Computational Fluid Dynamics) code FLUENT [1,2]. Our previous numerical studies were concerned with the prediction of film thickness distribution and transfer efficiency based on the quasi-steady airflow field with a static atomizer. The three-dimensional turbulent airflow and the electrostatic field including space charge were calculated. Based on the Lagrangian approach, the trajectories of the paint droplets were modeled considering electrical and aerodynamic forces. From the simulation the so-called static film thickness distribution or the static spray pattern could be obtained on the surface of arbitrary 3D-objects. In industrial application, however, only the dynamic film thickness distribution is useful. The static spray pattern has to be used to derive the dynamic film thickness by artificially moving the spray pattern along a given path and integrating the mass, given that the physical conditions of the work piece during the integration are essentially the same as those in the simulation with the static atomizer

It is difficult, however, to obtain the dynamic film thickness distribution using such an integration method for an irregular object shape, where the geometry changes continuously, corresponding to unsteady physical boundary conditions with respect to the direction of motion of the atomizer. Therefore, numerical simulation of the real dynamic painting process should be carried out, which involves the unsteady flow calculation with a dynamic mesh model. In this paper a numerical simulation of electrostatic spray-painting with moving atomizer has been performed using a dynamic mesh model in the CFD code FLUENT 6.2 [3]. Simple movement of the atomizer and simple geometry of the substrate were considered. The simulated film thickness distributions were compared with the experimental results.

2. Numerical methods

As atomizer a high-speed rotary bell with external charge system was applied in the present numerical simulation. Simple geometry of the grounded work piece, e.g., a flat plate and a

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buckled plate were used. The atomizer was moved horizontally above the plate in a single direction and a constant moving velocity of 50 mm/s.

A local remeshing model that is suitable for the relative boundary motions that involve both translation and rotation in FLUENT was used. This dynamic mesh model makes more practical sense, since the real movement of the atomizer with respect to the car body is highly complicated. Figure 1 shows the grid for the simulation with a flat plate using a local remeshing model. The mesh on the rotary bell and the electrodes is quite fine. In order to avoid difficulties and to keep the grid quality during the mesh movement, it is necessary to create a cylinder zone with interior boundary around the atomizer. Both the cylinder region and the atomizer are defined as moving zone. The initial position of the atomizer is located 300 mm away from the edge of the plate. During the movement the grid within the moving zone and the boundary layer mesh above the plate are not modified. An update of the grid topology in the dynamic zone is, however, performed after every time step. A detailed parameter setting in the remeshing model can be found in [4].

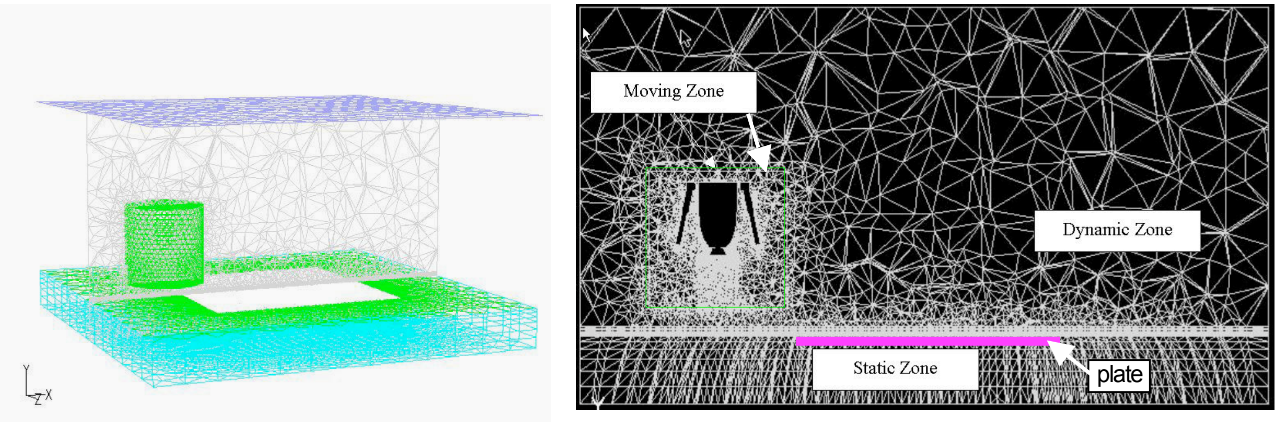

Figure 1: Grid 3D view and cross-section for local remeshing.

The time-dependent, three-dimensional, incompressible Reynolds-averaged Navier-Stokes equations with a k-ε RNG turbulence model were solved for the turbulent airflow. The computational domain is 2 x 2 x 1.7 m^3 with ca. 500 000 cells. The droplet phase created by the high-speed rotary bell was calculated using a Lagrangian approach with a stochastic tracking model. In the simulation, two-phase coupling was taken into account. The corresponding electrical field, electrical force on the particles and particle charge were calculated based on the approaches reported in our pervious studies [1, 5].

3. Results and discussions

Figure 2 shows contours of the velocity field at different time steps. At the positions where the atomizer is located outside of the flat plate, the velocity contour is characterized by a narrow spray jet. As soon as the atomizer moves above the plate, the boundary conditions for flow and electrostatic filed do change, resulting in a flow field with a broad spray. The film thickness distribution on the plate is plotted in Fig. 3. A cross-section film thickness profile in the middle of the plate (x = 0) was generated and converted to the dry film thickness distribution that was compared with the measured result, as shown in Fig. 4. A quite good agreement between measurement and simulation can be observed.

A simulation using somewhat more complex target geometry, i.e., a buckled plate, was also performed in which, as shown in Fig. 5, the atomizer was moved horizontally along the buckled edge. The simulation results are plotted in Fig. 5 and 6. The film thickness distribution along the buckled edge is relatively stable, whereas a higher film thickness can be observed on the horizontal part of the plate and close to the buckled edge. On the vertical part of the plate the film thickness reduces quickly. Figure 6 shows clearly a good prediction of the film thickness compared with the experiment.

Although the dynamic mesh models are compatible with all physical models in FLUENT 6 and are fully parallelized, a serial FLUENT code had to be used in the present simulation, as the parallel calculation with particle injection during the mesh movement in FLUENT 6.2 is not yet stable. A CPU time of 144 hours was required for the present simulation with a moving distance of 1.5 m. It is clear that the computing effort of the simulation of real dynamic spray painting processes is still considerable high for industrial application. However, with the improvement of the CFD code, e.g., stable parallel solver for the discrete phase model and dynamic mesh models, and with the increase in computer speed and capacity, a speed-up for real unsteady spray-painting simulations with moving atomizer will be possible in the future.

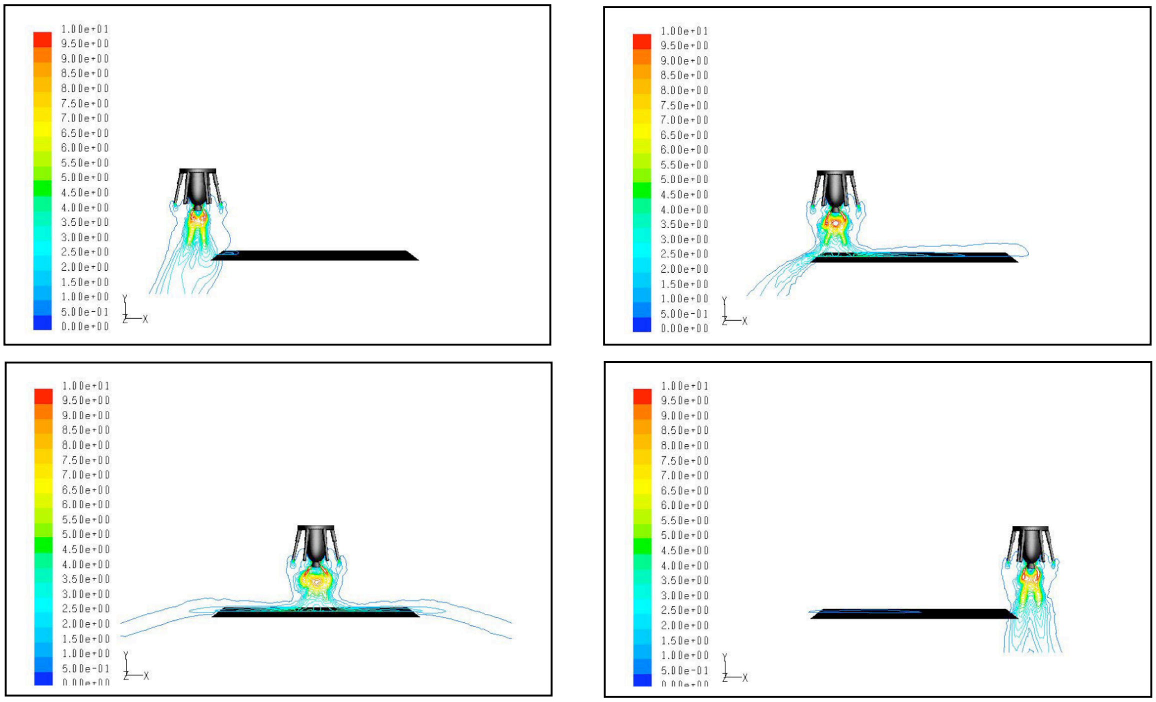

Figure 2: Visualization of the flow field velocity in m/s.

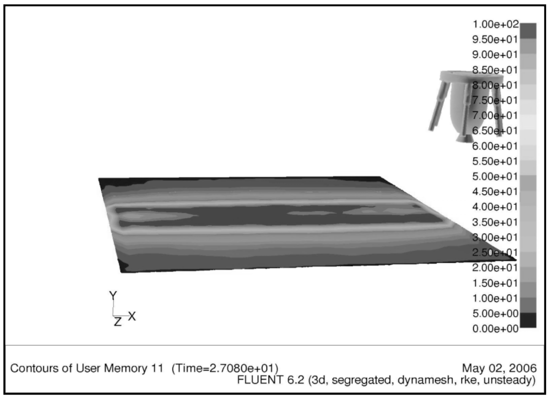

Figure 3: Wet film thickness distribution in µm on a flat plate.

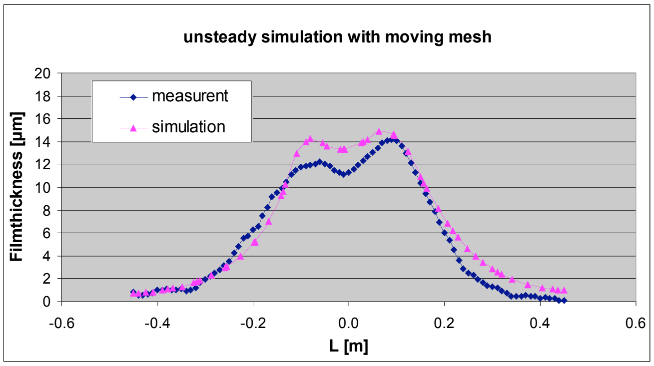

Figure 4: Comparison of simulated and measured dynamic film thickness in a cross section.

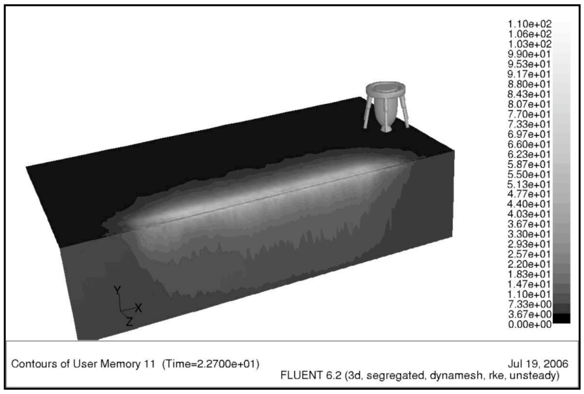

Figure 5: Wet film thickness distribution in µm on a buckled plate.

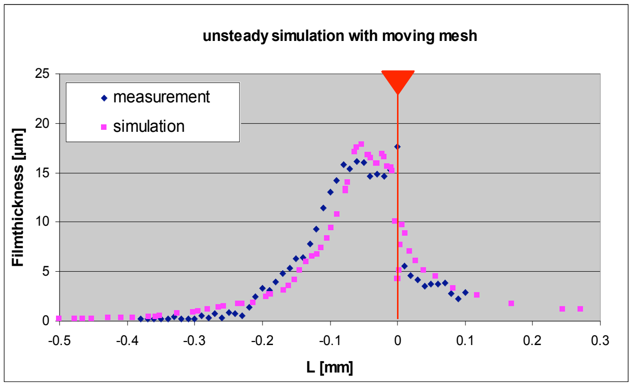

Figure 6: Comparison of simulated and measured dynamic film thickness in a cross section.

4. References

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[2] Q. Ye, J. Domnick, A. Scheibe, K. Pulli: Numerical Simulation of Electrostatic Spray-painting Process in the Automotive Industry. High Performance Computing in Science and Engineering'04, Springer-Verlag Berlin, Heidelberg, pp. 261-275.

[3] Fluent6.2 User's Manual.

[4] P. Wang: Using moving mesh features to simulate dynamic electrostatic spray painting with a high-speed rotary bell and external charge. Master thesis, University of Stuttgart, 2005

[5] Q. Ye, J. Domnick: On the simulation of space charge in electrostatic powder coating with a corana spray gun. Powder Technology 135-136 (2003) 250-260.