J. HAMBURGER(*), Guillaume VATON(*) , Amita TRIPATHI (*), Arun MURTHY(**), Anil KUMAR(**), Bobby KAUSHIK(***)

(*) Fluidyn France, CFD, process and Fluid-Structure Interaction Department
7, Bd de la libération, F-93200 SAINT-DENIS, France

(**)Fluidyn India, #146, sector 5, HSR Layout, I-560102 BANGALORE, India

(**)Fluidyn North America,

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Present paper describes a 3D numerical model for the simultaneous modelling of a low speed wall entrained film (wiping process), and a turbulent jet at high speed impacting the film. This air-jet wiping process generally utilizes fluid flow models which lead to high numerical diffusion rates at the film interface, or require some costly reconstruction interface models. Even then, the localisation of the free surface is not guaranteed. In the present poster, a specific methodology is considered in a commercial code, in order to simultaneously model the turbulent jet flow and the free surface level, including the use of a VOF model without reconstruction, a specific wall-impacting-turbulent modelling, and a pressure-based finite volume, collocated solver, Fluidyn-MP, for optimisation. This specific design increases the accuracy of the free surface description.
Hereafter a description of the equations solved for Volume Of Fluid (VOF) and turbulent flow is shown, along with the numerical solver. This specific wiping module is tested on two cases: 1. Wiping without transversal jet, 2. Wiping with transversal turbulent jet influence.

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1. Description of physical set of equations solved

Three dimensional unsteady Navier-Stokes equations are solved using a finite volume, collocated and pressure based segregate solver. The turbulence is modelled using standard k-ε model. The free surface and hence the film thickness are modelled by solving the following advection equation for the volume fraction of the liquid being drawn:

$$\frac{\partial}{\partial t}(\phi) + \nabla \cdot (\phi \vec{v}) = 0$$

where ϕ is the volume fraction and $\vec{v}$ is the velocity. To reduce the diffusion of the scalar representing the volume fraction at the liquid-air interface and hence to compute the film thickness accurately the Compressive Interface Capturing Scheme for Arbitrary Meshes (CICSAM) [Ubbink, 1997] is used. The Continuum Surface Force (CSF) model is used for modeling surface tension forces. Though surface tension force acts on the interface which is a discrete surface, the CSF models it as a volumetric force which acts in the region where the interface is located. According to the CSF model, the surface tension force is formulated as follows:

$$\mathbf{F}_{sv} = \frac{\rho}{\langle\rho\rangle}\mathbf{f}_s\delta_s$$

where $\mathbf{F}_{sv}$ = volumetric surface tension force

$\mathbf{f}_s$ = $\sigma\kappa\mathbf{n}$, surface tension force per unit interfacial area

σ = surface tension coefficient

κ = $-\nabla \bullet \mathbf{n}$, mean interfacial curvature

$\mathbf{n}$ = $\nabla\rho/|\nabla\rho|$, interface unit normal

δ_s = $|\nabla\rho|/[\rho]$, surface delta function

$[\rho]$ = $|\rho_2-\rho_1|$, jump in density across interface

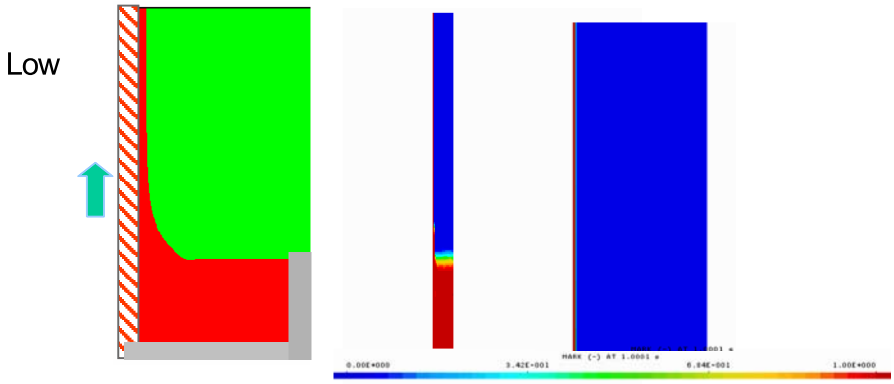
$\langle\rho\rangle$ = $\frac{1}{2}(\rho_2+\rho_1)$, average density

The problem is solved as an unsteady flow and at each time step, first the continuity and momentum equations are solved to the desired accuracy iteratively, and then the volume fractions are evaluated in an explicit manor.

2. Results in a specific geometry

First test is made to validate wall entrained film thickness on a common geometry without jet impingement. The geometry used there is described on the following picture:

- Geometry description for wiping without jet



$$e_f = \frac{2}{3}\sqrt{\frac{\mu U}{\rho g}}$$

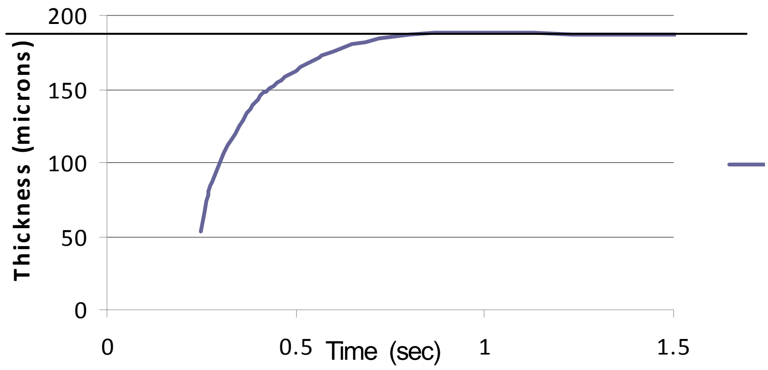


Figure 1: Description of geometry and results for wiping without jet. Film Thickness matches well with analytical formula.

- Geometry description for wiping with jet impingement

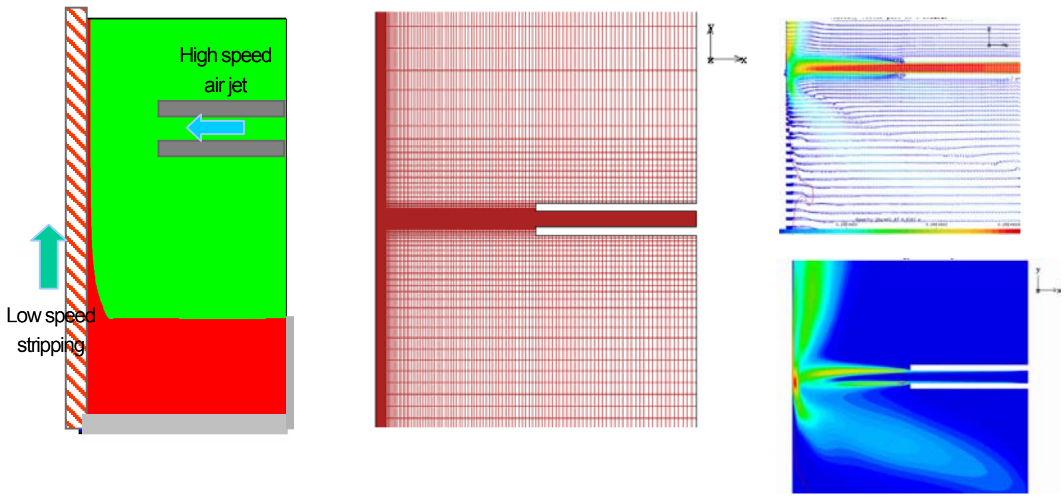


Figure 2: Description of geometry and results for wiping with jet impingement.

Results are analyzed in terms film thickness, and variation of turbulent properties through the interface. It is shown that despite the close proximity of the jet (<1cm) and the high speed velocities engaged, the model predicts very low diffusion through the interface, and accurate film thicknesses compared to analytical values. A fluid flow analysis of the jet oscillation, along with a power spectrum analysis of the film thickness variations at different heights is performed. A phenomenological interpretation is given for the film thickness air-jet dependency.

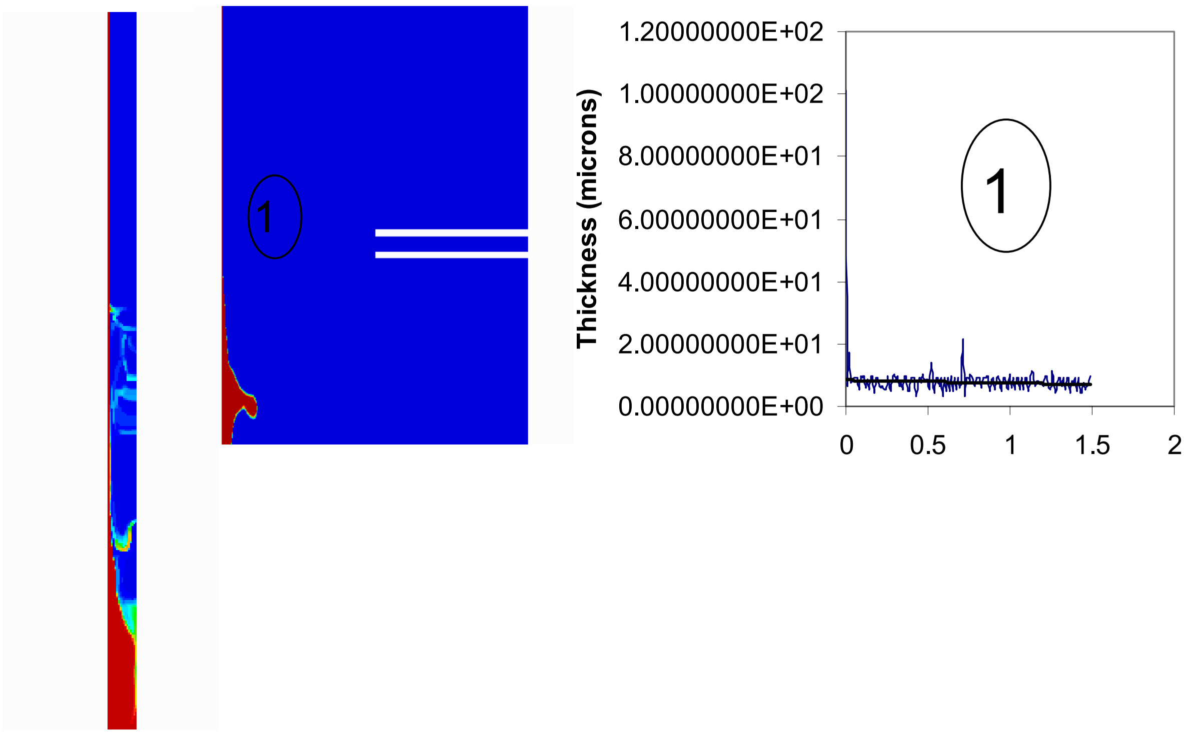


Figure 3: Results of the interaction between the jet and the film.

Conclusion:

An available and easy methodology has been developed within the frame of a commercial code, in order to compute the film thickness resulting from a wiping process submitted to a high speed impinging air-jet. Results obtained are satisfactory both in terms of turbulent flow impinging jet (high speed) and also in terms of low-numerical-diffusion of the free surface interface. It is proven that the turbulent properties belonging to the jet flow are not crossing the free surface and therefore not participating to an additional diffusion. Also the variations of the film thickness are mainly due to jet fluctuations.

Reference:

Ubbink O., *Numerical prediction of two fluid systems with sharp interfaces*, Ph.D. Thesis, Dept. Of Mechanical Eng., Imperial College of Science, Technology & Medicine, January 1997.