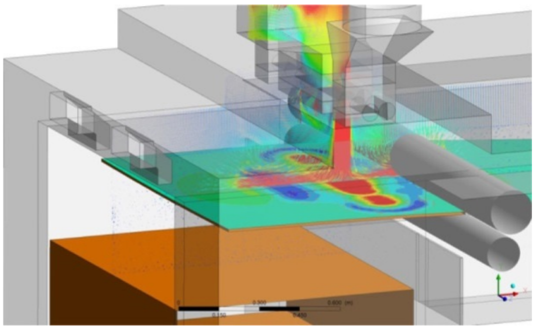
Construction of CFD-MBD Co-simulation Technology to Improve Product Reliability of Box Making Machines



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In order to accurately predict and analyze the behavior of cardboard sheets during high-speed operation of the box making machine products of Mitsubishi Heavy Industries, Ltd. (MHI) Group, we reproduced the flow field in a box making machine with CFD (Computational Fluid Dynamics) and modeled the elastic deformation and movement of cardboard sheets with MBD (Multi Body Dynamics) to construct a CFD-MBD co-simulation model. As a result, the prediction of the flying behavior of cardboard sheets inside the box making machine has been made possible without making a prototype, and the optimum control for stabilizing the cardboard sheet behavior can be considered. This report presents this effort.

1. Introduction

The demand for cardboard boxes has been increasing due to the increase in logistics volume caused by the recent expansion of e-commerce, etc. MHI group has been manufacturing box making machines since 1955, and develops box making machines offering the world's top level production performance. One of the factors that hinder high-speed production is the risk of paper jams inside the box making machine while conveying cardboard sheets. In order to make high-speed conveyance stable, it is necessary to accurately predict the behavior of cardboard sheets, which requires the calculation of the force acting on the cardboard sheet during conveyance. For that purpose, we reproduced the flow field in the box making machine with CFD and modeled the deformation, posture, and movement of cardboard sheets, which are important parameters for analysis accuracy, with MBD to construct a CFD-MBD co-simulation model(1). This report presents the results of CFD-MBD co-simulation for the cardboard sheet stacking process of a box making machine.

2. Analytical model and boundary conditions

2.1 Configuration of box making machine and analysis target

Figure 1 shows the configuration of a box making machine(2). Plate-shaped cardboard put into the paper feed unit is conveyed into the processes of surface character printing, slotting・creasing, gluing, folding, and then counting and stacking. The analysis target handled in this report is the counter ejector(4), which performs counting and stacking, of an EVOL high-speed box making machine that can produce cardboard boxes at the world's fastest speed of 400 sheets per minute (3). As shown in **Figure 2**, the counter ejector passes conveyed cardboard sheets through the rollers, discharges into the air, and stacks them stably by blowing air with a blower. In addition, a structure with which the tip of discharged cardboard sheets collides with the front stopper is provided in order to reduce rebound. After that, the stacked cardboard sheets are moved downward by the elevator.

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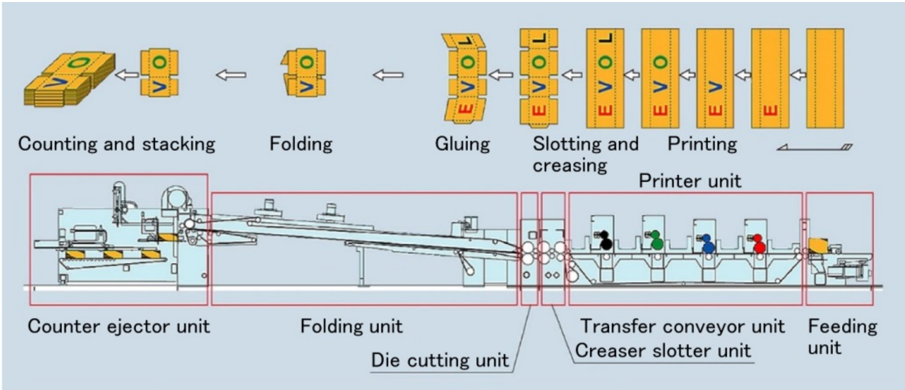

Figure 1 Cardboard making processes and outline of inside of box making machine

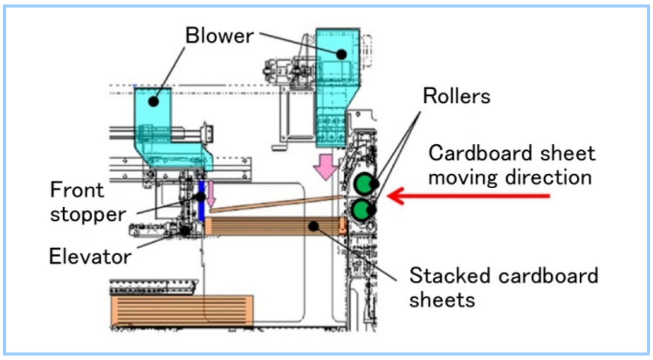

Figure 2 Outline of counter ejector unit

2.2 Analysis model

Figure 3 shows the analysis model. This report describes the evaluation of the process from passing cardboard sheets through the rollers to discharging them into the air. With CFD, the conveyed cardboard sheets, blower, and elevator were simulated, and with MBD, which took contacts into consideration, the rollers and front stopper were also simulated. The analysis conditions were set as shown in **Table 1**, simulating the actual operating conditions.

Table 1 Analysis conditions

	CFD	MBD
Solver	ANSYS Fluent Ver.18.2	MSC ADAMS 2018
Model	Realizable k-ε	—
Time interval	0.0002 [s]	0.001 [s]
Co-simulation time interval	0.002 [s]	
Boundary conditions	Entrance: Velocity (blower) Exit: Pressure (side surface, under surface)	Cardboard sheet: Elastic object Roller: Friction

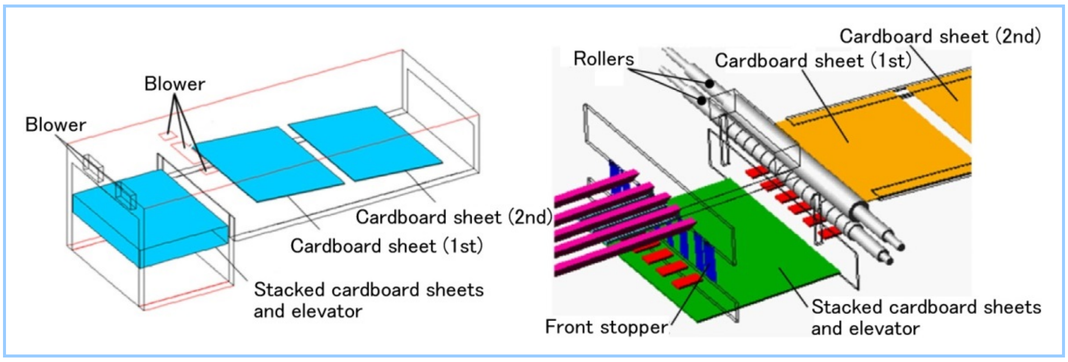

Figure 3 Outline of analysis model

2.3 Outline of co-simulation analysis

As the solver, ANSYS Fluent was used for CFD, and MSC ADAMS for MBD, and different software co-simulation was performed. The co-simulation used an in-house tool[5] that interchanged data. This transferred the fluid force on the surface of the cardboard sheet from CFD to MBD, and the position and displacement information of the cardboard sheet from MBD to CFD, which made CFD analysis that took into account the deformation of the cardboard sheet possible. In the CFD analysis, the cardboard sheet position was updated from moment to moment by MBD. For this updating, the remesh method built into Fluent was used.

Figure 4 shows the co-simulation method. This is performed by repeating the following steps [1] to [7]. This procedure enables co-simulation.

[1] Executing CFD at the initial position
[2] Outputting the fluid force at the coupled interface of co-simulation
[3] Mapping the fluid force to MBD
[4] Calculating the posture and movement amount of the object with MBD
[5] Outputting the displacement of the coupled interface of co-simulation
[6] Mapping the amount of movement to CFD
[7] Moving the mesh in CFD and executing CFD

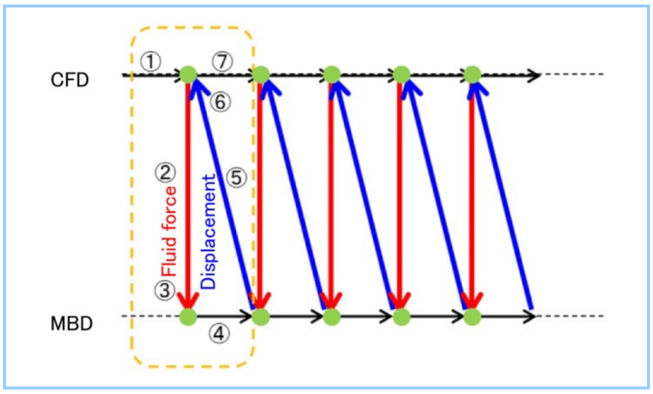

Figure 4 Flow of co-simulation analysis

3. Analysis results and verification

3.1 Co-simulation results

After we construct the in-house co-simulation tool, we used it to evaluate the flow field in the box making machine, taking into account the ever-changing cardboard sheet position. The diagrams in **Figure 5** show the cardboard sheet position and velocity vector in the central cross section with the blower absent in time-series order. The velocity vector and time were made dimensionless by the blower flow velocity with the blower present described below and the time when the posture of the cardboard sheet became horizontal, respectively. It can be seen in Figure 5 how the cardboard sheet conveyed between the rollers was conveyed to the upper part of the stacked cardboard sheets. Meanwhile, the stacked cardboard sheets were moved downward by the elevator. The cardboard sheet that was conveyed in a posture inclining downward to the right at the time t = 0.4T deformed elastically to a bow-like shape at the time t = T. At the time t = 0.7T, a circulating vortex was formed between the under surface of the cardboard sheet and the stacked cardboard sheets. The downward force due to this vortex caused the tip of the cardboard sheet to lower and the cardboard sheet to become horizontal. It was found from this co-simulation results that the circulating vortex contributed to the stability of the cardboard sheet posture.

3.2 Confirmation of effect of blower

Figure 6 compares the diagrams of velocity vector in the central cross section at the time t = 0.7T with the blower present and absent. It can be seen that there was a difference in the flow field and the posture of the cardboard sheet compared with the case where the blower was absent. When the blower was present, flows along the upper surface of the cardboard sheet toward the front and rear ends were generated. On the side of the tip of the cardboard sheet, a flow was directed toward the underside of the cardboard sheet and collided with the stacked cardboard sheets, which strengthened the circulating vortex described in the section 3.1. This flow caused downward force on the under surface of the cardboard sheet, and the tip of cardboard sheet turned downward as a result.

This result indicates that by controlling the flying posture of cardboard sheets by using blower air, it is made possible to prevent collision with the subsequent cardboard sheet and ensure stable cardboard sheet conveyance.

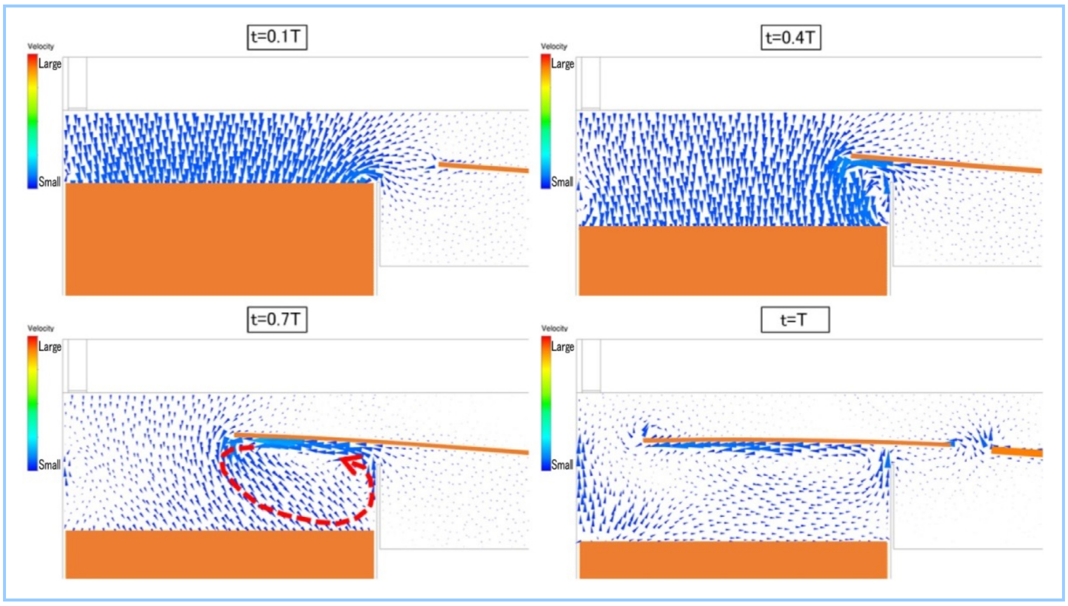

Figure 5　Time-series change in flow field around cardboard sheet in central cross section

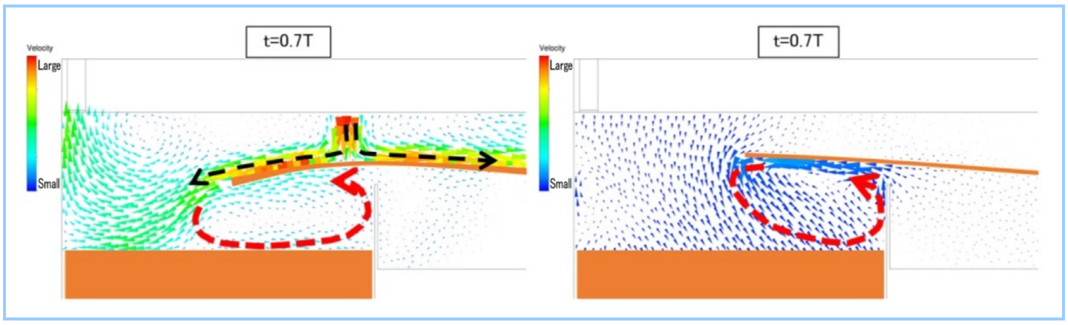

Figure 6　Flow velocity in central cross section at time t = 0.7T (comparison of cases with blower present and absent)

3.3　Verification

In order to verify the analysis results, a comparison with the position of a cardboard sheet identified based on the video shot inside the actual equipment was performed. **Figure 7** compares the analysis results and the test results of the position of a cardboard sheet discharged from between the rollers. As shown in Figure 7, the relationships between the flying posture and the height of the reaching point with the blower present and absent were consistent between the test results and co-simulation results. It is confirmed from this that the developed co-simulation technology can be used to evaluate applicability to actual equipment.

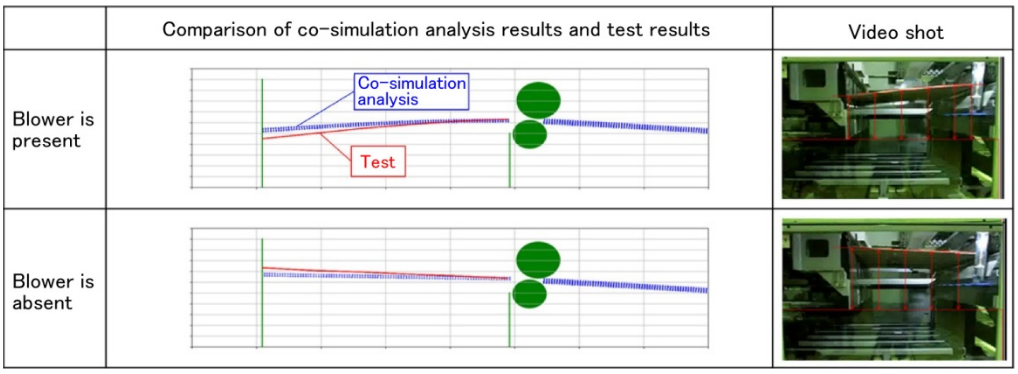

Figure 7　Comparison results between analysis and test

4. Conclusion

We construct a CFD-MBD co-simulation model that can precisely analyze the behavior of cardboard sheets during high-speed operation in MHI group's box making machine products, and made an evaluation of the flow field in a box making machine, by which it was confirmed that the circulating vortex below the under surface of the cardboard sheet contributes to the stability of cardboard sheet posture and that blower air can prevent collision with the subsequent cardboard sheet. As a result, it was confirmed that EVOL, a box making machine product of our group, can perform stable conveyance of cardboard sheets. In addition, a comparison of the analysis results of cardboard sheet posture with the behavior in actual equipment resulted in the relationships between the flying posture and the height of the reaching point being consistent between the analysis results and the behavior in actual equipment.

As a result, the analysis-based prediction of the flying behavior of cardboard sheets in the counter ejector unit has been made possible without making a prototype, which enables desktop consideration of control technology required for the stable production of cardboard sheets at the world's fastest level. In addition, by utilizing this analysis model, considering operating methods and deriving optimum set values based on parameter study have also been made possible.

Moving forward, we will carry out development for higher speed conveyance for this product and the parameter study of optimum conditions to improve product performance.

References

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