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SPACE-CUPID Coupling and Verification

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1. Introduction

The importance of multi-dimensional flow effects during various accidents is well known through various large-scale experiments, such as the UPTF tests. In order to analyze a multi-dimensional thermal-hydraulic behavior, the coupling between system analysis code like SPACE and three-dimensional analysis code like CUPID is necessary. In this study, SPACE-CUPID coupling is achieved and verified with simple test problems.

2. SPACE-CUPID Coupling Methodology

The SPACE-CUPID coupling methodology is based on the RELAP5-COBRA coupling methodology [1-2]. In addition, CUPID code already has the interface to couple to the system analysis code of MARS with the same methodology [3].

2.1 Coupling Process

Fig. 1 shows example of SPACE-CUPID coupled system. Basically, the existing MARS-CUPID coupling interface in the CUPID is used as much as possible. But, the CUPID interface in SPACE is newly implemented with modification of the existing TFBC (pressure boundary) component. Table I shows major coupling procedure of SPACE-CUPID. All coupling variables are shared with same memory structure. The control of the coupling sequence is managed with the 'iwhere' index. For example, when the iwhere = 3, the time steps of both CODE are calculated and the identical time step is decided. The major coupling methodology is explicitly solving momentum equation in the both CODE.

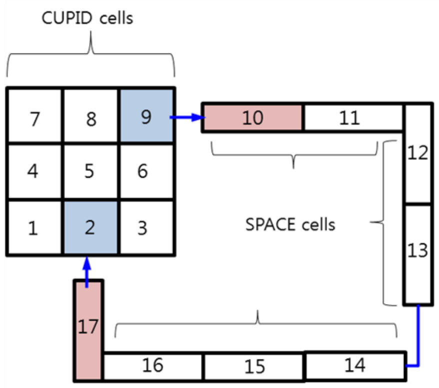

Fig. 1. Example of SPACE-CUPID Coupled System

Table I: SPACE-CUPID Coupling Process

No.	SPACE	CUPID
1	Read input and CUPID B.C.	Read input and SPACE B.C.
2	Initialization	Initialization
3	Set time step size	Set time step size
4	Send and obtain donor properties	
5	Setup the discretized equations	Setup the discretized equations
6	Modify and solve the system pressure matrix	
7	Send coefficients in pressure matrix	Setup and Solve pressure matrix
8		Send pressure drop in the CUPID cell
9	Solve the system pressure matrix	
10	Back-substitution	Back-substitution
11	New time step	New time step

2.2 Momentum Coupling

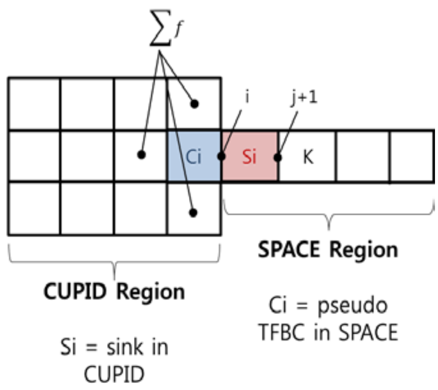

Fig. 2. Conceptual Nodalization of SP Coupling

Fig. 2 shows conceptual nodalization of SPACE and CUPID code. The momentum equation at the interface between Ci and Si is solved by SPACE. The phasic momentum equation are solved to represent the phasic velocity at i-junction in terms of pressures of the adjoining cells,

$$V_{k,i}^{n+1} = \alpha_{k,i} + \beta_{k,j}(\delta P_{Ci} - \delta P_{Si}) \quad (1)$$

$$\delta P = P^{n+1} - p^{n} \qquad (2)$$

When phase velocity is replaced with Eq.(1), the Eq.(3) can be obtained. And this matrix included δP_{Ci} for the connected cell. Multiplying inverse matrix of $[A_s]$, the system pressure matrix is derived Eq.(4). Therefore, the pressure variation at the connected cell in the SPACE, Si can be expressed with pressure variation at the connected cell in the CUPID, Ci as shown in Eq.(5). Using Eq.(5) the interface velocity can be evaluated with Eq.(6). The coefficients, α, β, ξ, and η are the major variable to be transferred to CUPID by SPACE, which represents the coefficient in the step 7 of the Table I. In this way, the system pressure matrices, which are set up in each code, are coupled via the momentum modeling at the interfaces and solved simultaneously.

$$[A_s]\underline{\delta P} = b + \sum_{i=1}^{NS} \gamma_i \delta P_{Ci} \qquad (3)$$

$$\underline{\delta P} = [A_s]^{-1} b + \sum_{i=1}^{NS} ([A_s]^{-1}\gamma_i)\delta P_{Ci} \qquad (4)$$

$$\delta P_{Si} = \xi_i + \sum_{j=1}^{NS} \eta_{i,j} \delta P_{Cj} \qquad (5)$$

$$V_{k,i}^{n+1} = \alpha_{k,i} - \beta_{k,i}\xi_i + \beta_{k,i}\left(\delta P_{Ci} - \sum_{j=1}^{NS} \eta_{i,j}\delta P_{Cj}\right) \qquad (6)$$

3. Verification Test

It should be confirmed that the code coupling scheme and its implementation are valid, before code assessment process. For this verification, simple vertical channel tests with three different connections between SPACE and CUPID are selected. Fig. 3 shows test cases with three different coupling order from the inlet to outlet:

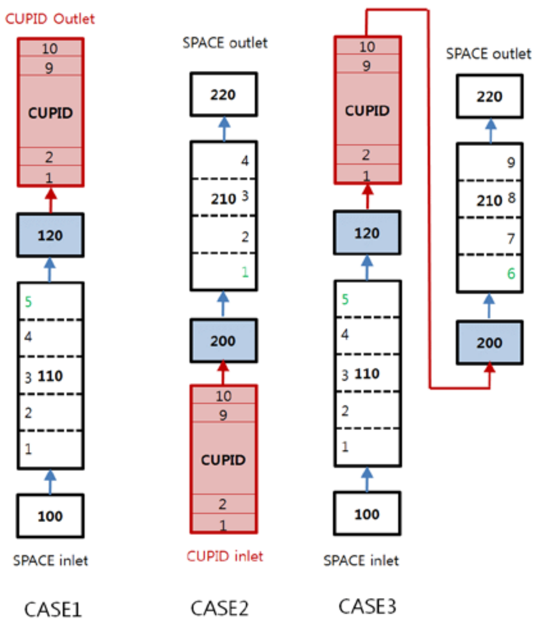

Fig. 3. Three Cases for Verification Tests

1) SPACE(5 volumes)-CUPID(10 volumes)
2) CUPID(10 volumes)-SPACE(4 volumes)
3) SPACE(5)-CUPID(10)-SPACE(4)

The lengths of the volume for SPACE and CUPID are 0.2 m and 0.1 m, respectively. The flow area is constant of 0.01 m^2. The inlet water velocity is gradually increased from 0 m/s to 0.1 m/s for 5 seconds. The outlet pressure is constant of 1.0 MPa. To verify the coupled results, SPACE only calculation is conducted with same node configuration.

Fig. 4 shows results of the CASE-1. The line is result of the SPACE-only calculation and blue and red simbols indicate SPACE and CUPID results, respectively. At the boundary the SPACE code can solve momentum equation for the half cell. Thus, the pressure at the connected cell is slightly under-estimated (circular symbol). Thus, differing from the MARS-CUPID coupling, the boundary pressure is modified using the pressure drop in the connected CUPID cell. The results with this pressure correction is exactly same to the SPACE-only as shown in square symbol. Fig. 5 and Fig. 6 show the pressure results for the CASE-2 and CASE-3, respectively. In addition, difference of the pressure between the SPACE-only and the S-C coupled are summarized in Table II. With the boundary pressure correction, perfectly same results are obtained.

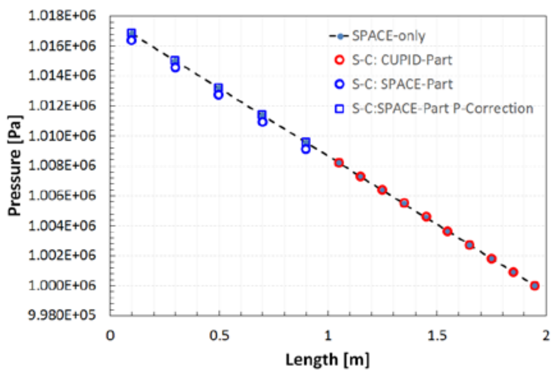

Fig. 4. Pressure Distribution for the CASE-1

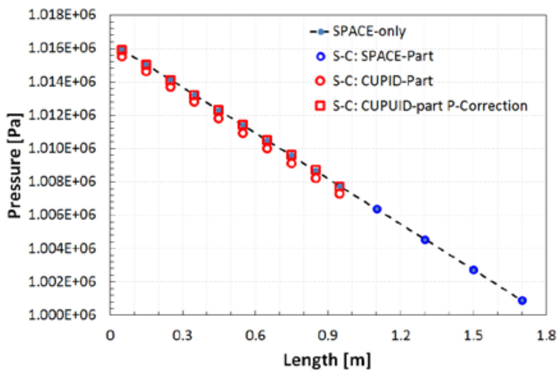

Fig. 5. Pressure Distribution for the CASE-2

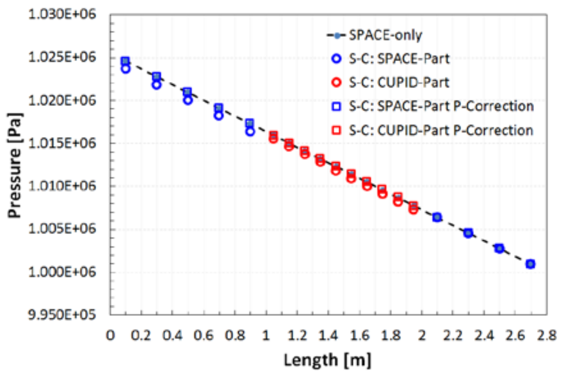

Fig. 6 Pressure Distribution for the CASE-3

Table II: Pressure Difference for SPACE-CUPID

<table>
<tr><th rowspan="2">Node</th><th colspan="2">CASE1</th><th colspan="2">CASE2</th><th colspan="2">CASE3</th></tr>
<tr><th>C[1]</th><th>Diff[2]</th><th>C[1]</th><th>Diff[2]</th><th>C[1]</th><th>Diff[2]</th></tr>
<tr><td>1</td><td rowspan="5">S</td><td>0</td><td rowspan="10">C</td><td>50</td><td rowspan="5">S</td><td>10</td></tr>
<tr><td>2</td><td>0</td><td>30</td><td>10</td></tr>
<tr><td>3</td><td>0</td><td>20</td><td>10</td></tr>
<tr><td>4</td><td>0</td><td>10</td><td>10</td></tr>
<tr><td>5</td><td>0</td><td>0</td><td>10</td></tr>
<tr><td>6</td><td rowspan="10">C</td><td>0</td><td>-10</td><td rowspan="10">C</td><td>50</td></tr>
<tr><td>7</td><td>-20</td><td>-20</td><td>30</td></tr>
<tr><td>8</td><td>-30</td><td>-30</td><td>20</td></tr>
<tr><td>9</td><td>-40</td><td>-40</td><td>10</td></tr>
<tr><td>10</td><td>-50</td><td>40</td><td>0</td></tr>
<tr><td>11</td><td>40</td><td rowspan="4">S</td><td>0</td><td>-10</td></tr>
<tr><td>12</td><td>30</td><td>0</td><td>-20</td></tr>
<tr><td>13</td><td>20</td><td>0</td><td>-30</td></tr>
<tr><td>14</td><td>10</td><td>0</td><td>-40</td></tr>
<tr><td>15</td><td>-4</td><td colspan="2" rowspan="5"></td><td>40</td></tr>
<tr><td>16</td><td colspan="2" rowspan="4"></td><td rowspan="4">S</td><td>0</td></tr>
<tr><td>17</td><td>0</td></tr>
<tr><td>18</td><td>0</td></tr>
<tr><td>19</td><td>0</td></tr>
</table>

1 CODE for calculation part, S: SPACE , C: CUPID
2 pressure difference [Pa]

4. Summary and Future Works

The capability of multi-dimensional analysis in a system analysis code is very important for accurate analysis in a multi-dimensional thermal-hydraulic behavior. In this study, system analysis code, SPACE and multi-dimensional analysis code, CUPID are coupled with explicit coupling of momentum calculation. For the verification of SPACE-CUPID coupling, simple vertical channels are tested. The perfectly verified results are obtained with the pressure correction in the interface between SPACE and CUPID.

Currently, a single phase water flow is verified. However, in order to handle general problem, such as the UTPF, two-phase condition should be verified. In addition, SPACE-CUPID coupled code should be validated with appropriate experimental results. In the near future, additional verification and validation tests will be achieved.

ACKNOWLEGEMENT

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REFERENCES

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