P1. The following loop is executed for 1,000 iterations.

```
Loop: ld    x10, 0(x13)
      ld    x11, 0(x14)
      mul   x12, x10, x11
      add   x16, x16, x12
      sd    x12, 0(x17)
      addi  x17, x17, 8
      addi  x14, x14, 8
      addi  x13, x13, 8
      beq   x13, x12, Loop
```

a) Assume that this loop is executed on the five-stage RISC-V pipelined processor studied in the class. Assume also that this processor solves all data hazards through forwarding and stalls, resolves the branch instructions in the decode stage, and has one-cycle branch delay. How many cycles are needed to execute the 1,000 iterations ignoring the time needed to fill the pipeline?

b) Unroll this loop two times and schedule it for the static dual-issue processor studied in the class?

c) Assuming same conditions as in (a) above, how many cycles are needed to execute the unrolled loop on the dual-issue processor?

P2. Assume that the following loop is executed by a speculative pipelined processor of degree 3. This processor uses reservation stations, common data buses, and reorder buffer. The fetch stage takes one cycle and the issue stage takes one cycle. The integer/branch latency is 1 cycle and the load latency is 2 cycles (1 cycle for address calculation and 1 cycle for data memory access). The processor has two address calculation units, two memory access units, two integer ALU units, and one branch unit.

```
Loop: ld    x10, 0(x13)
      ld    x11, 0(x14)
      mul   x12, x10, x11
      add   x16, x16, x12
      sd    x12, 0(x17)
      addi  x17, x17, 8
      addi  x14, x14, 8
      addi  x13, x13, 8
      beq   x13, x12, Loop
```

a) Assume that branch prediction is used and the branch instruction is predicted wrongly as not taken at the end of the first iteration. Draw the multi-cycle pipeline diagram for the execution of the first two iterations of this loop to find how many cycles are needed to fetch and commit the two iterations.

b) Now assume that this processor has perfect branch prediction with no branch delay. Estimate the number of cycles needed to execute 1,000 iterations of this loop ignoring the time needed to fill the pipeline? (Show your work clearly)