Georgia Institute of Technology | Marquette University | Milwaukee School of Engineering | North Carolina A&T State University | Purdue University | University of California, Merced | University of Illinois, Urbana-Champaign | University of Minnesota | Vanderbilt University

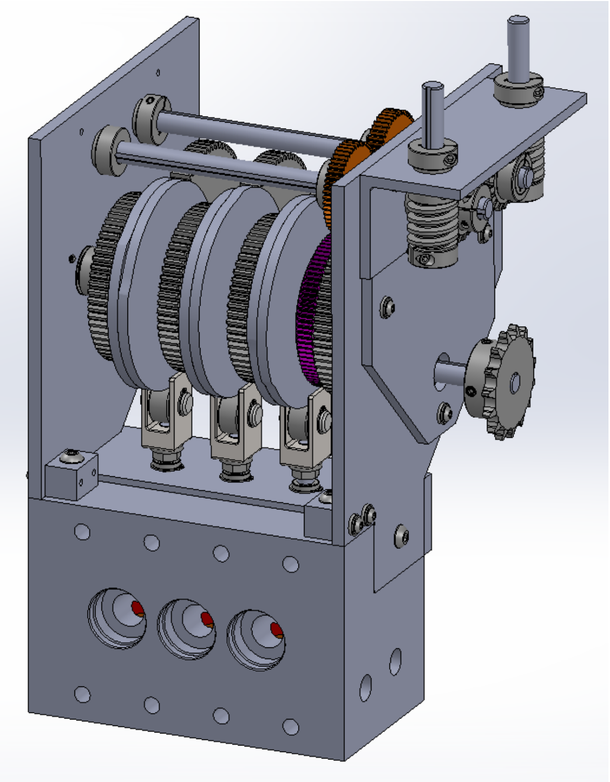
Four-Quadrant Multi-Fluid Pump/Motor

James Marschand
Graduate Researcher
Purdue University
Advisor- John Lumkes

2018 Industry- University Summit
Lexington, KY | March 7-9, 2018

Overview

- What is a four-quadrant multi-fluid pump/motor?
- Operating strategies
- Digital displacement control benefits
- Mechanically actuated prototype
- Model validation
- What are the next steps to develop an improved solution?

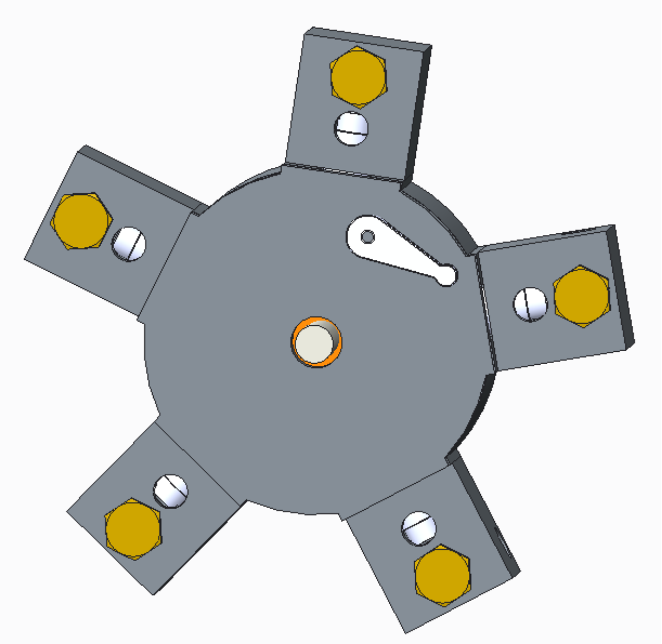


Mechanically actuated valve prototype

Background

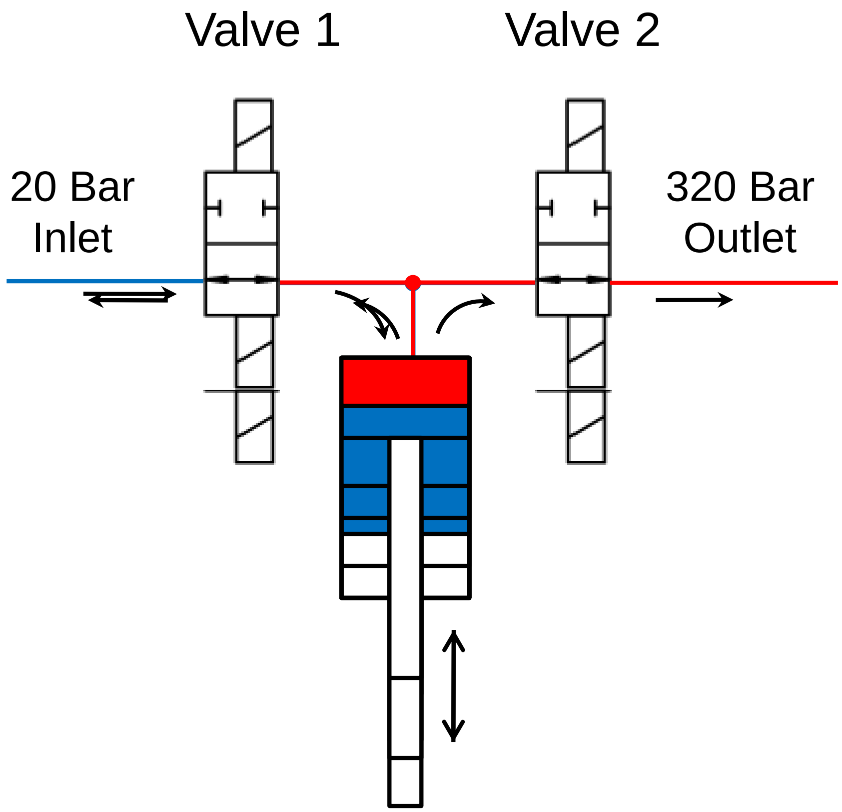
Digital Four Quadrant Multi-fluid Pump/Motor

- Digital: utilizes digital displacement control
  - On/off valves at inlet and outlet of each piston
- Four-quadrant: capable of pumping and motoring each in CW and CCW rotation
- Multi-fluid: pump lubrication does not depend on operating fluid



Operating Strategies

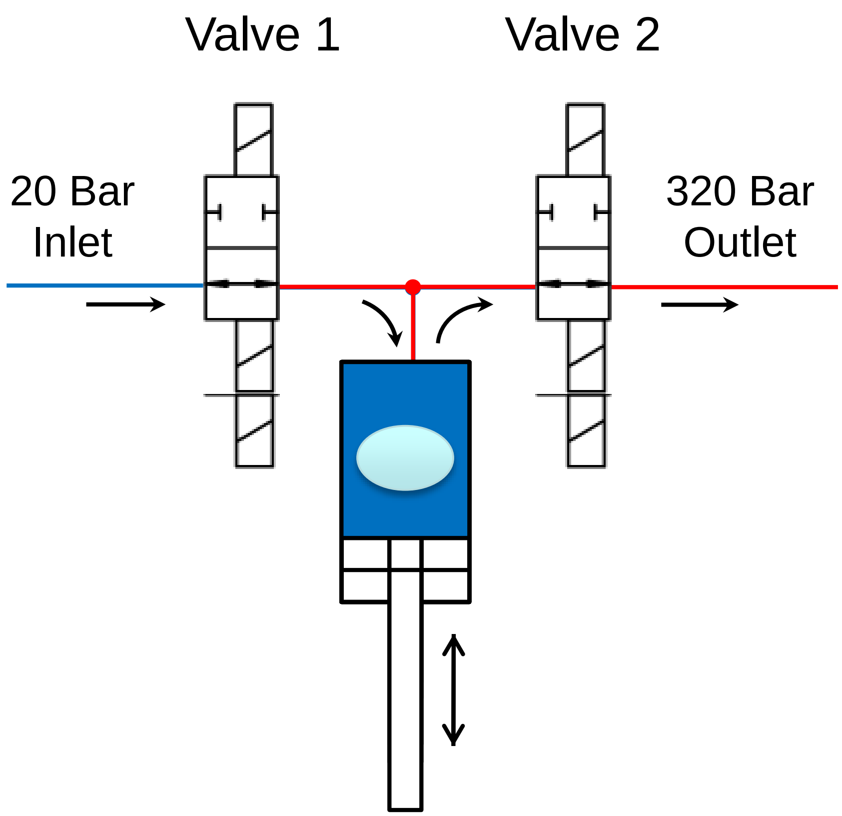
- Flow Diverting
  - Excess flow taken into the chamber is diverted back to the low pressure port
- Flow Limiting
  - Amount of flow taken into the chamber is limited to the desired flow
- Sequential (Diverting or Limiting)
  - Individual cylinders are operated at full or zero displacement



Digital displacement control

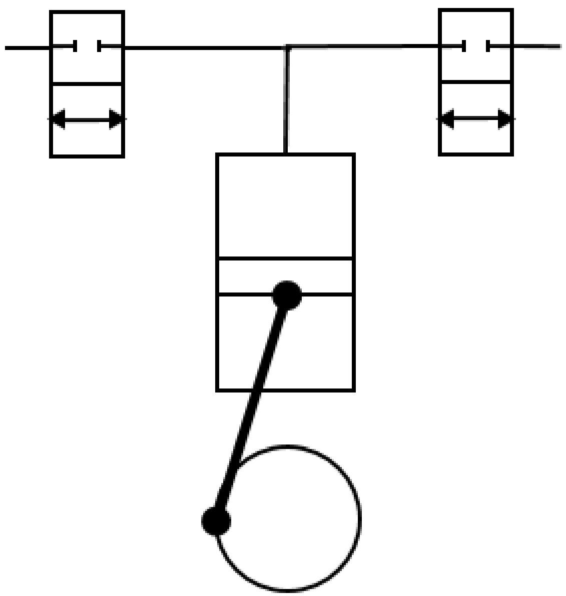
Operating Strategies

- Flow Diverting
  - Excess flow taken into the chamber is diverted back to the low pressure port
- Flow Limiting
  - Amount of flow taken into the chamber is limited to the desired flow
- Sequential (Diverting or Limiting)
  - Individual cylinders are operated at full or zero displacement



Digital displacement control

Benefits of Digital Displacement



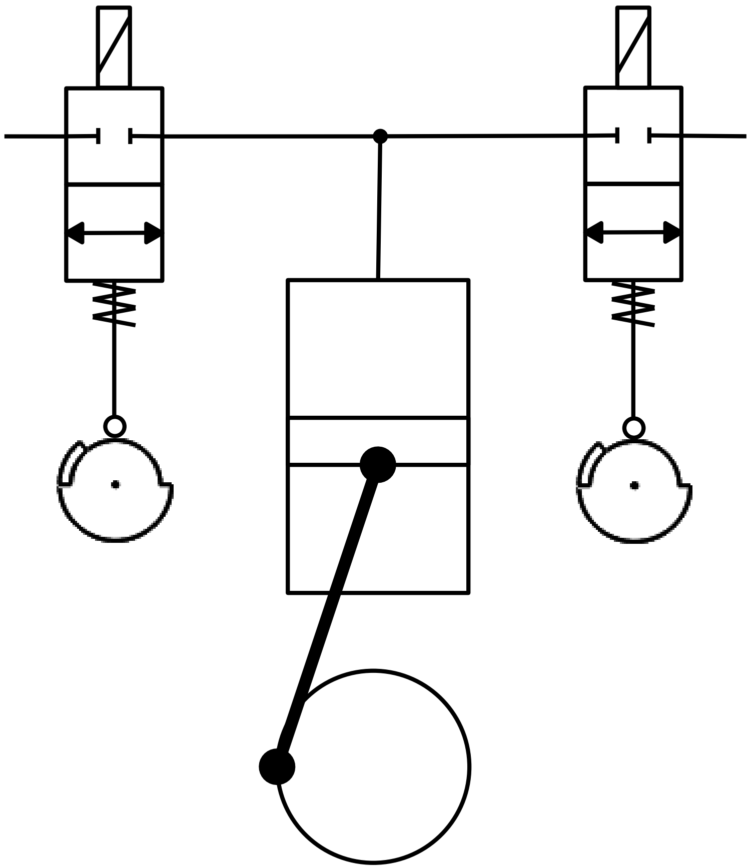
Digital displacement control on/off valve placement

Digital Pump/Motor Advantages

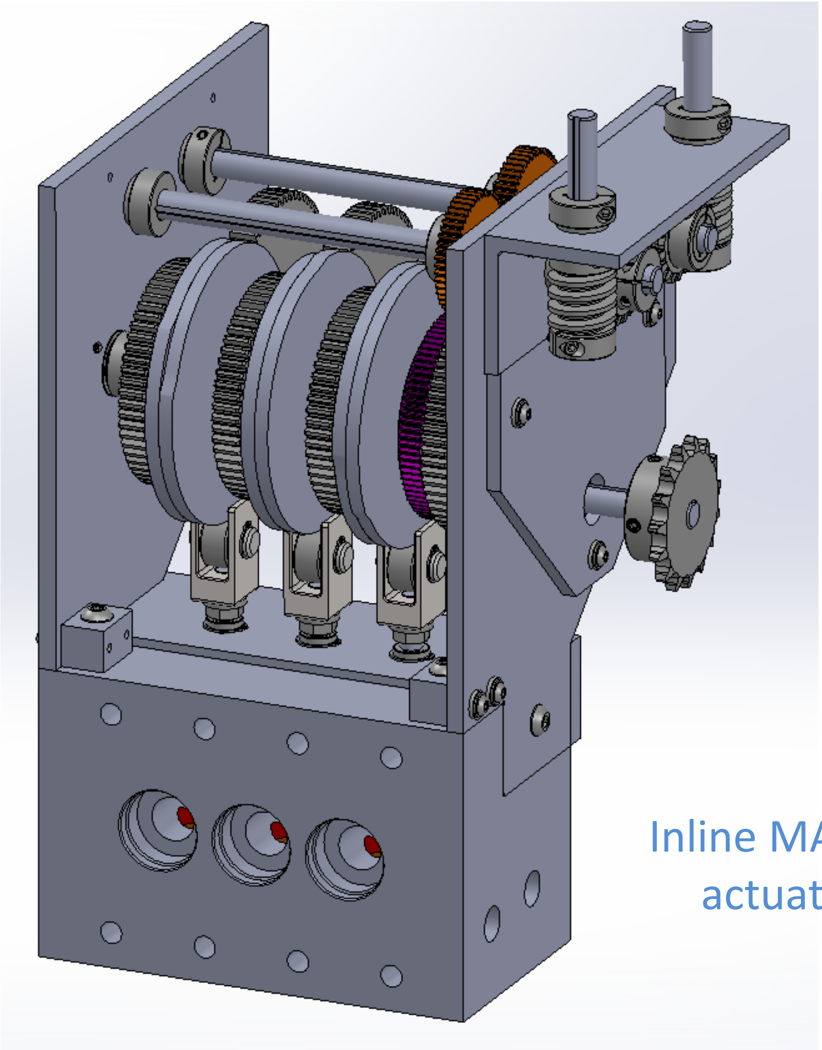
- Higher efficiency across operating range
  - Eliminates valve plate and port plate
  - Leakages scale closely with displacement
- Pumping of non-conventional fluids (water)
- Valves can open against high pressure
  - Self starting in motoring
- Freedom in operating strategies
- Lower cost
  - No need for pilot pressure
  - No electrical energy needed

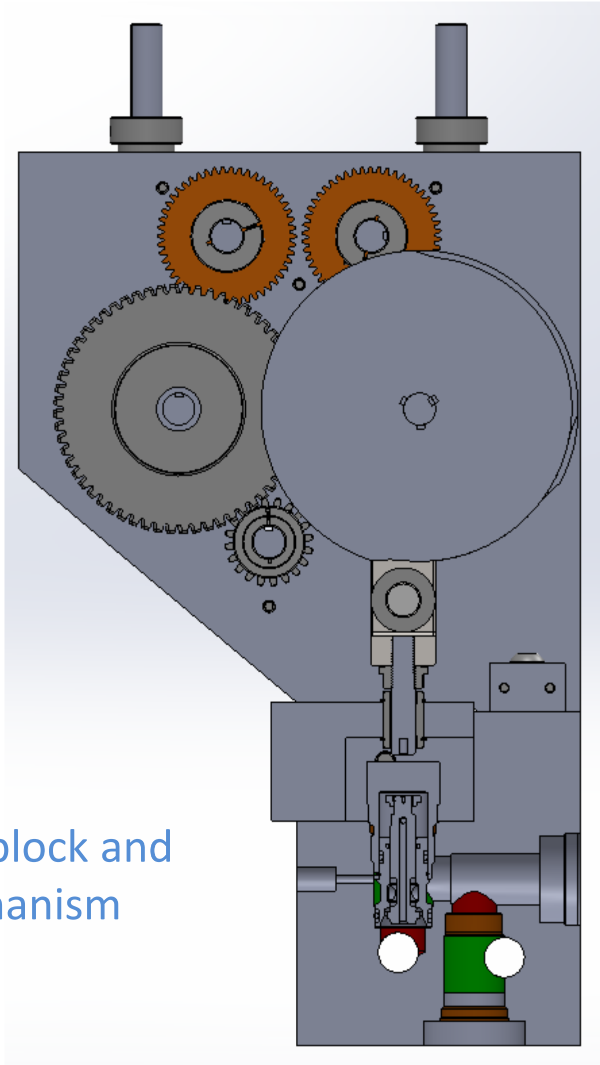
Mechanically Actuated Valves

- First prototype use electrical actuation of on/off valves
- Mechanical actuation advantages
  - Fast and consistent
  - No electrical energy needed
  - No sensors or embedded controls
  - Actuation repeatability is increased
    - Critical for efficiency



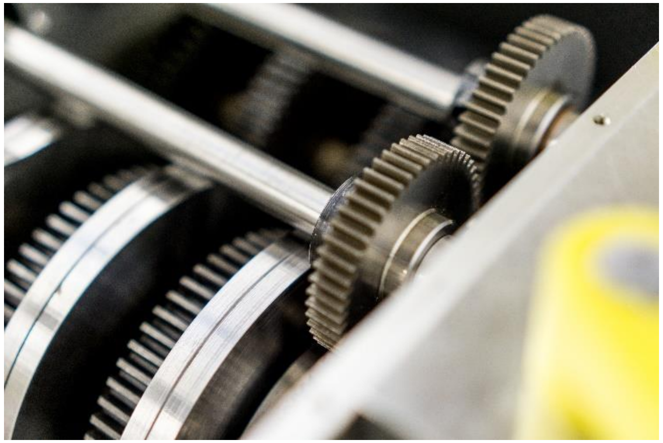
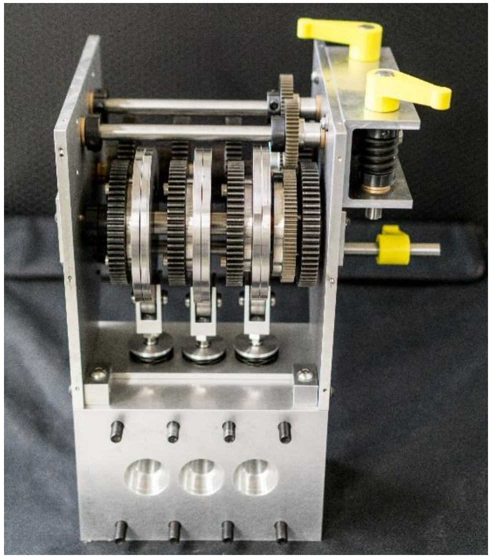
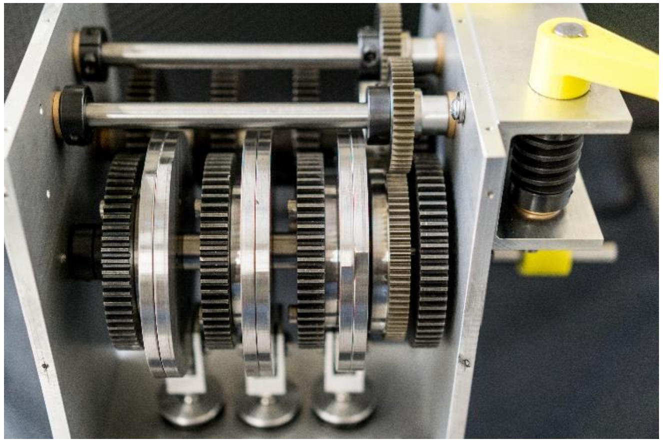
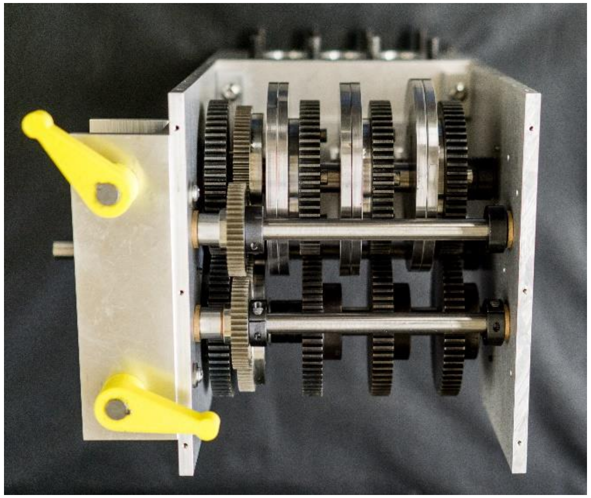
Implementation





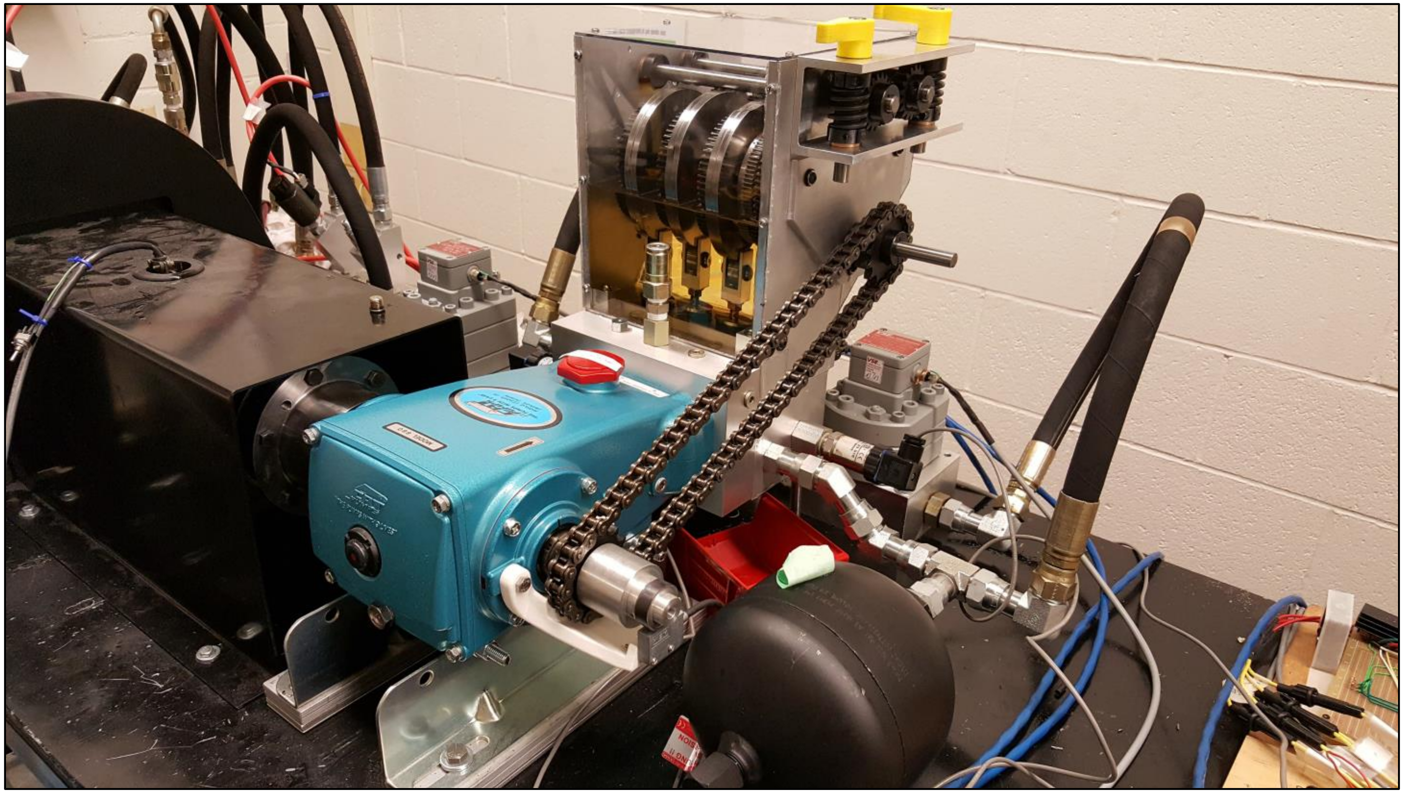
Inline MAV valve block and actuation mechanism

Prototype

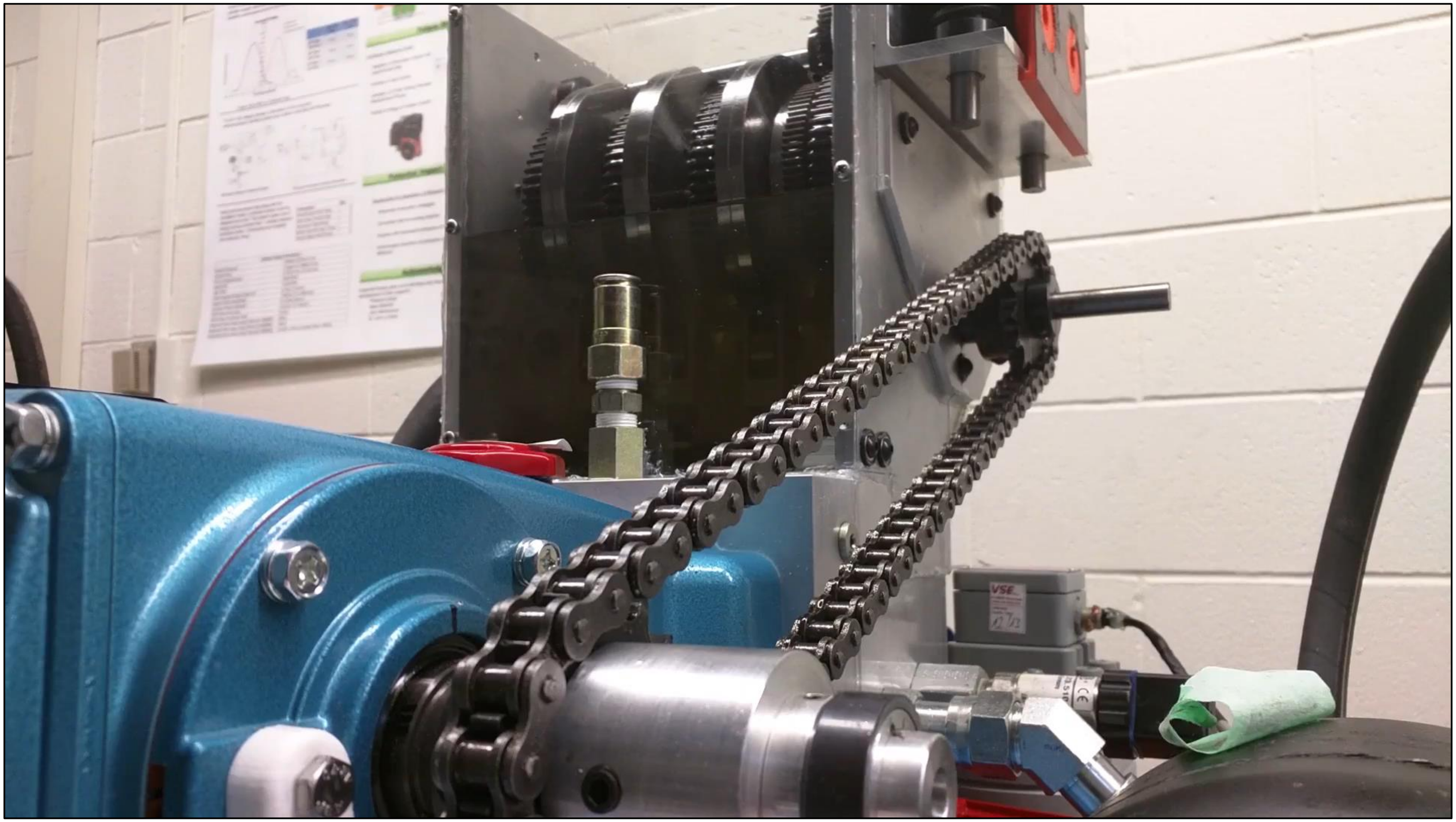
Experimental Test Stand

Multi-piston digital pump/motor test stand

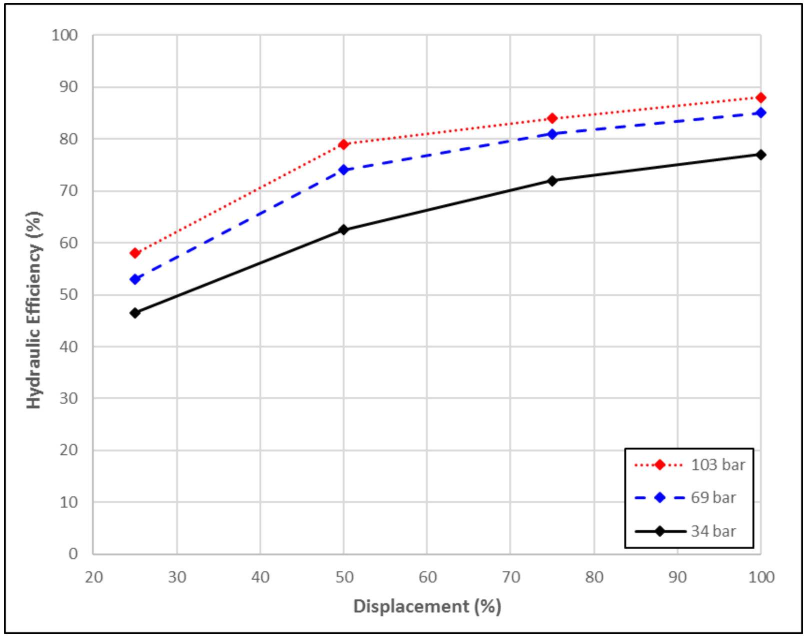


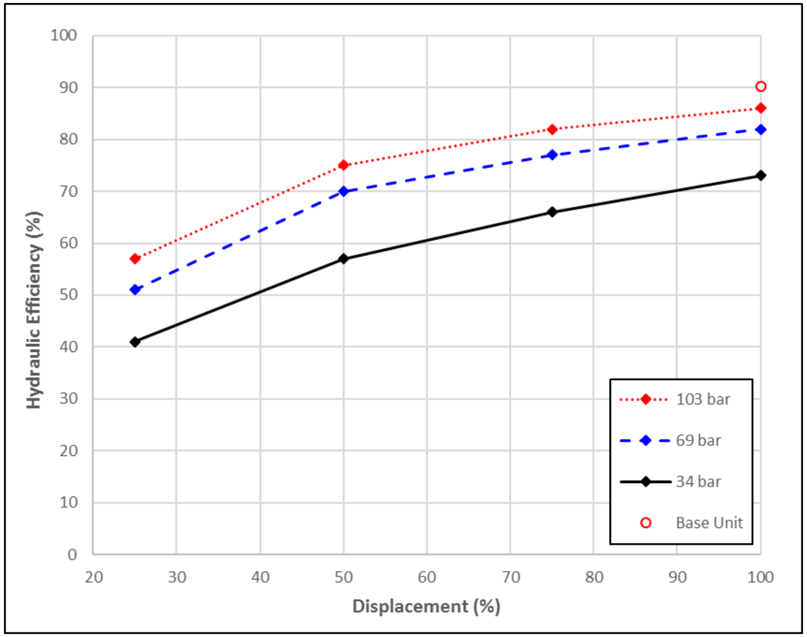
- 3-piston digital pump
- One on/off valves per piston
- One check valve per piston
- Three 2,000 Hz pressure transducers
- Two accumulators

Experimental Testing



Results for Mechanical Actuation



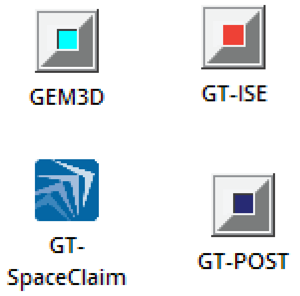


Overall hydraulic efficiency for pumping at 300rpm (left), 500rpm (right)

- Partial flow diverting only operating strategy tested
- Efficiency does not fall below 40%

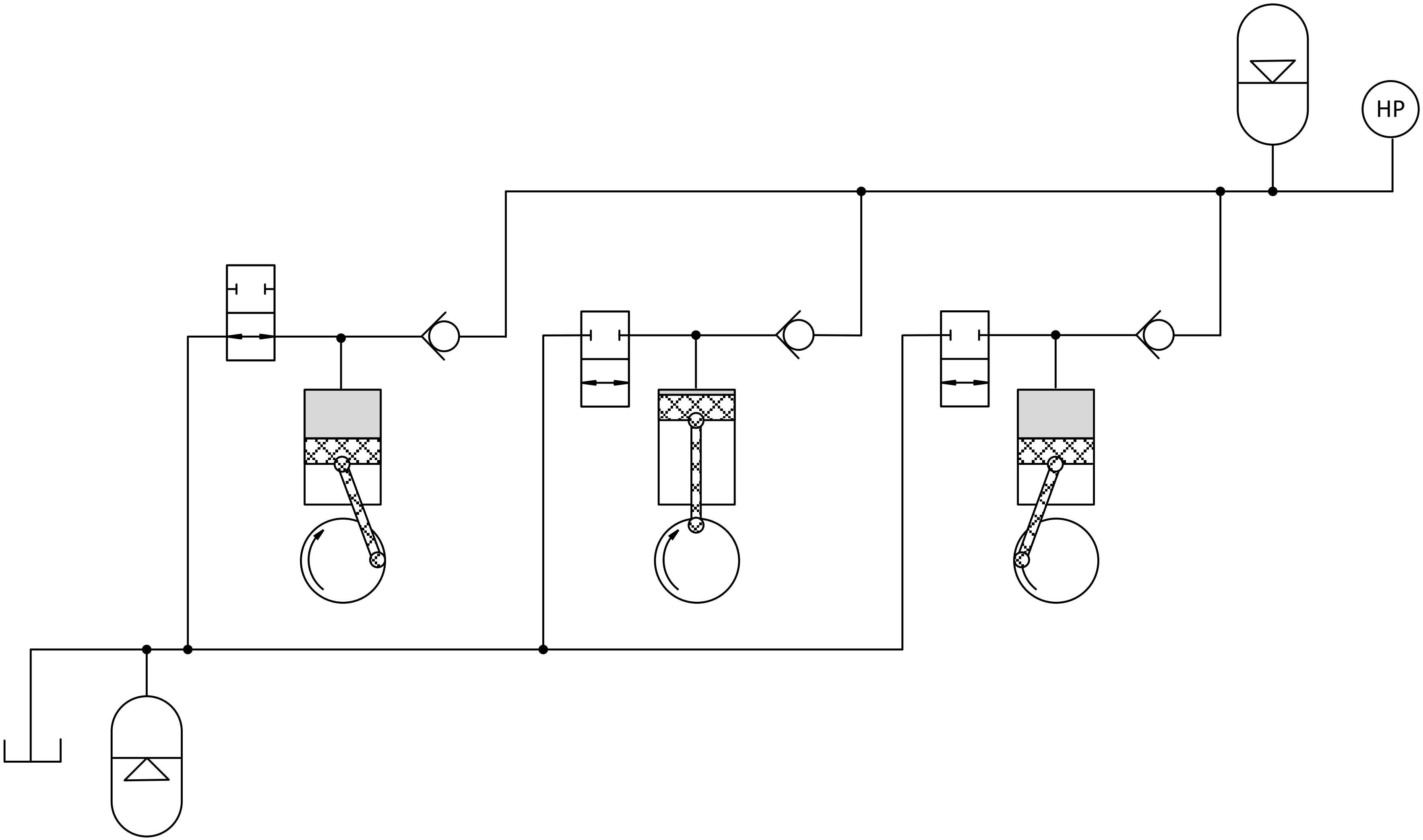
GT Suite Overview

- 1D multi-physics system simulation software
- GT-Suite Tools
  - CAD modeling and preparation
  - Converting 3D CAD model into GT model
  - Model building and run control
  - Post processing

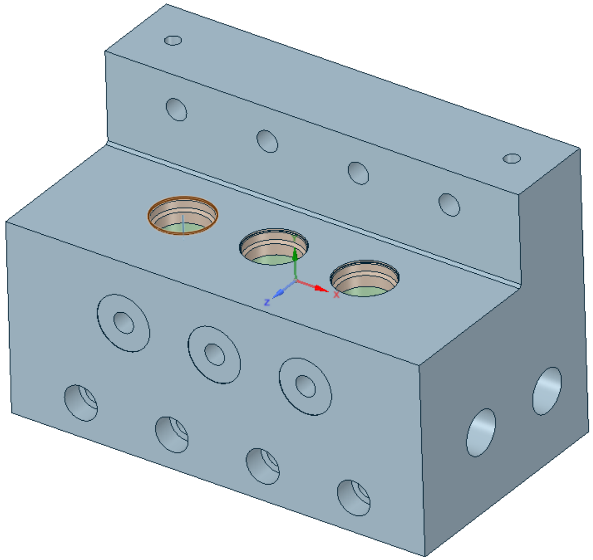


- Hydraulics applications
  - System and component level models
  - Existing piston pump and valve component templates
  - Accurate pressure wave dynamics
  - Advanced features such as DoE and optimization

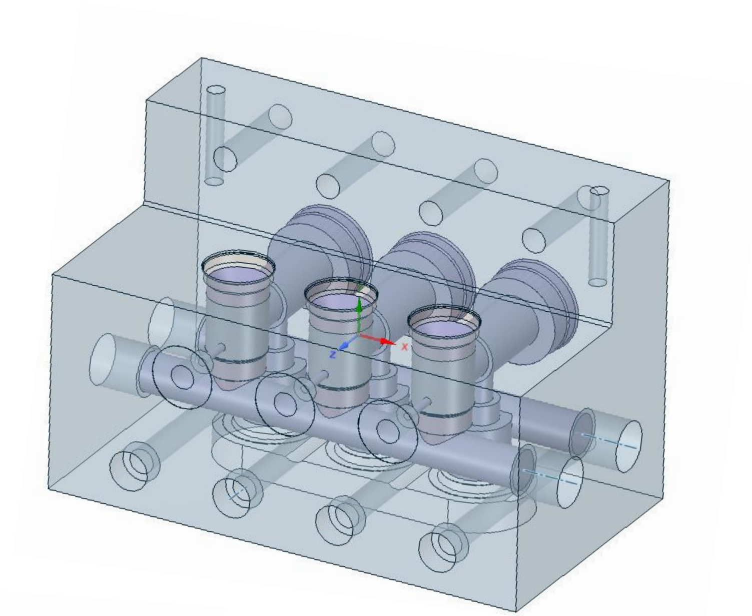
MAV Inline Schematic



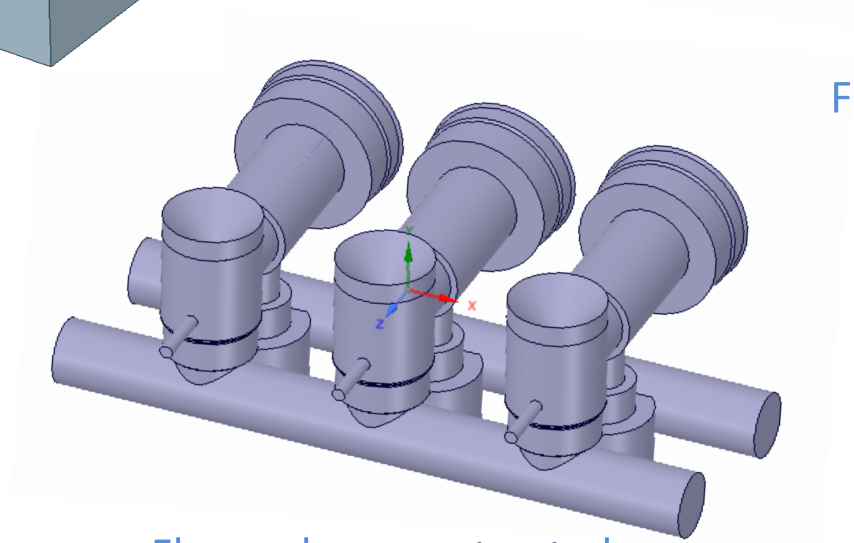
CAD Model Preparation



Solid block

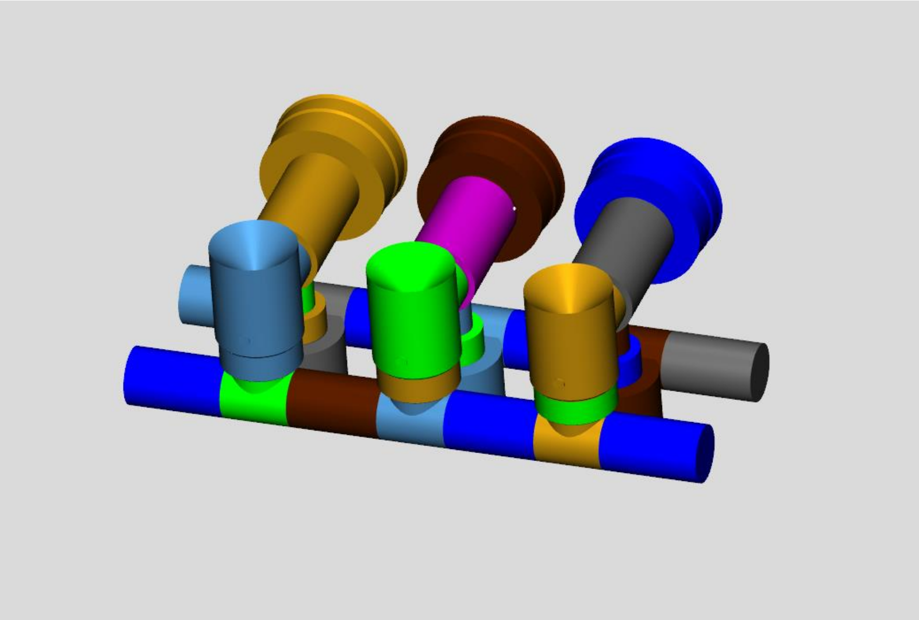


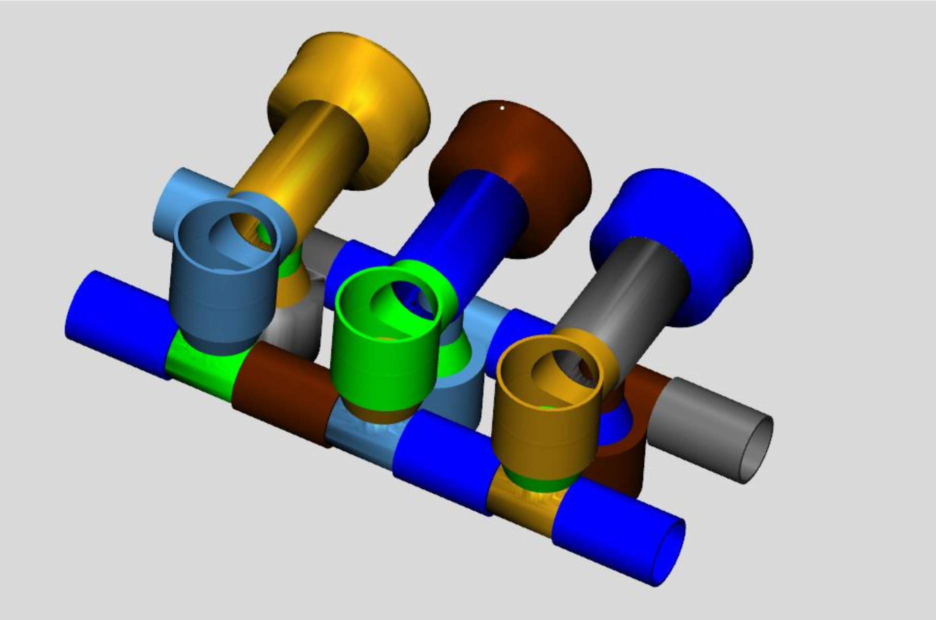
Flow volumes selected



Flow volumes extracted

Converting to GT Components

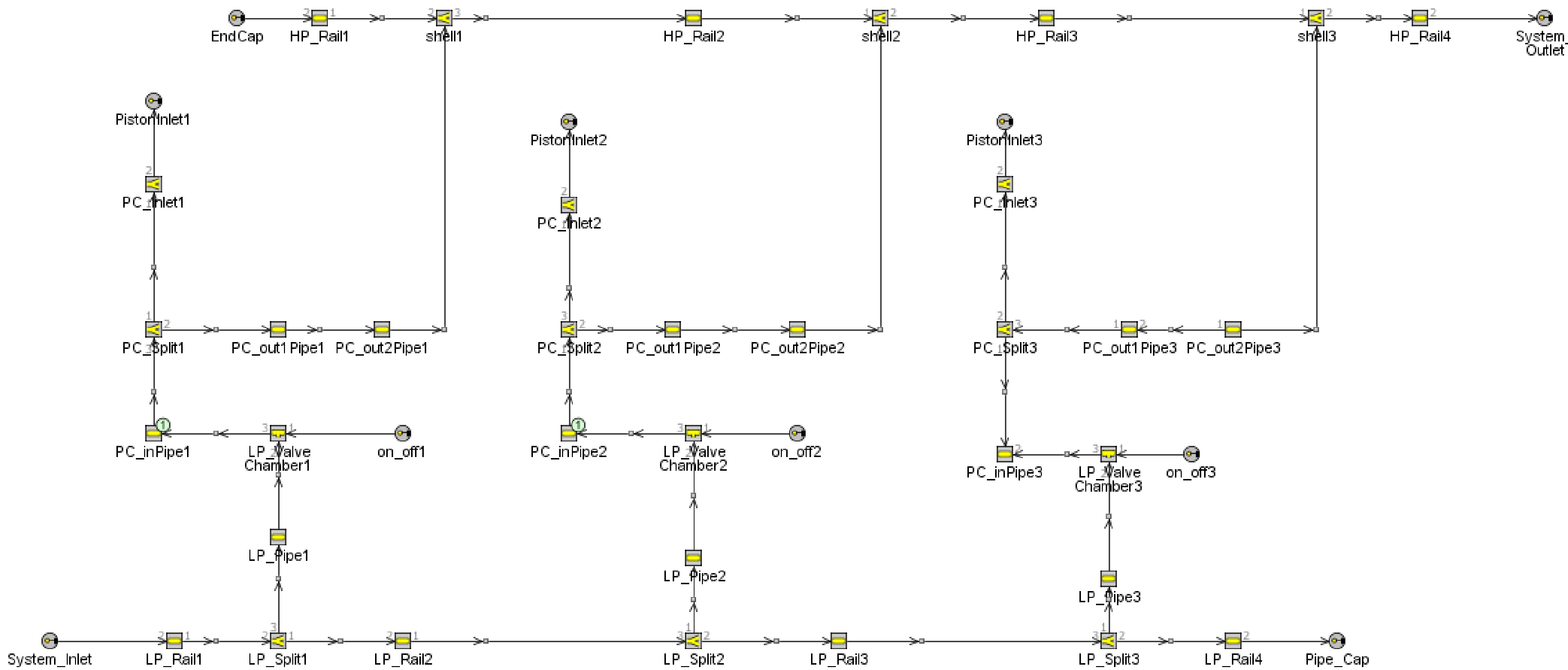




Split into individual parts

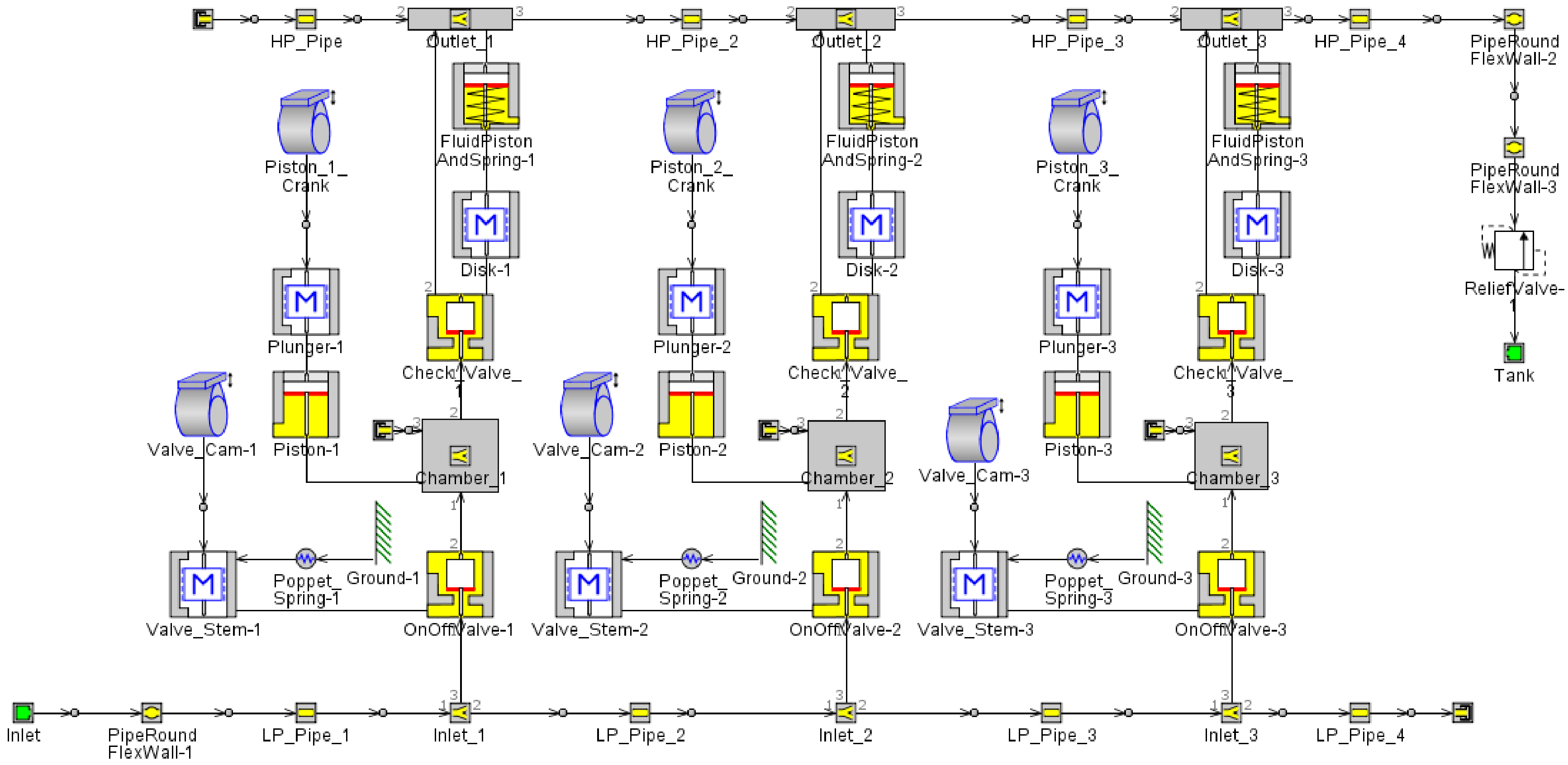
Converted into pipes and flow-splits

Model Geometry

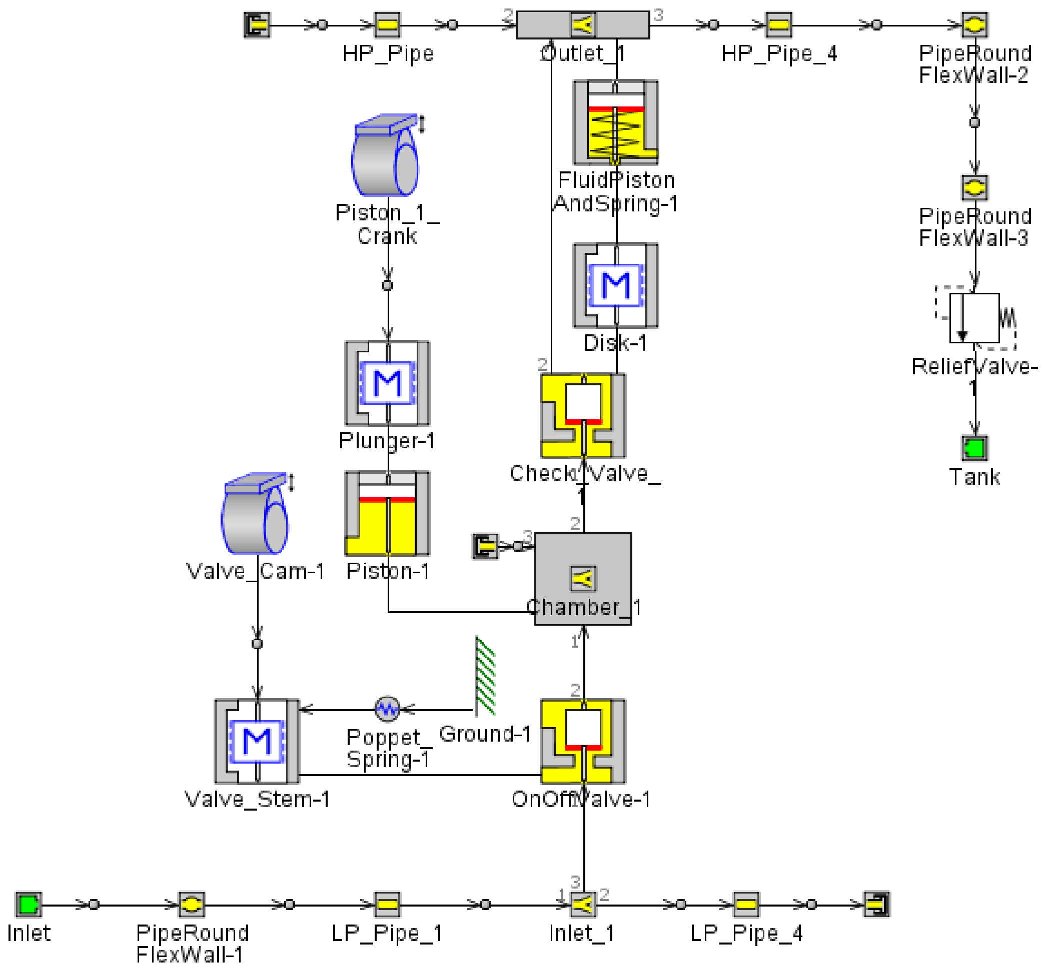


GT-ISE components

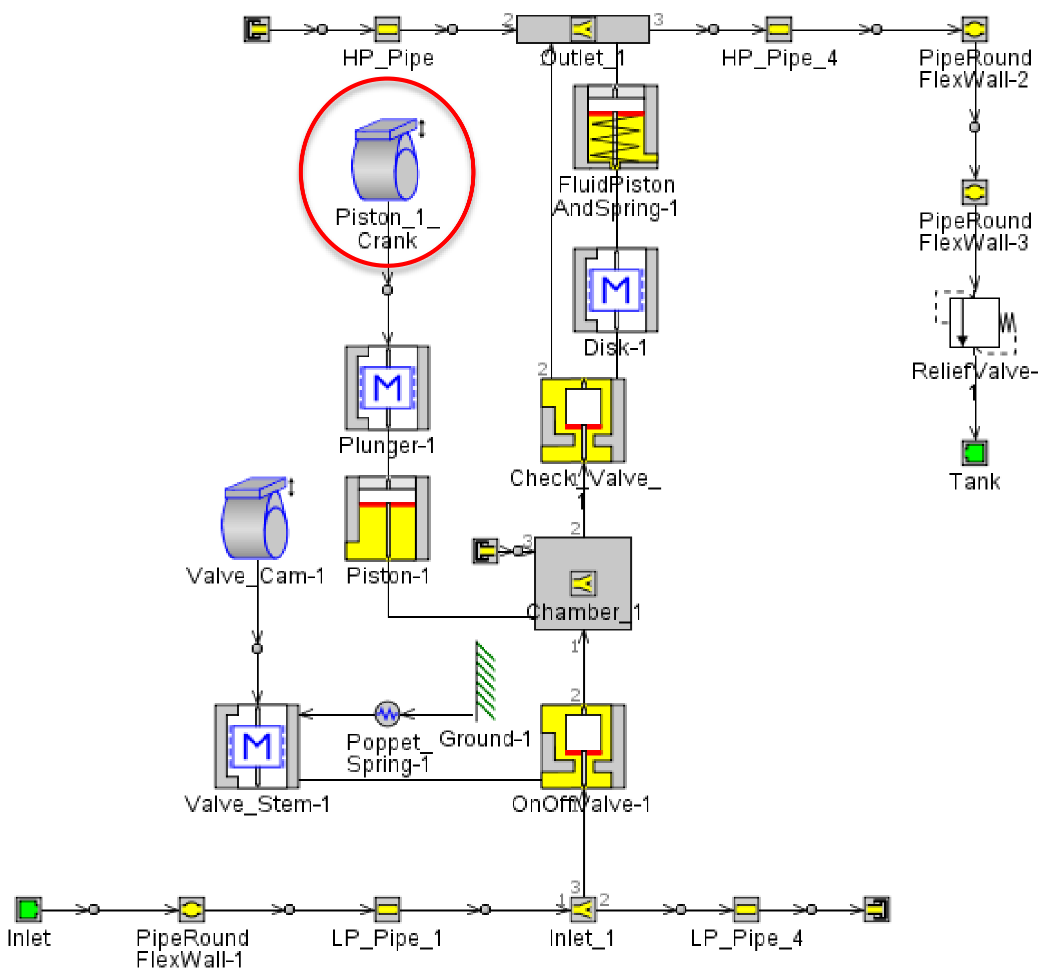
MAV Inline Simulation



One Piston Simulation

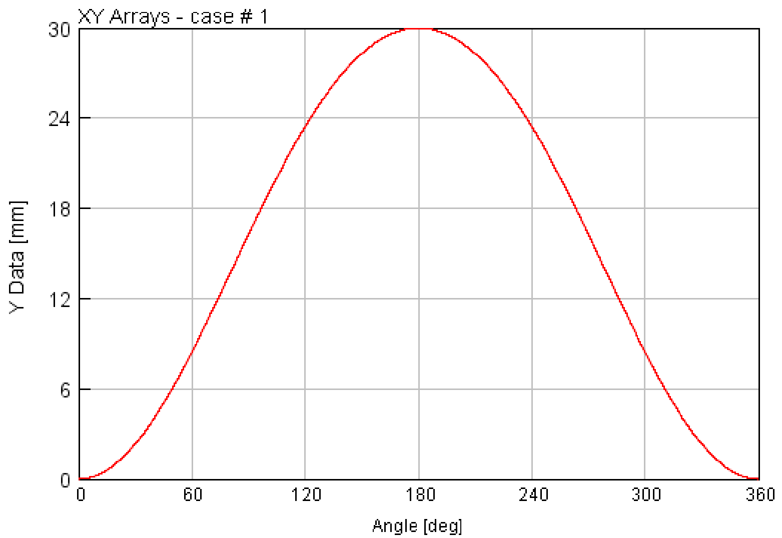


One Piston Simulation

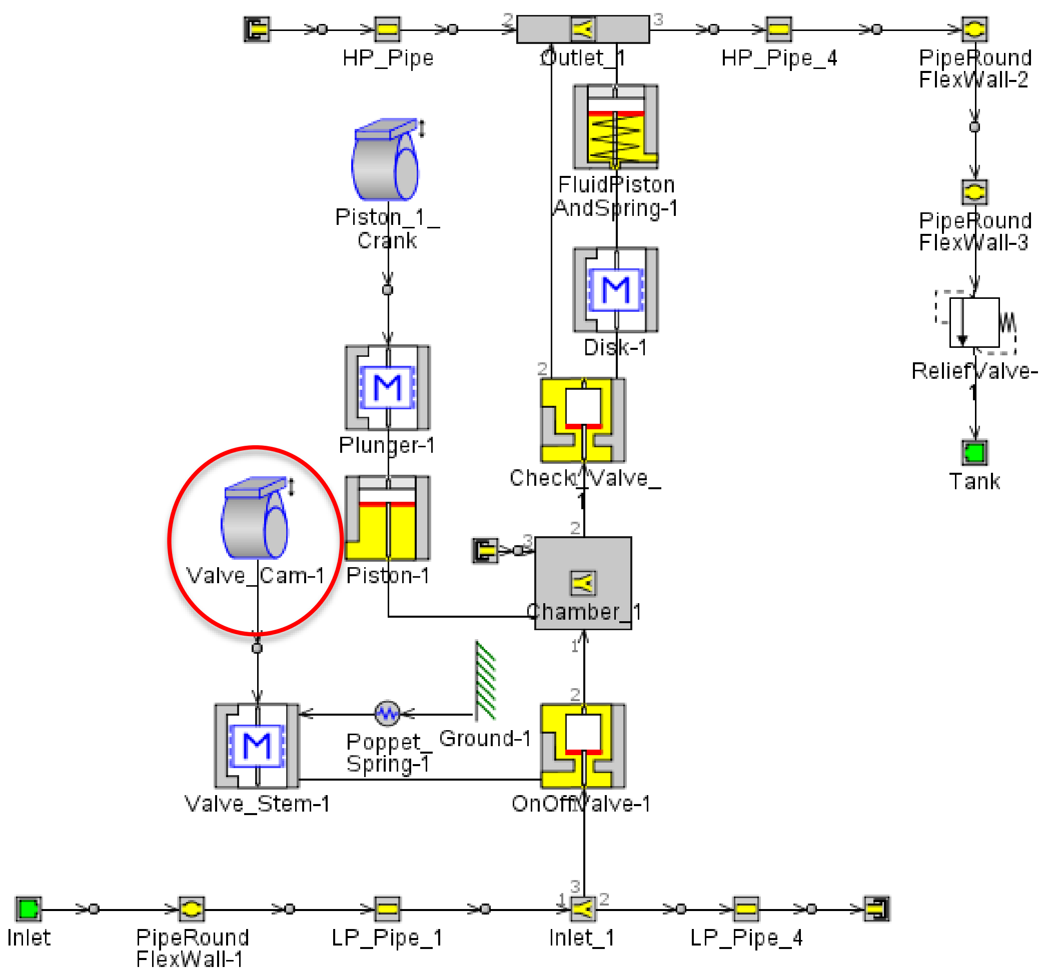


Piston crank-slider input

- Angle and speed defined by main driver
- Piston stroke angle profile

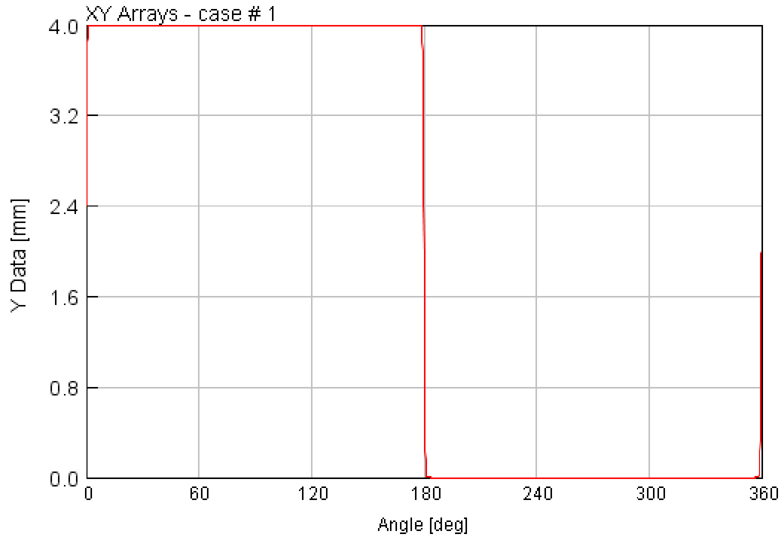


One Piston Simulation

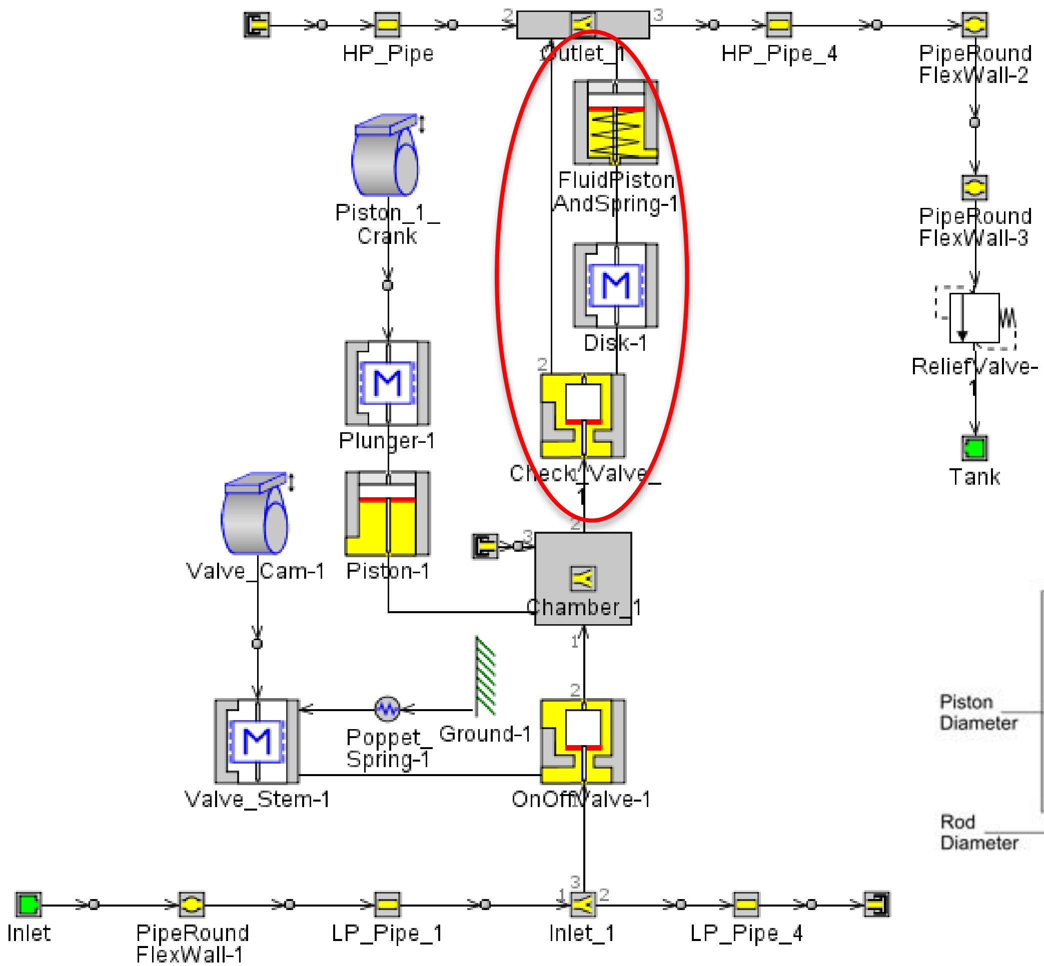


Valve cam input

- Angle and speed defined by main driver
- Offset between each piston
- Valve stroke profile

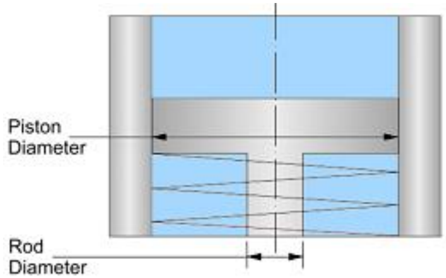


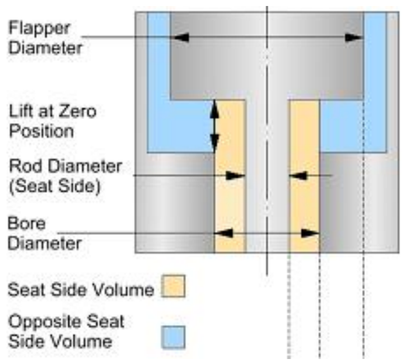
One Piston Simulation



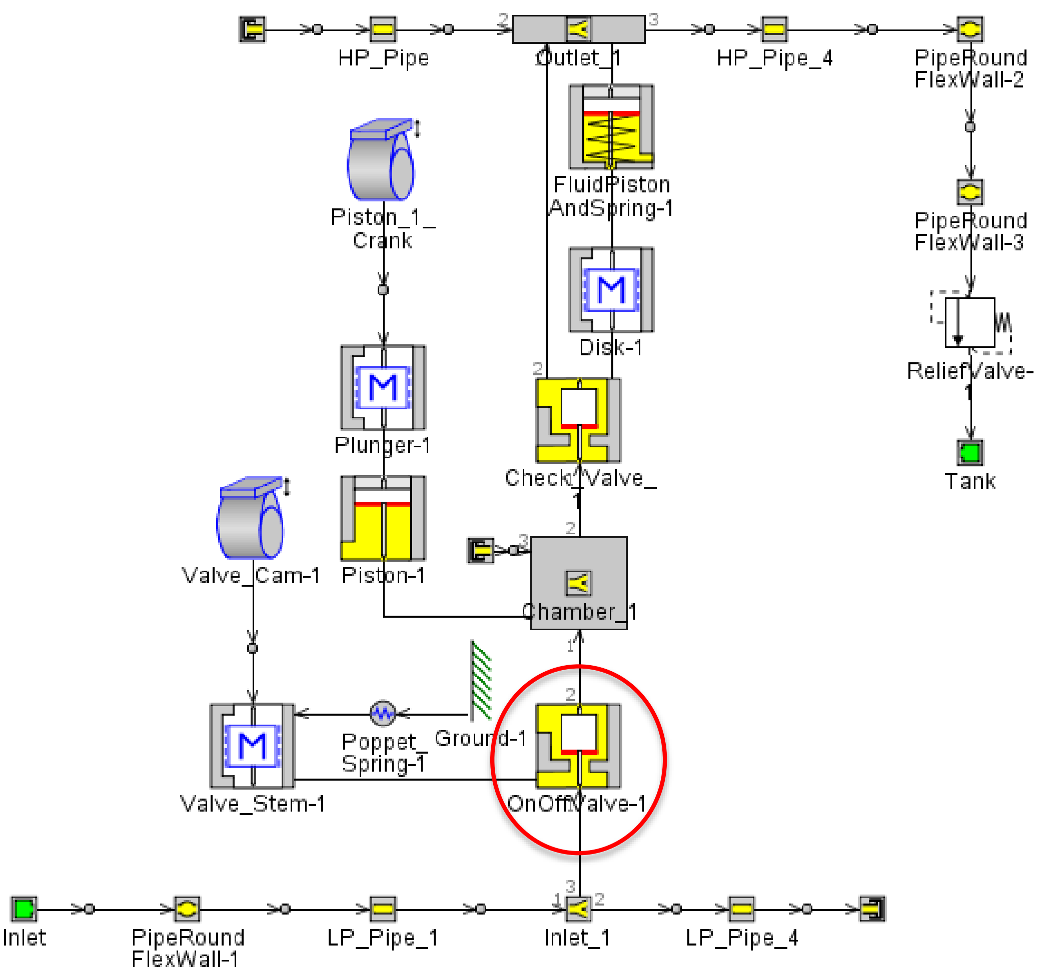
Check valve

- Flapper disk dimensions
- Spring properties



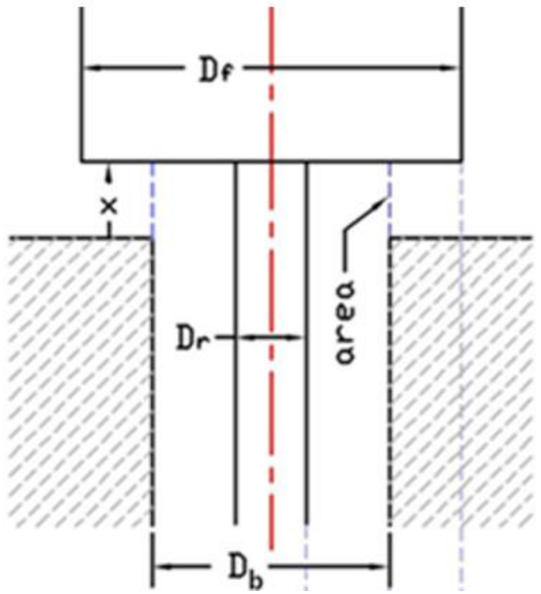


One Piston Simulation

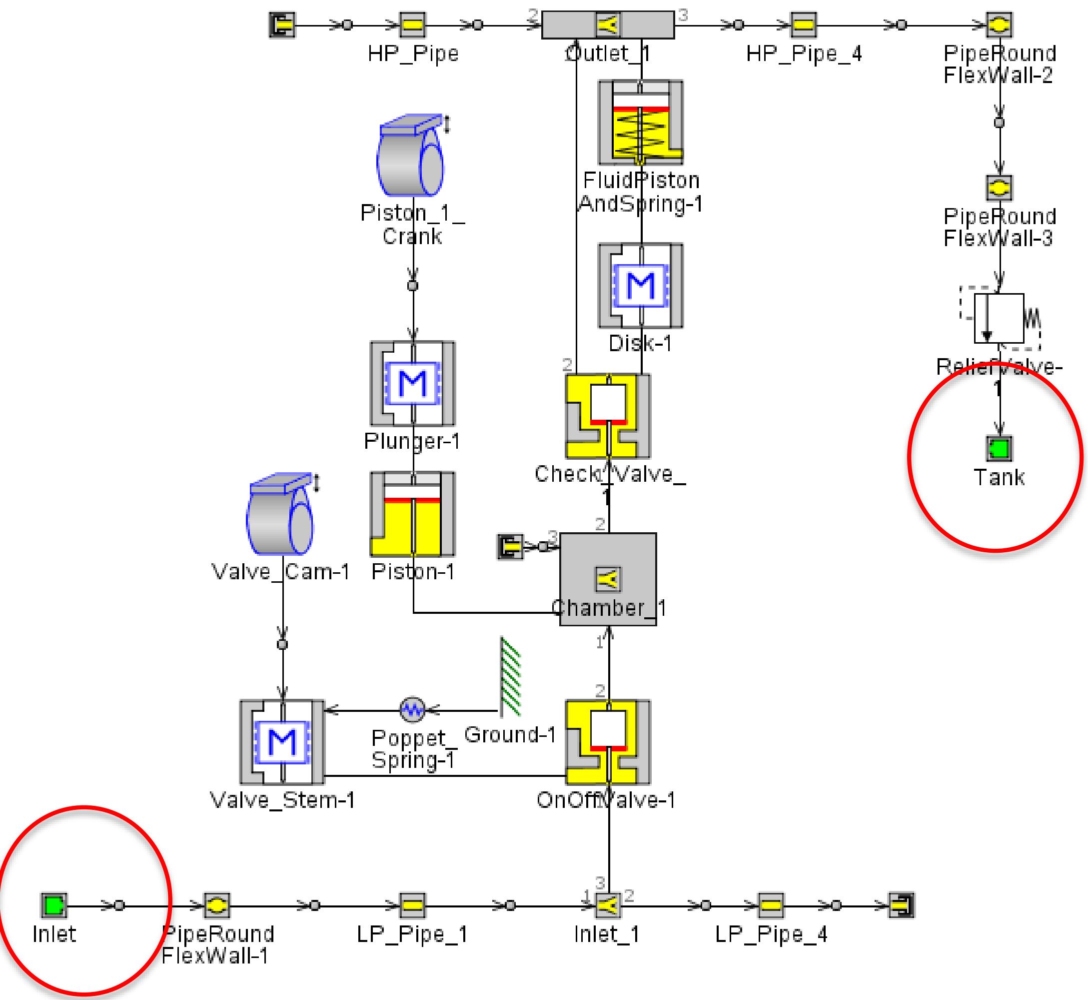


On/off valve

- Valve opening area
- Poppet parameters



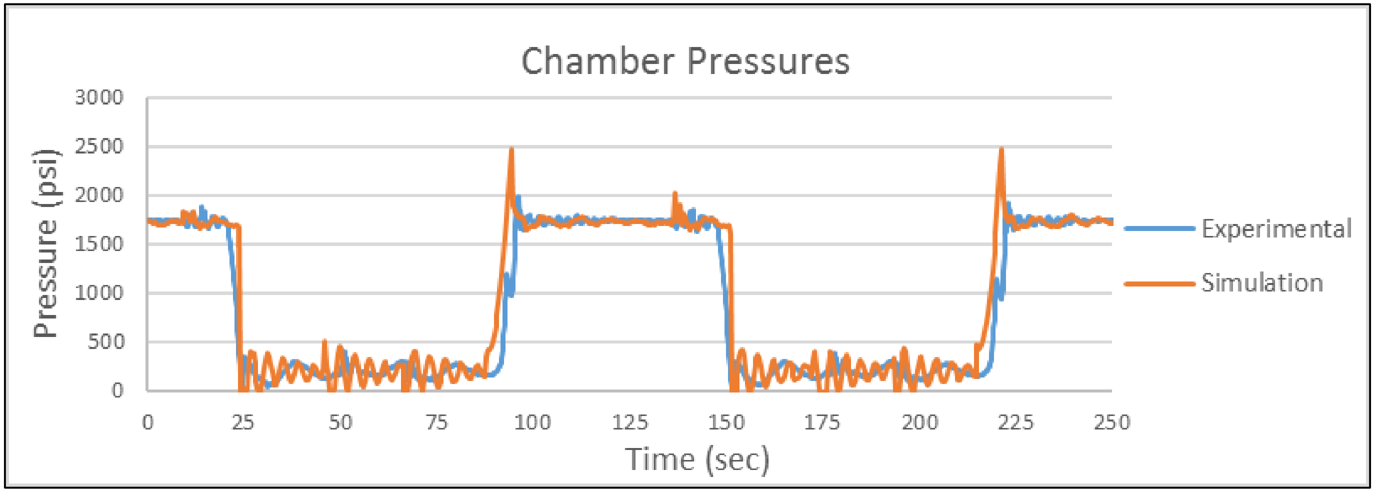
One Piston Simulation



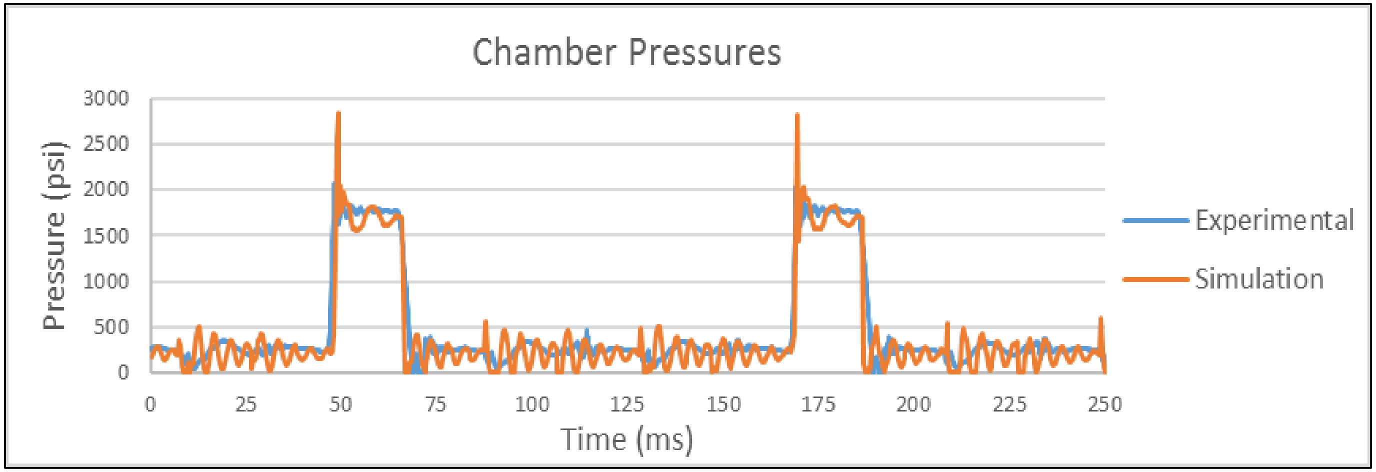
End Environment

- Constant pressure
- Initial temperature and fluid conditions
- Represent constant pressure of accumulator

MAV Inline Simulation

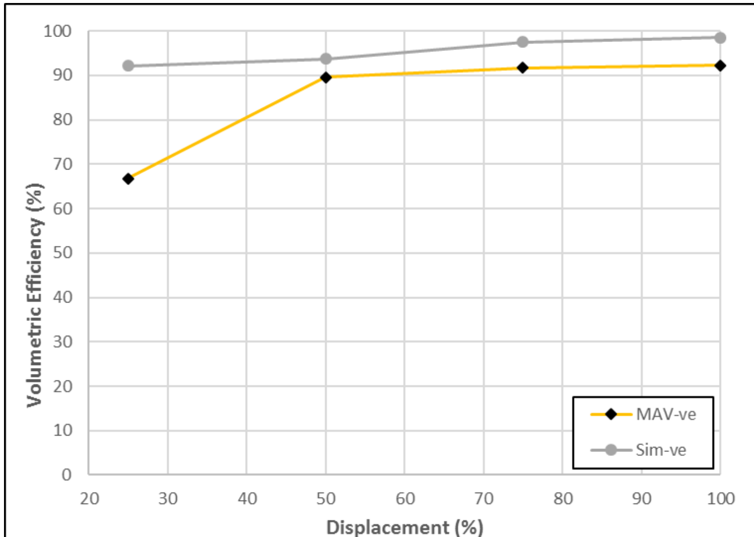


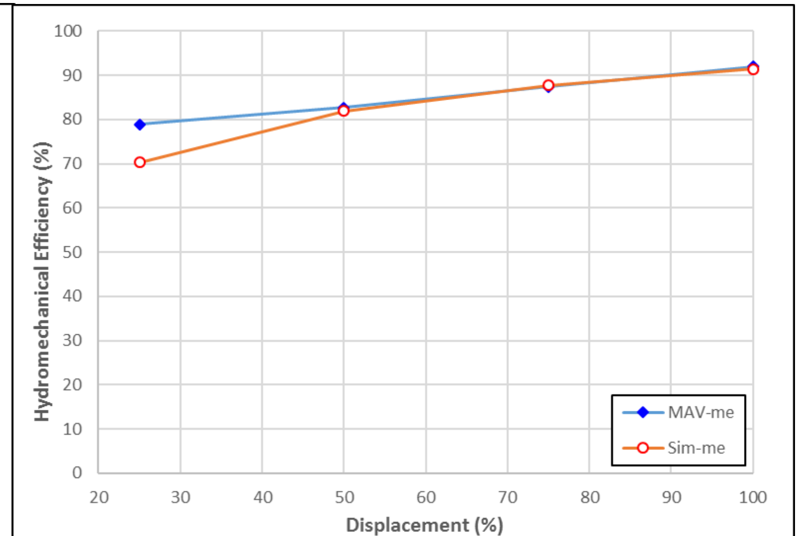
103 bar, 500 rpm, 100% displacement

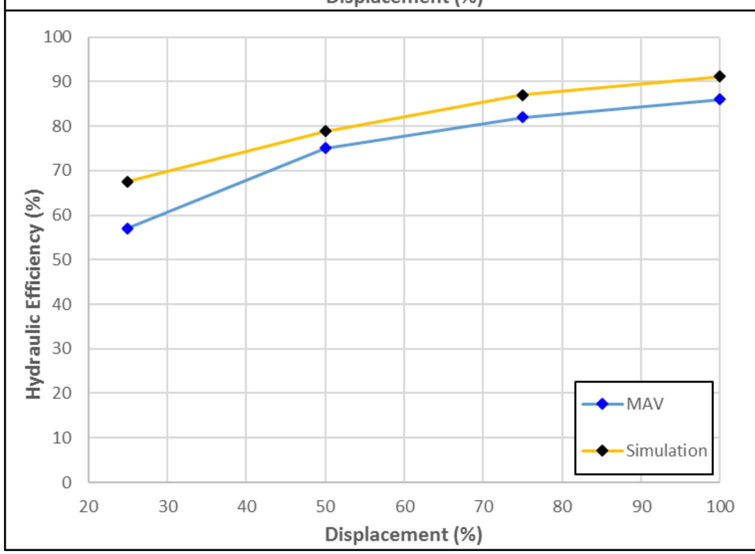


103 bar, 500 rpm, 25% displacement

Inline Simulation Results







Efficiency plots for 1500psi, 500 rpm

- Top Left- Volumetric Efficiency
- Top Right- Mechanical Efficiency
- Bottom- Total Efficiency

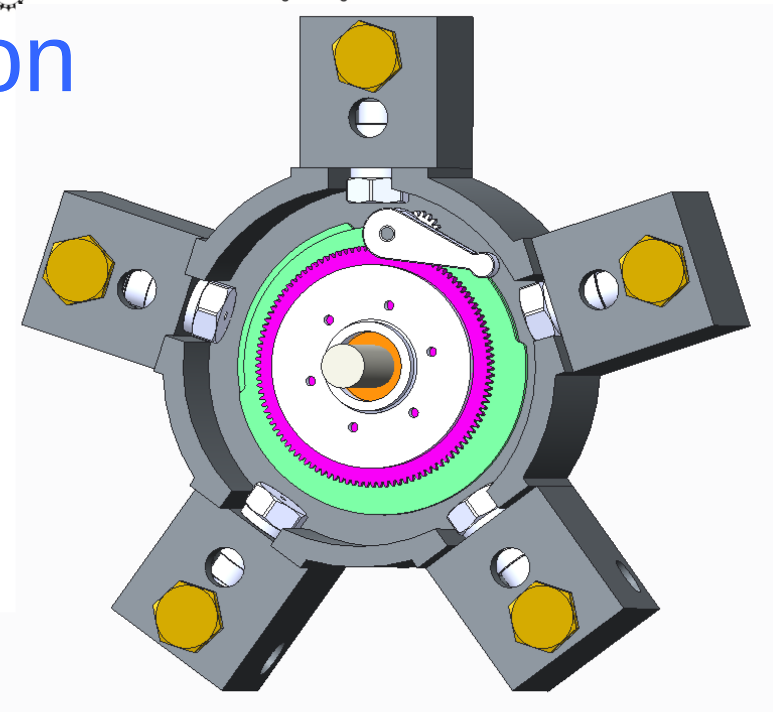
Next Generation MAV

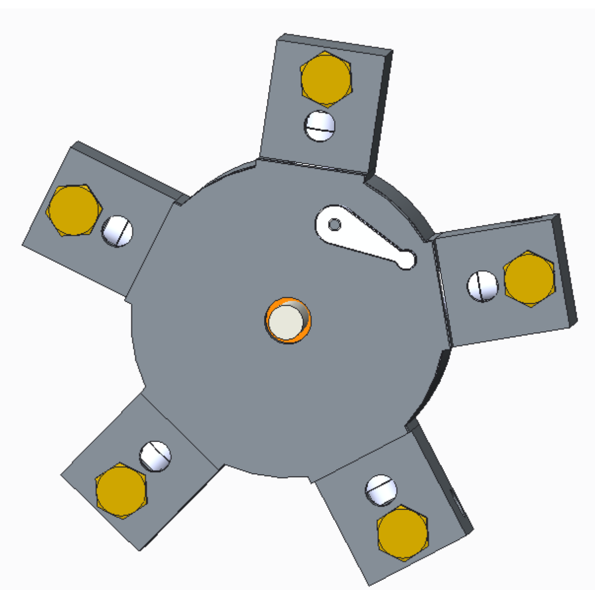
- Optimal design, open-ended best system
- Requirements
  - One cam assembly for all pistons
  - Minimal gearing
  - Smaller physical size
  - Four quadrant capability

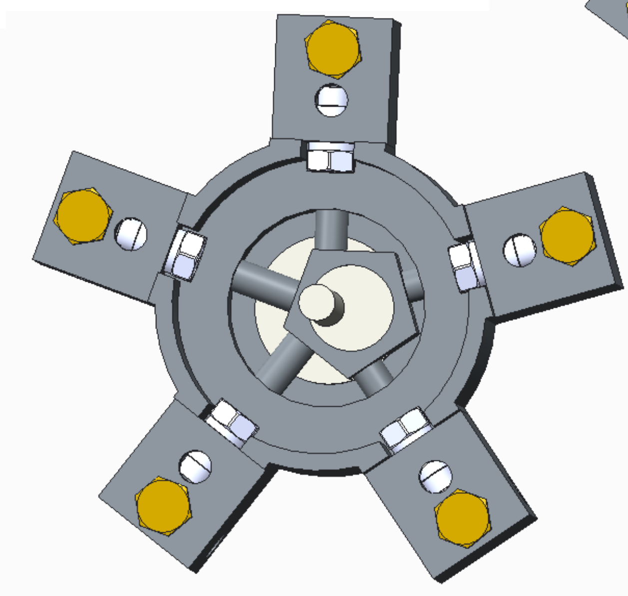
Radial Piston Orientation

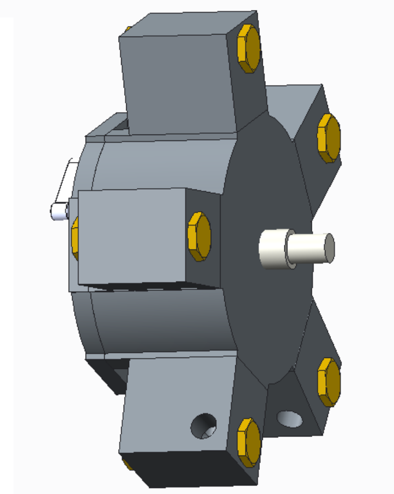
Benefits

- Access to valves
- Thru-shaft
- Modular and compact design
- Fewer moving parts









Summary and Future Work

- Tested inline unit on existing digital pump/motor test stand
  - Results provided proof of concept for mechanical actuation
- Modeled and simulated inline unit
  - Validated modeling techniques
- Next steps
  - Model and simulate radial unit
  - Use simulation to determine optimal pump parameters

CENTER FOR COMPACT AND EFFICIENT FLUID POWER

Contact Information

James Marschand

jmarsch@purdue.edu

Dept. of Ag. & Bio. Eng.

225 S. University St.

West Lafayette, IN 47907