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Preliminary Modeling of Triply Periodic Minimal Surface (TPMS) Structures with RELAP5-3D

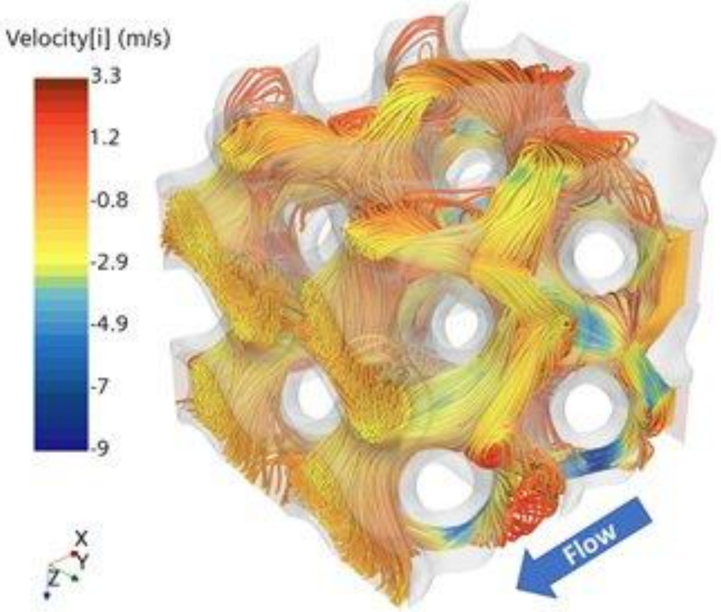
Project Review

Abstract

This presentation goes over preliminary work performed on modeling triply periodic minimal surfaces (TPMS) with RELAP5-3D. The presentation starts off with a background on what a TPMS is and then moves onto the motivation for why this geometry is being modeled. The methodology is then explained for how data from different experiments will be used for pre-test predictions and eventual creation of coefficients and multipliers to be used in models. The simulation models' pre-test results are then presented for both tests, along with a comparison between CFD and RELAP5-3D pressure drop values. There is then conclusions drawn from the pre-test predictions along with areas lacking currently that can be made up for when tests are completed. To finish out the presentation, future work discusses the future steps with the coefficients, multipliers, and correlations for the heat transfer coefficient and pressure drop.

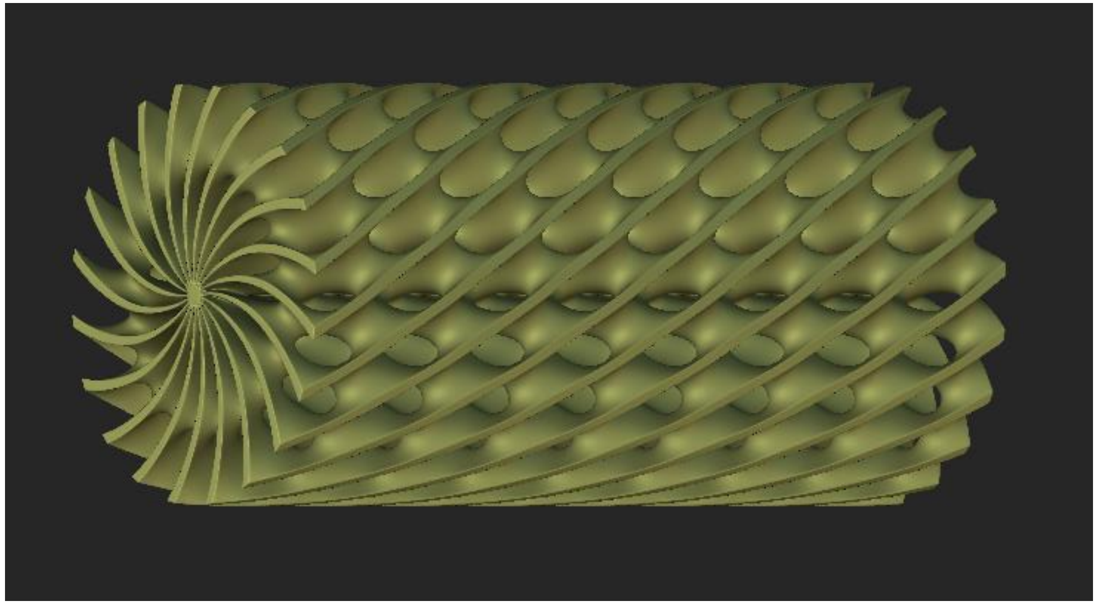
Presentation Overview

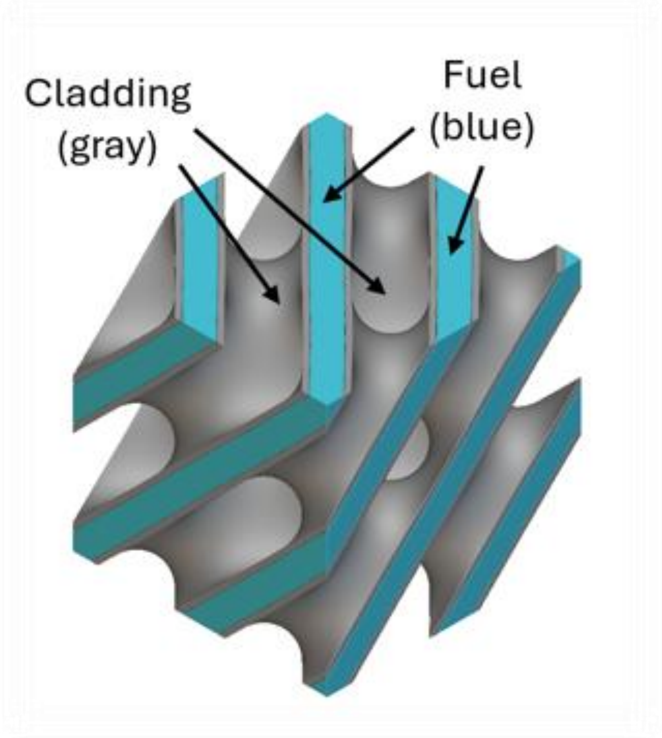
- Background
- Motivation
- Methodology
- Pre-test Predictions
- Conclusion
- Future Work
- Acknowledgement



Triply Periodic Minimal Surface (TPMS)

- TPMSs are repeating 3D unit cells found in nature and defined by level-set equations
- By filling a TPMS with a solid domain, we can create a lattice structure for a heat source or heat exchanger
- Has rapid area changes within the structure
- Large surface area to volume ratio

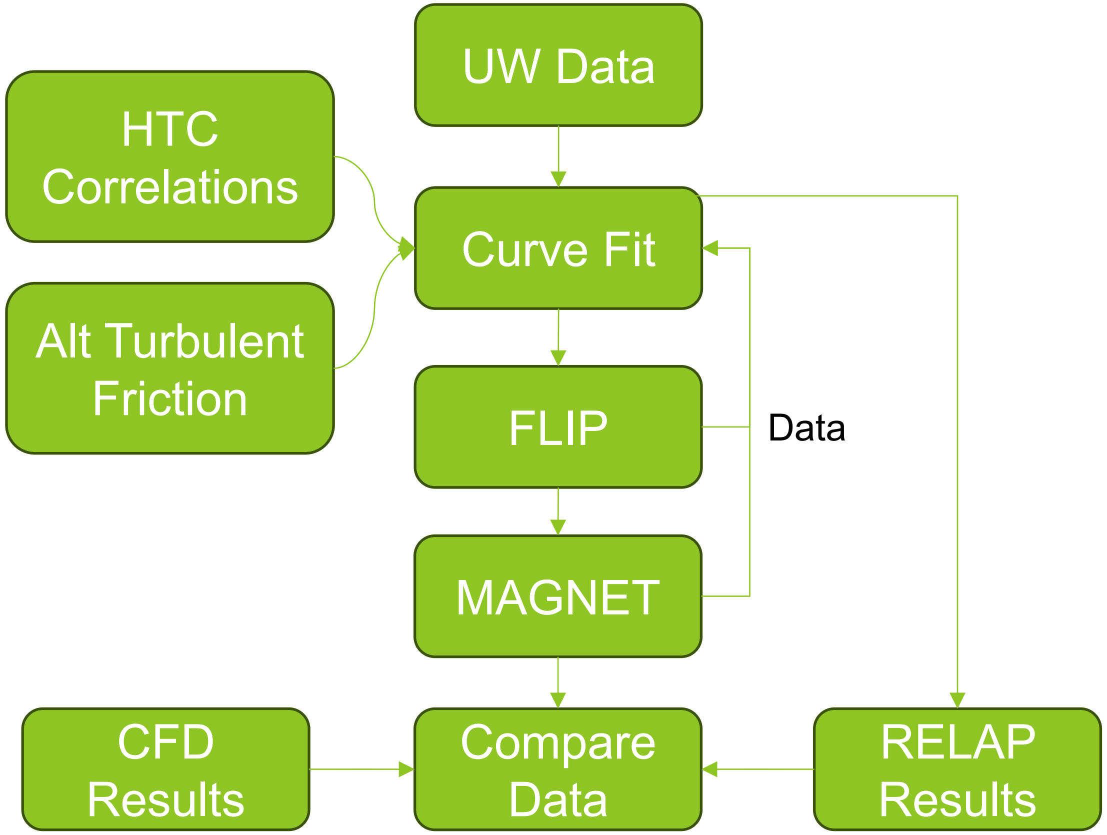




Motivation

- Increased Surface Area + Increasing heat transfer coefficient(HTC) → Decreased fuel temperature → Greater margins for fuels → Higher power density → Smaller Reactors
- Possibilities due to a large, non-uniform surface area:
  - Mostly turbulent
  - High HTC
  - Large pressure drop
- Mostly low Reynolds number research, so minimal information at reactor conditions
- Relatively little experience modeling TPMS geometries in 1D systems codes, so minimal number of direct correlations and validation

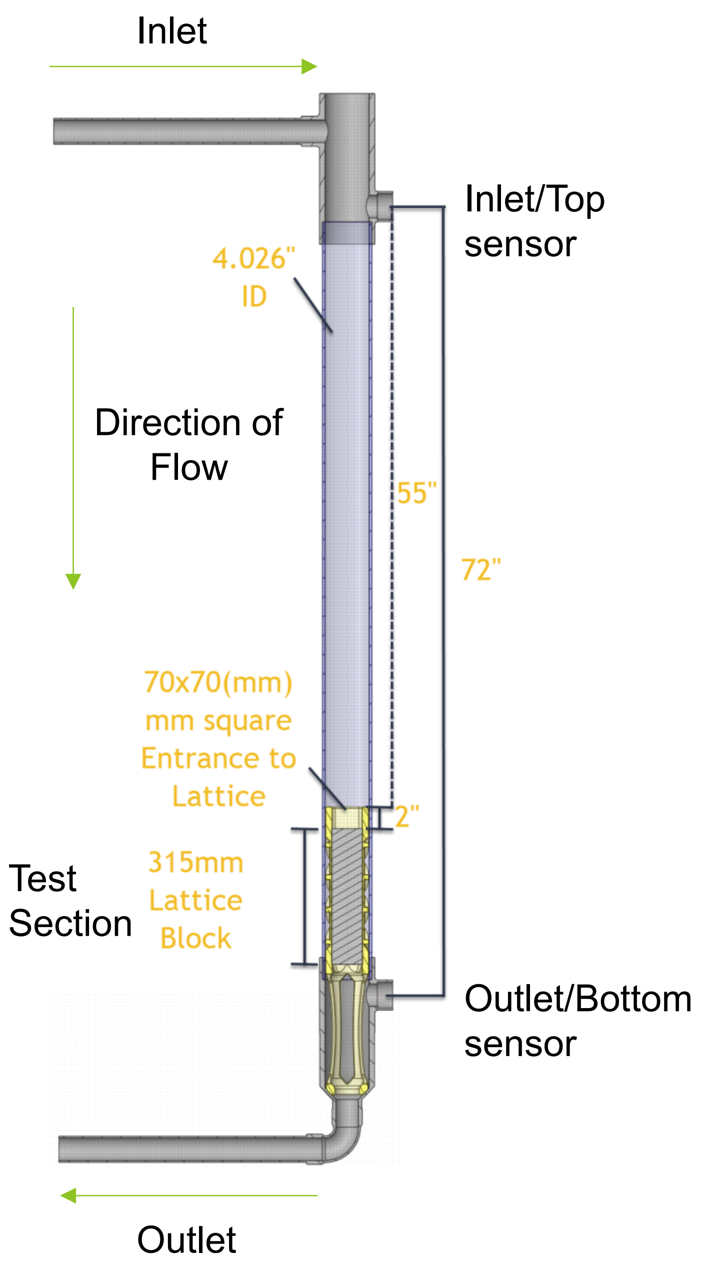
Methodology



Brett Prussack, Ian Jentz, Tiago A. Moreira, Nicolas Woolstenhulme, Casey Jesse, Greg Nellis, Mark Anderson, Thermal and hydraulic performance of volumetrically heated triply periodic minimal surface heaters, Applied Thermal Engineering, Volume 248, Part B, 2024, 123291, ISSN 1359-4311, https://doi.org/10.1016/j.applthermaleng.2024.123291. (https://www.sciencedirect.com/science/article/pii/S1359431124009591)

FLIP Test – (Hydrodynamic/Hydraulic Test)

- Working fluid is water at ambient temperature and pressure
- Inlet flow from 2.7-4.9 kg/s (16,028 < Re < 20,630)
- FLIP will be used to determine pressure drop at higher Reynolds number
- Pre-test pressure drop predictions are made using pressure drop data from the University of Wisconsin (UW) data
- **Figures of Merit**:
  - Pressure drop across sensors
  - Pressure drop across test section



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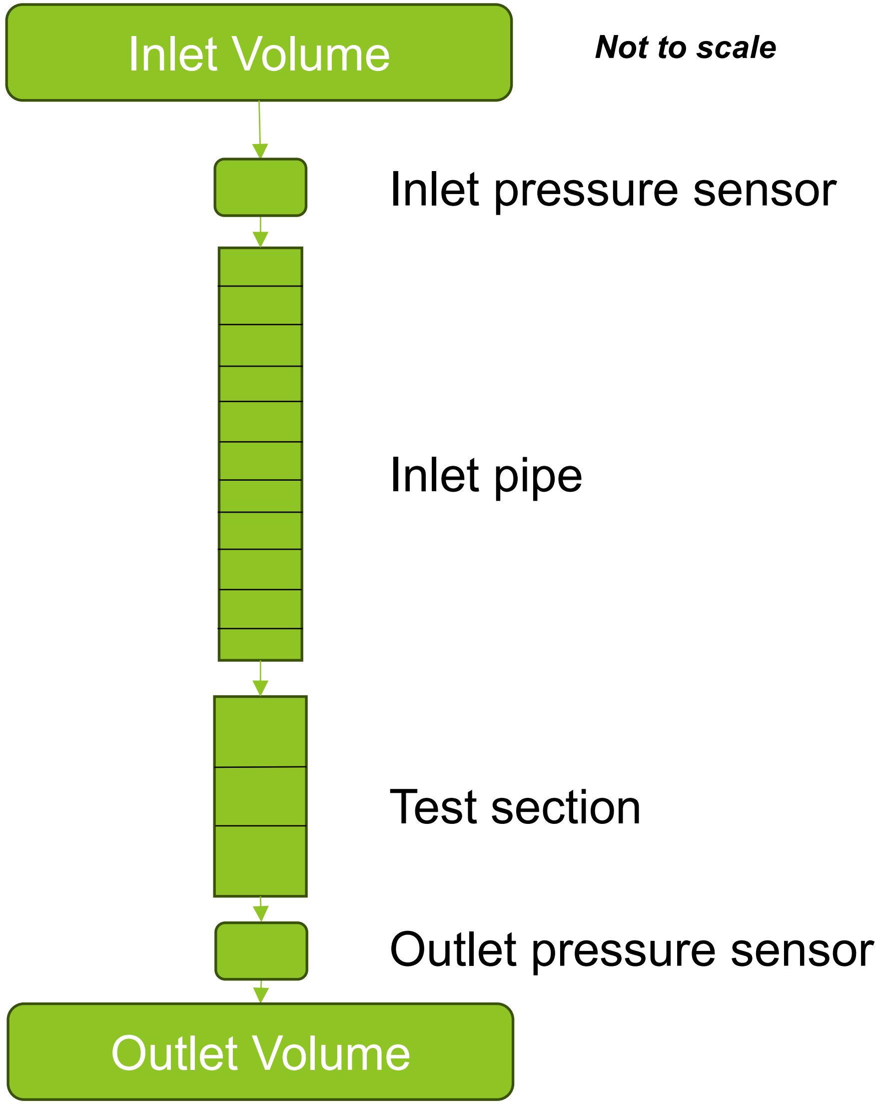
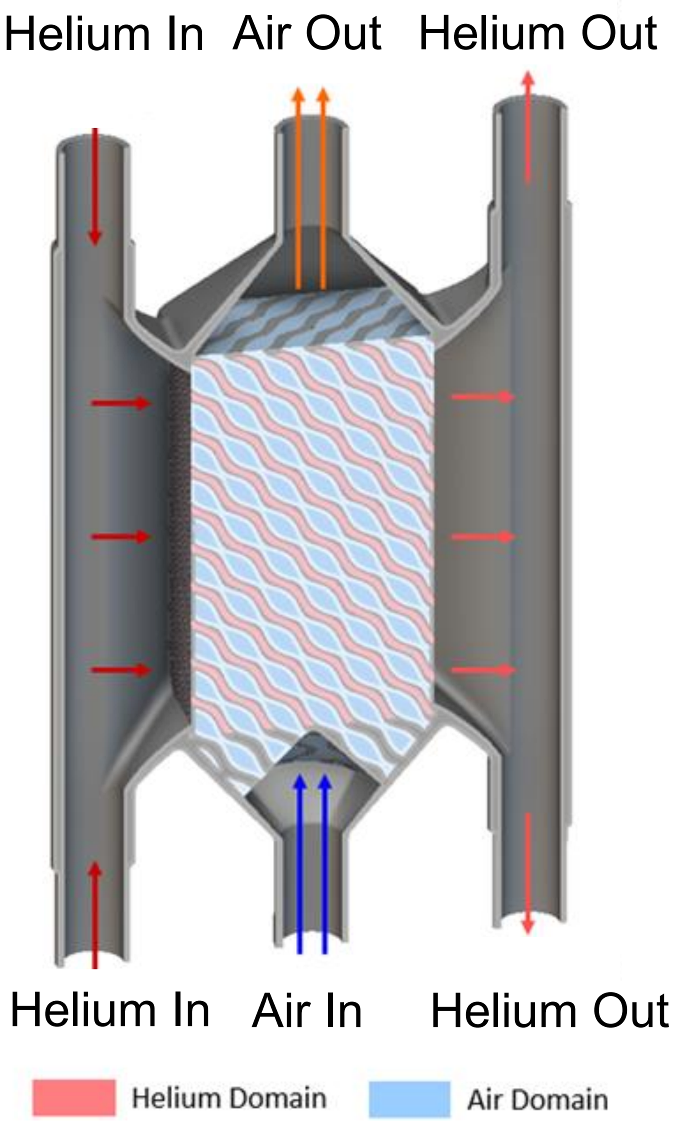
RELAP5-3D FLIP Implementation

- We use the average cross-sectional area of the TPMS lattice as the flow area of the test piece
- Use a 75mm-diamond geometry pressure drop correlation, obtained from the UW data
  - A = 0 B = 297.39 C = 0.58



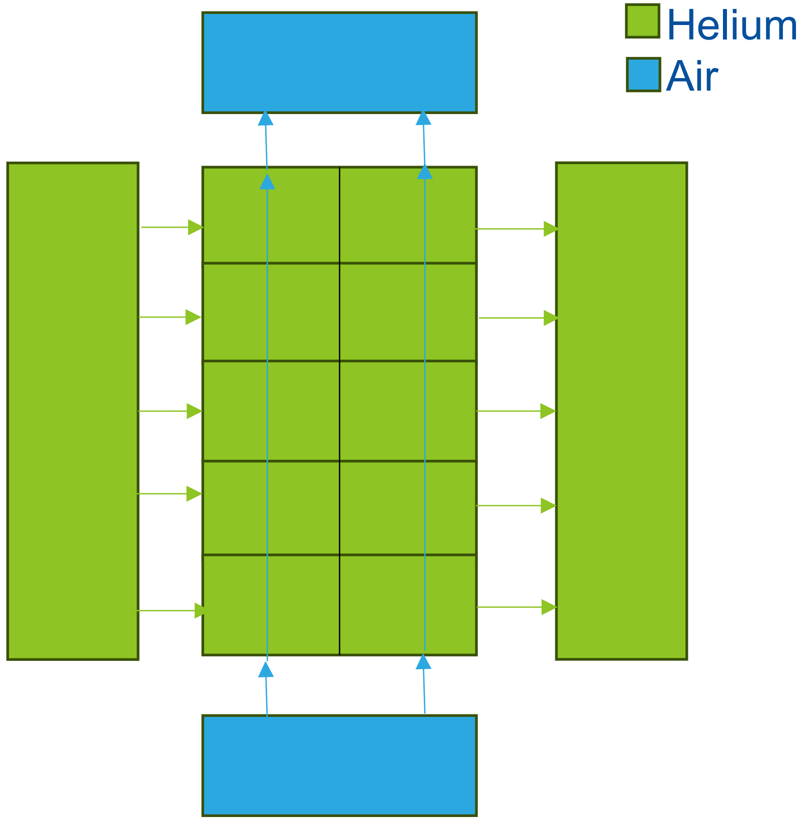
MAGNET Test (Hydrodynamic & Thermal Test)

- The Microreactor Agile Non-nuclear Experimental Test(MAGNET) facility test is a heat exchanger; this includes both pressure drop and HTC
- Helium and air are used as working fluids for the primary and secondary loops, respectively
- **Figures of Merit**:
  - Pressure drop (both sides)
  - Temperature drop/rise (both sides)
  - Enthalpy flow change (both sides)
  - HTC



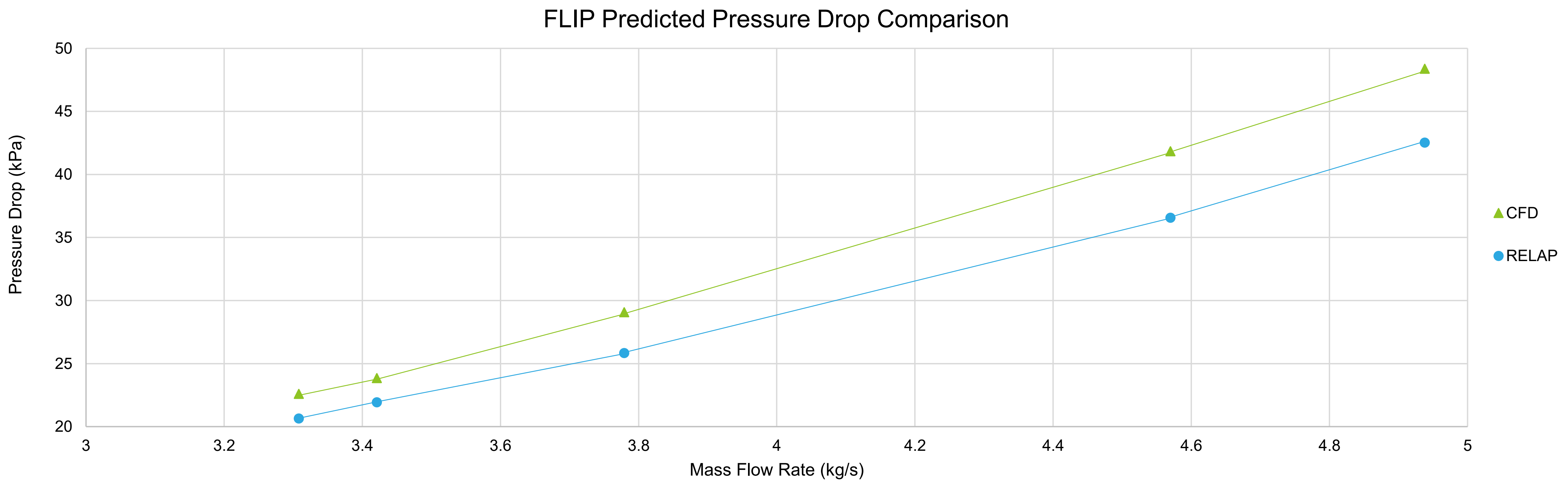
RELAP5-3D MAGNET Implementation

- Solid domain is modeled as a slab
  - Heat structure input requires each side to have the same surface area
  - Modeled heat structure with the average surface area of both domains, then applied HTC scaling factors to each side to preserve hA
- Uses the same pressure drop correlation as FLIP
- Uses the Dittus-Boelter correlation with a multiplier of 10.50 informed by the UW data



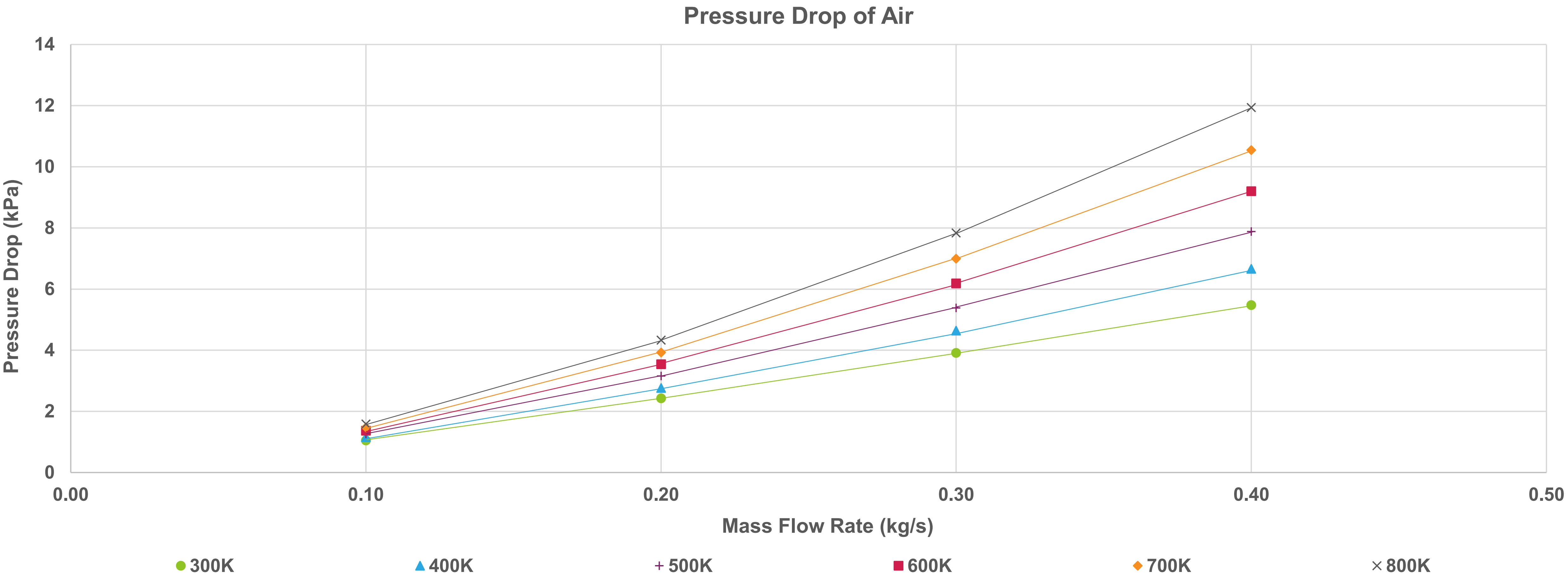
Pre-Test Predictions - FLIP

- Each data point was done at a prescribed mass flow rate and temperature from the CFD results
- The average fractional difference is 11% and the range is from 8-13% between CFD and RELAP5-3D



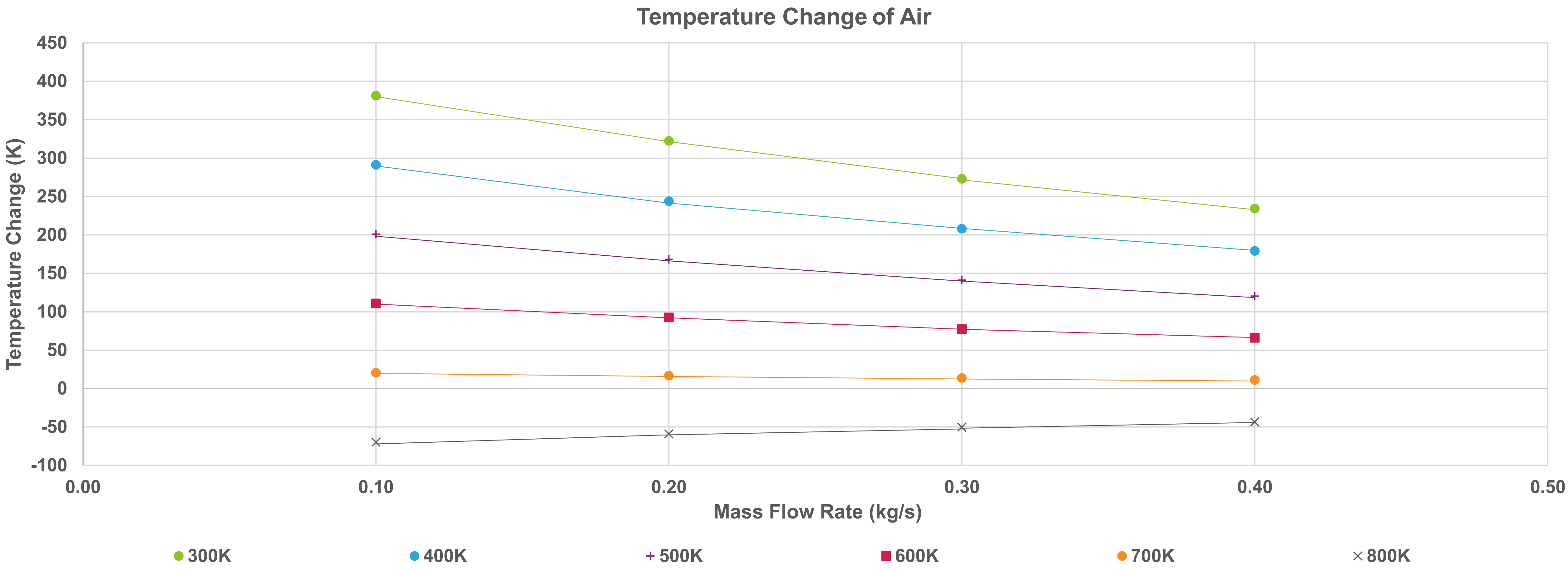
Pre-Test Predictions – MAGNET (Pressure Drop)

- The helium mass flow rate and inlet temperature were kept constant for all tests



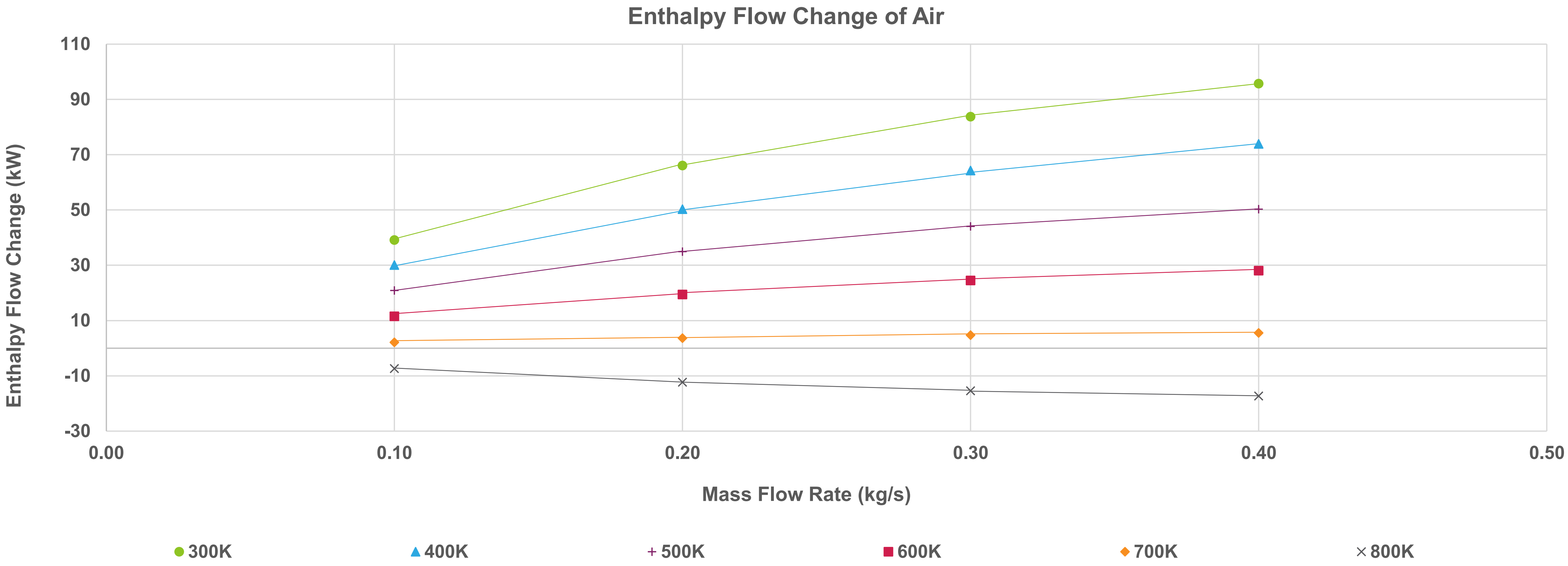
Pre-Test Predictions – MAGNET (Temperature Change)

- The helium mass flow rate and inlet temperature were kept constant for all tests



Pre-Test Predictions – MAGNET (Enthalpy Flow Change)

- The helium mass flow rate and inlet temperature were kept constant for all tests



Conclusion

- Predictions for FLIP are on average 11% lower than CFD
  - Alternate coefficients could increase agreement between RELAP and CFD
  - Increased minor loss coefficients may need to be added to better account for the inlet/outlet area expansion/contraction
- FLIP data should extend the use range for the alternate turbulent wall friction factor correlation values
- With MAGNET values and models, when there is CFD or experimental data to compare against, new simulations can be run for comparisons
- Pre-test predictions provide starting point for RELAP TPMS modeling demonstrations

Future Work

- Take test data from FLIP and MAGNET to refit the coefficient and multiplier values, and then retest the simulation for new values
- Investigate additional correlations for HTC and pressure drop

Acknowledgment

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Questions?

Idaho National Laboratory