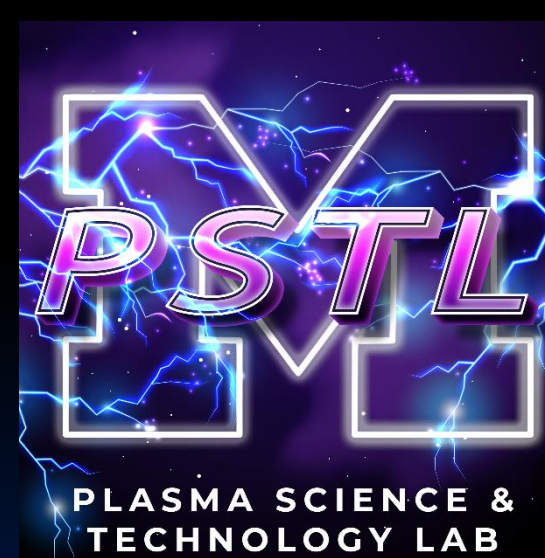




Optimization considerations for annular linear electromagnetic pumps for space nuclear power and propulsion



Nuclear and Emerging Technologies for Space (NETS2024)
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Background

The Need for High Performance Liquid Metal Pumps Testing

Liquid metal cooled reactors is one option for space nuclear power for settlements and electric propulsion vehicles (Snap 10 A, SP100, Soviet Topaz reactors)

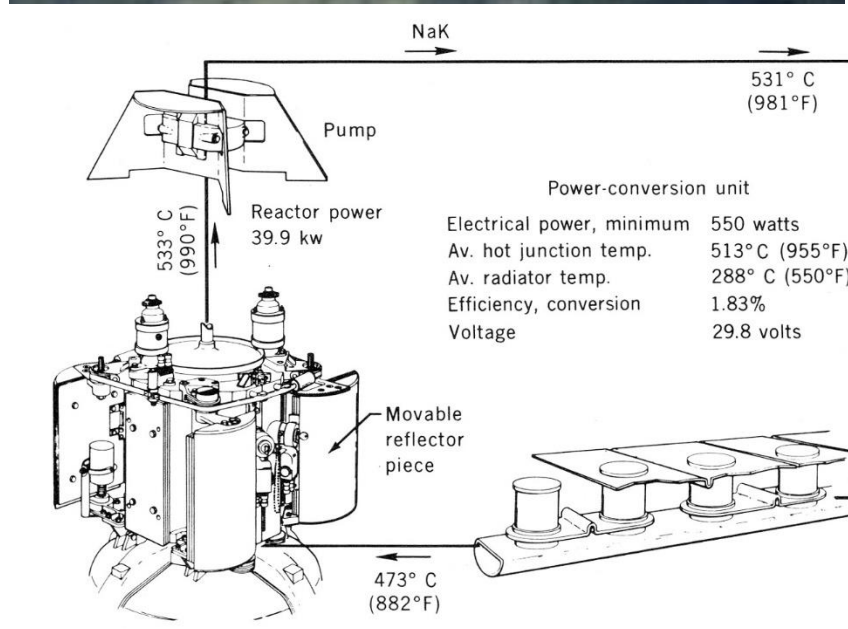
- High heat capacity
- High boiling point (NaK~1200K)
- Simplified heat transfer loop
- Good neutronics

Liquid metal EM pumps are desired over conventional pumps owing to lack of seals, bearings elimination of cavitation issues, lower mass and eliminates mechanical impeller

- Conduction pumps (typically DC-high current, low voltage; ~5% efficiency)
- Induction pumps (typically AC, high efficiency ~40%)

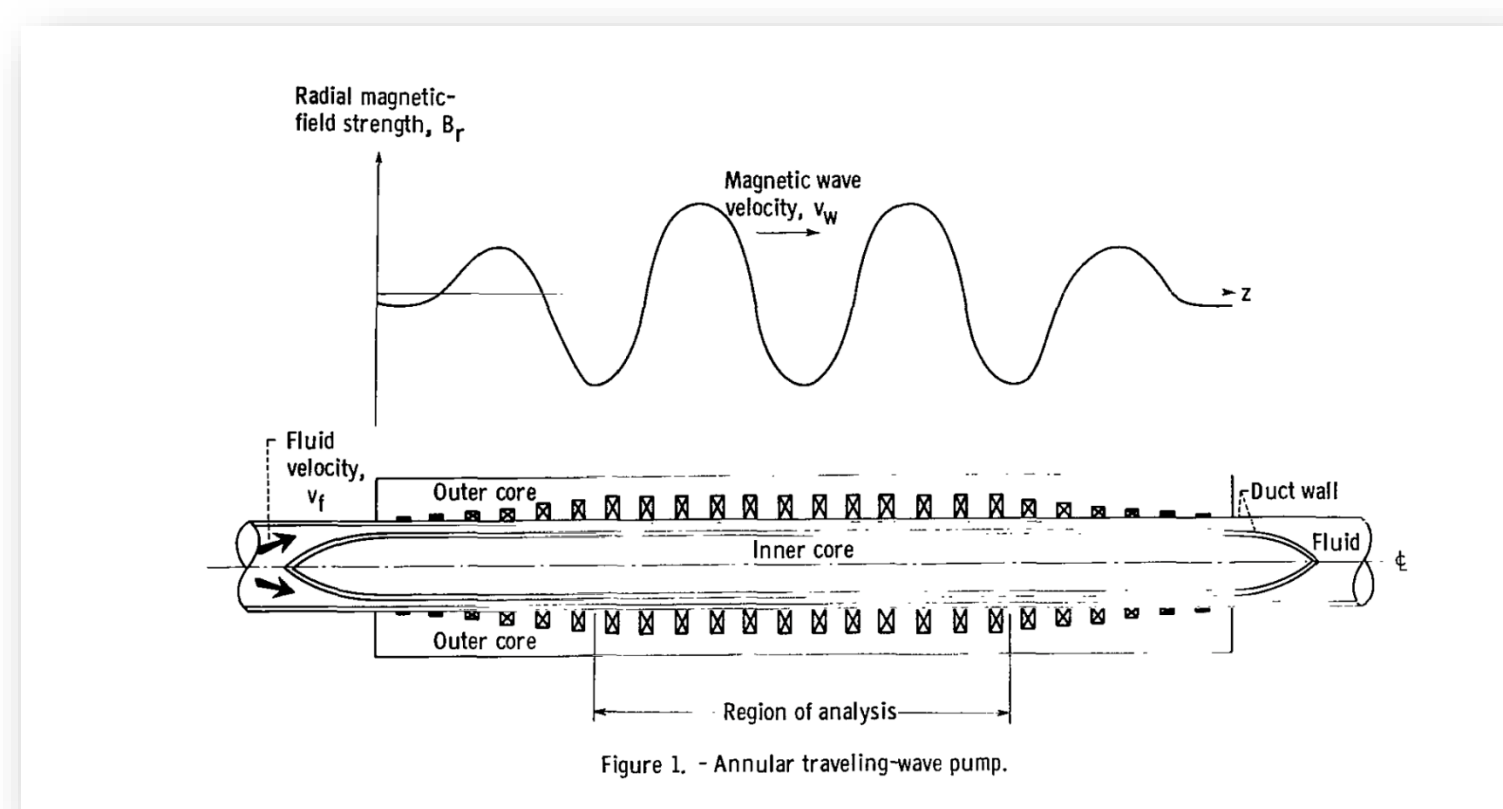
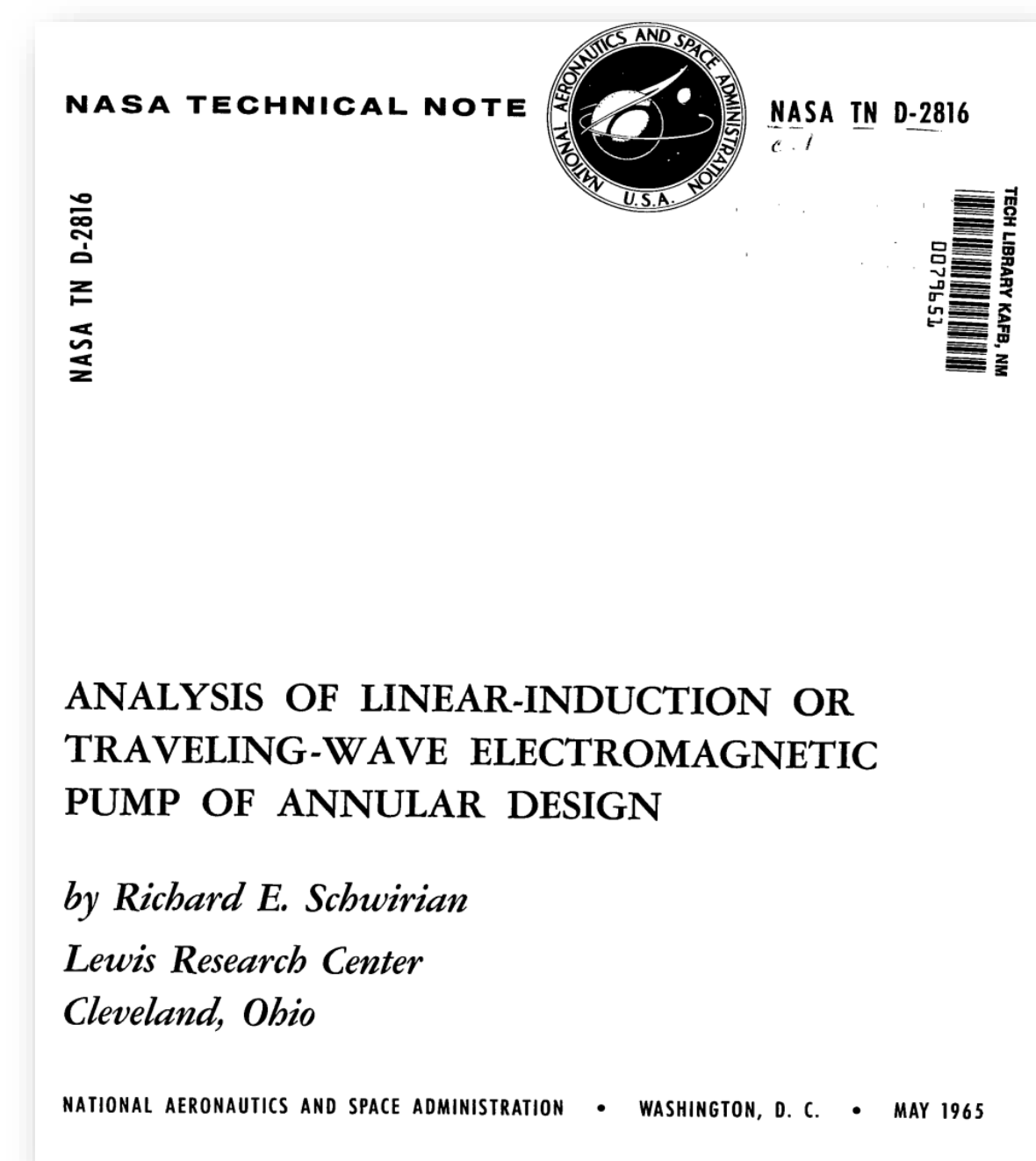
Annular linear induction pump is an EM pump with no moving parts and of cylindrical/tubular geometry which makes it straightforward to integrate in conventional piping architectures

- Higher inherent reliability
- Invented by Einstein and Szilard



SNAP 10 A-NASA

The Annular Linear Induction Pump (ALIP)



The pump operation based on Faraday's law of induction

- Time varying magnetic field generates a nonconservative time varying electric field that drives current to flow within the skin depth of liquid metal

- The interaction of this time varying current with the applied field gives rise to a force—developing pressure to push fluid through the device

- The pump uses multiple magnet coils to establish a traveling magnetic wave to move the fluid through an annular channel

- Radial magnetic field imposed on liquid metal generated at stators
 - the larger the number of stators, the smoother the magnetic wave and thus smoother pressure wave

Power and Efficiency Considerations

Parameter	Physics	Calculation
W_A	Real Work over wavelength segment	$\int \mathbf{J} \times \mathbf{B}$ dotted with fluid velocity integral over volume
$W_{f,2}$	Hydraulic losses due to processes like turbulence	Proportional to Fluid to duct shear stress and fluid velocity
$W_{c,2}$	Coil losses	Ohmic dissipation in coil
$W_{f,1}$	Electrical losses in fluid, stator, duct and core	$I^2 R$, Eddy current dissipation
W_T	Total power	
η	System efficiency	Net to total power

$$\eta = \frac{W_A - W_{f,2}}{W_A + W_{c,2} + W_{f,1}}$$

NASA TN D-2816

NASA/INL ALIP

GRC Demonstration of Fission Surface Power – Non-Nuclear

- ALIP identified as a critical component for the then 40 kWe surface power effort by NASA Fission Surface Power (FSP) project in the 2000s
- Plans were made to demonstrate a single string of a 4 string-48 kWe Liquid Metal Cooled Reactor with Stirling converters for power conversion (12 kWe per engine)
- Idaho National Laboratory (INL) was tasked to design and build an ALIP to support a test demonstration unit of fission surface power
 - 2 units were built and delivered to Marsh Space Flight Center (MSFC)
- ALIP was integrated at into subscale Technology Demonstration Unit (TDU) at NASA Glenn Research Center (GRC) and underperformed
- Poor performance of the ALIP had parasitic effect on overall system performance owing to its reduced efficiency (pump efficiency 5 % versus 10%)

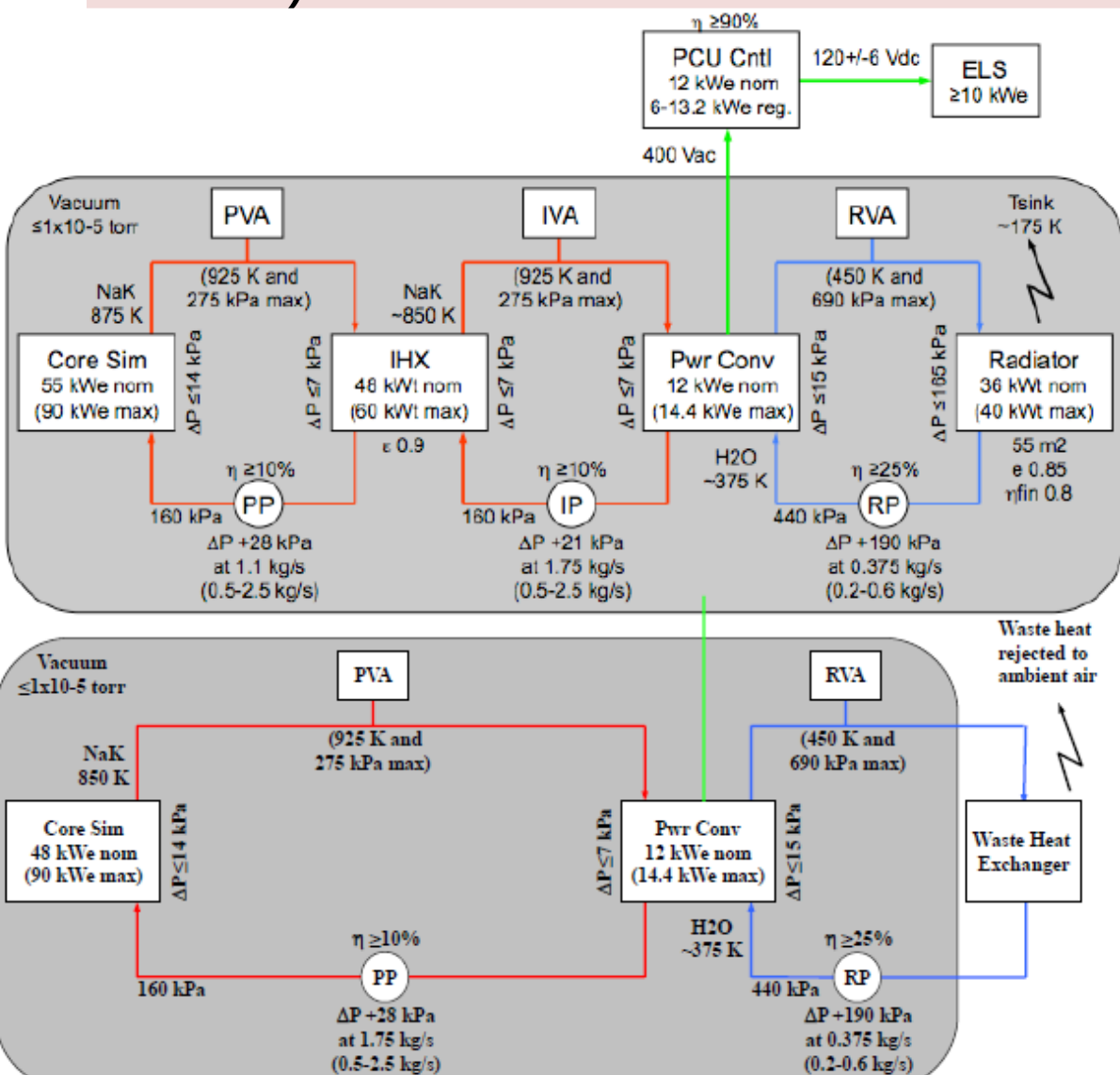


Figure 2. Schematic of the Fission Surface Power Technology Demonstration Unit showing the original configuration (upper) and the as-built configuration (lower)

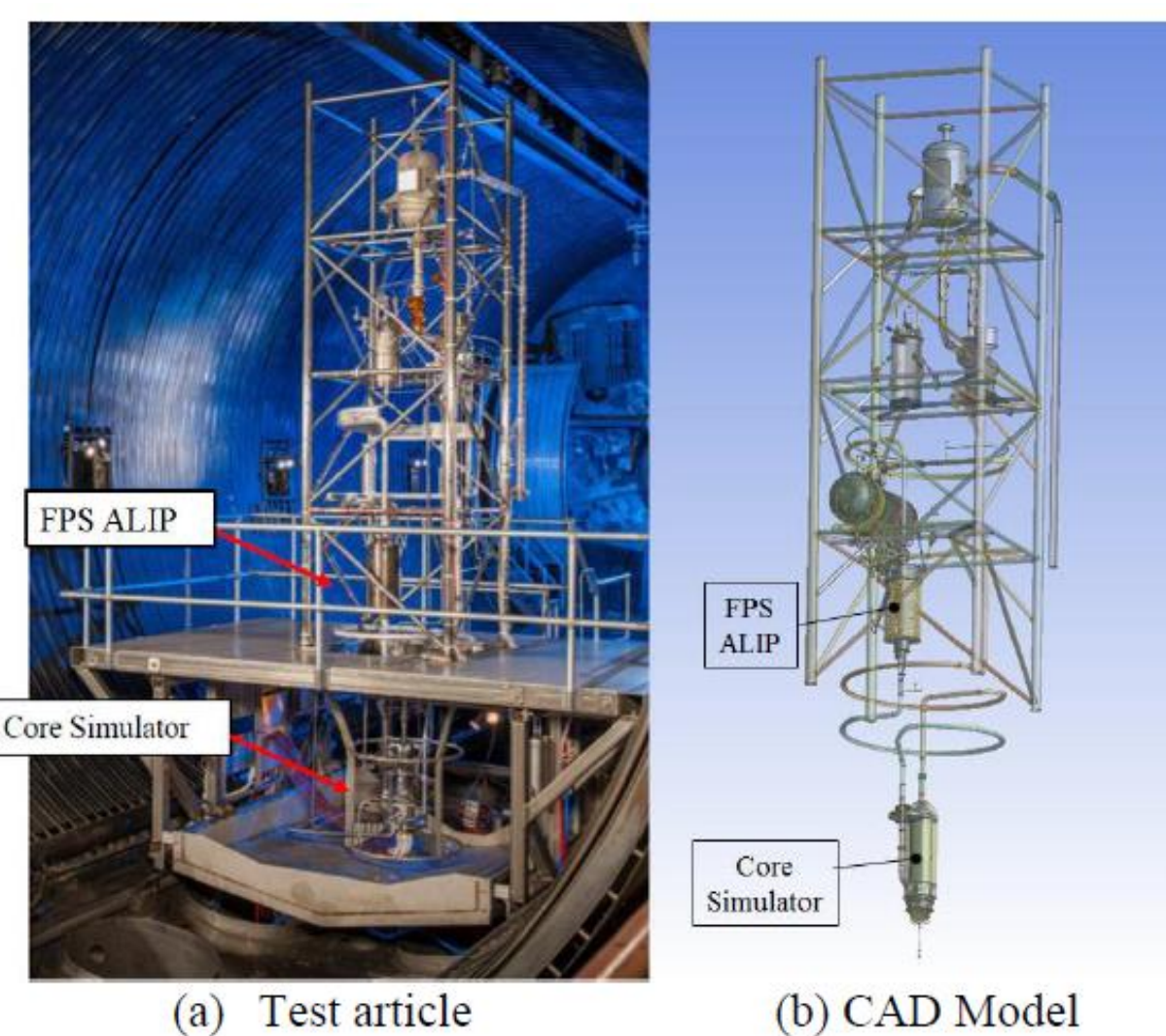
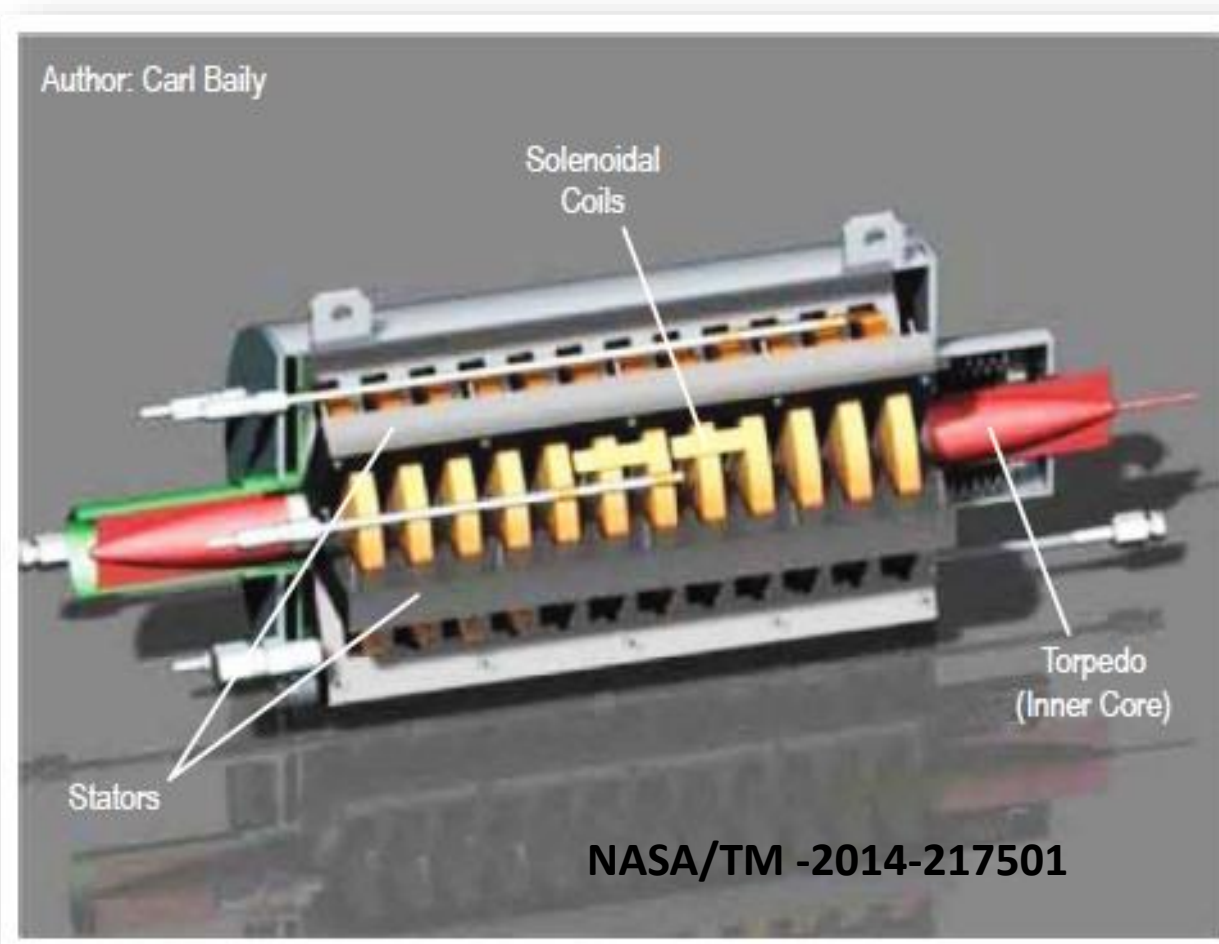


Figure 1. Fission Power System (FPS) Technology Demonstration Unit (TDU).

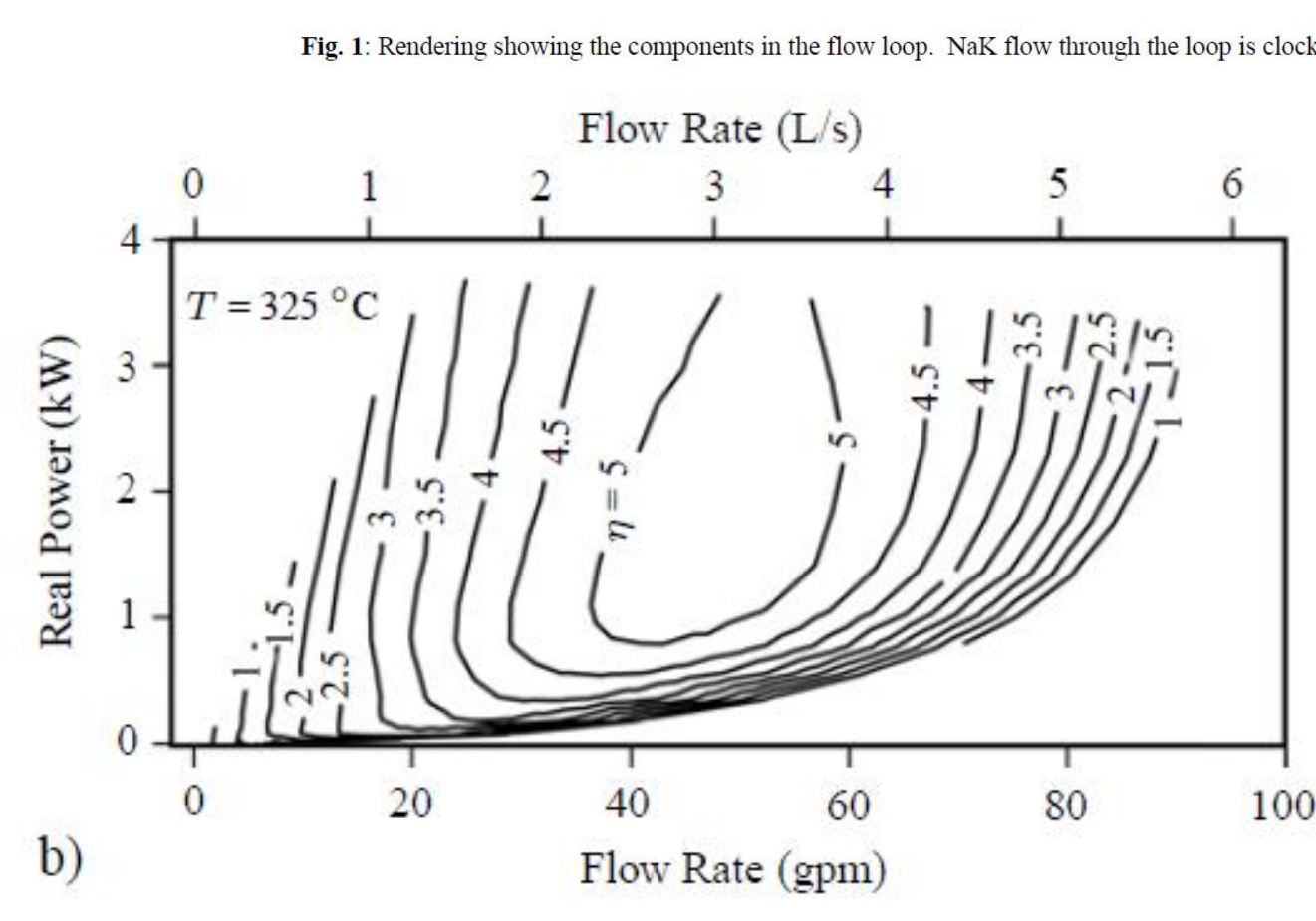
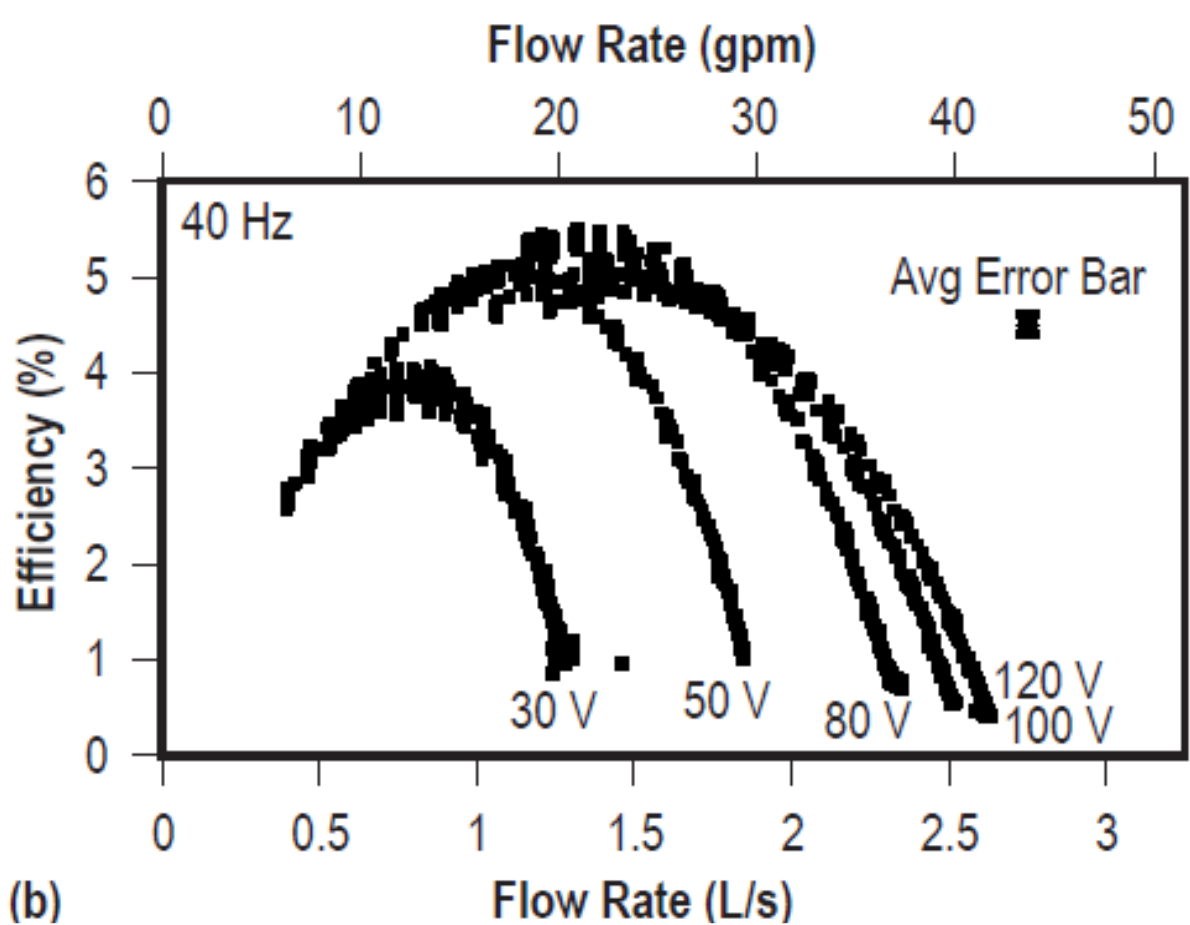
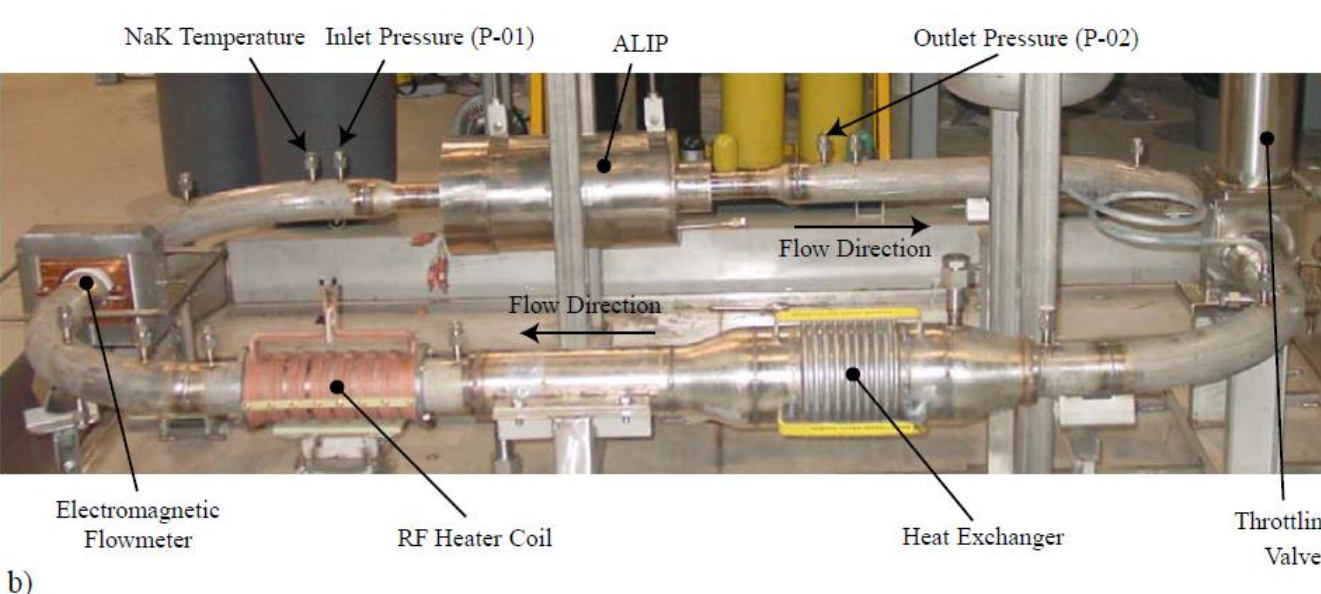
NASA TM 2016-219382

NASA/INL ALIP Design Description



NASA/TM -2014-217501

MSFC Standalone ALIP Performance Testing and the Identification of the Efficiency Problem



NASA/ TP 2010-216430

Future Work and Implications

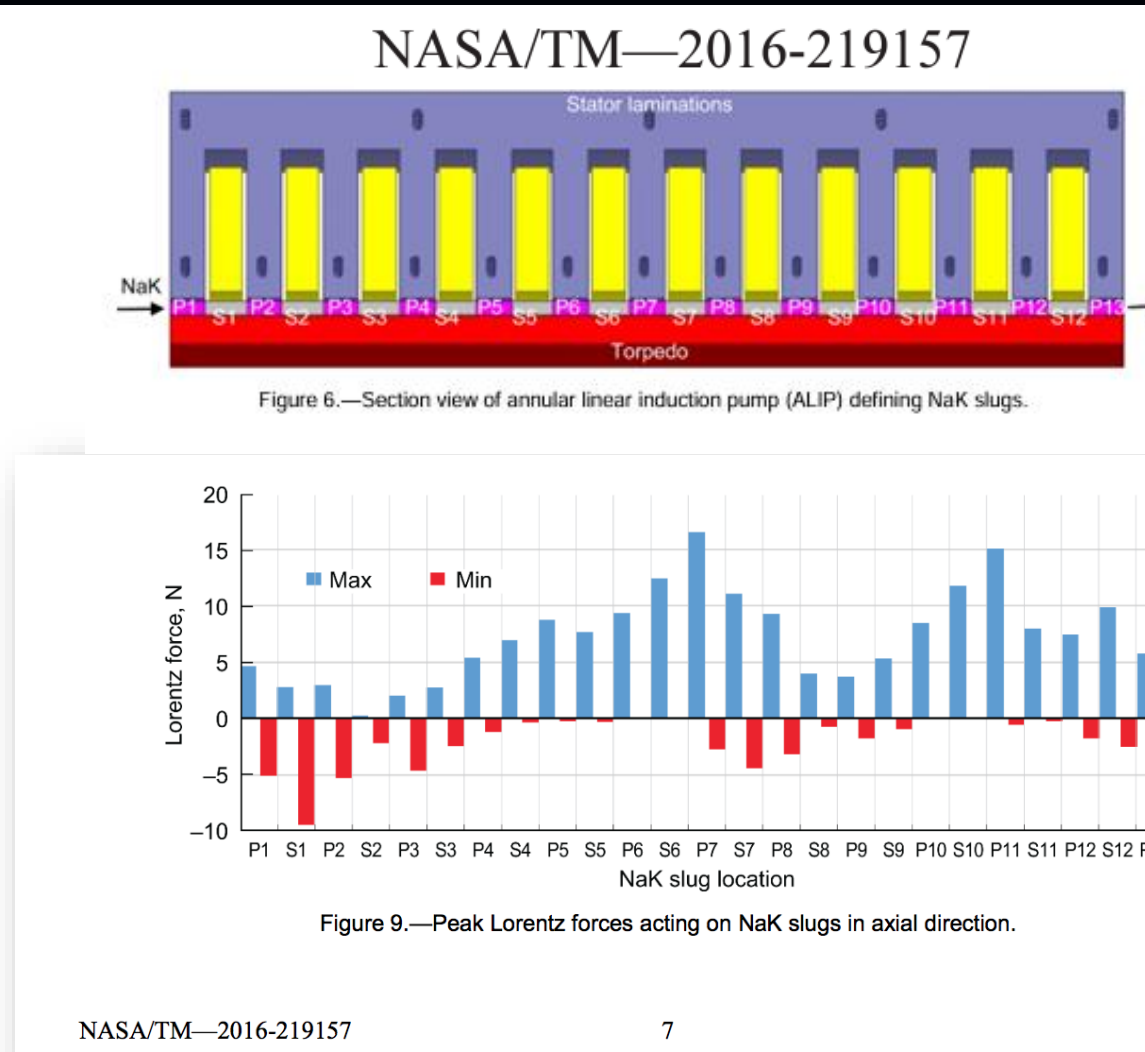
Possible reasons for poor ALIP performance:

- Hiperco-50 not annealed (core and stator)-so they may have been saturated
- Currents of the three phases were unbalanced (significant)
- Magnet coil wire had larger diameter than expected so fewer coil turns
- Turbulent flow in channel (radial forces)
- Unoptimized stator and torpedo core design (need to optimized radial field)

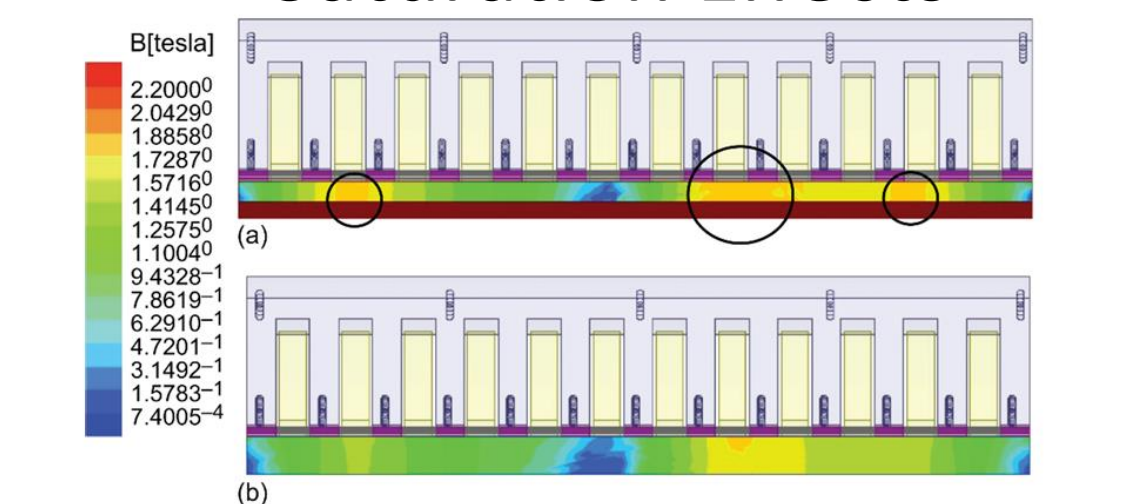
Solution can be explored computationally

- Geng and Reid used a two-step approach to replicating performance
 - Magnetic model→force→pressure per differential element→Fluid model→iterate

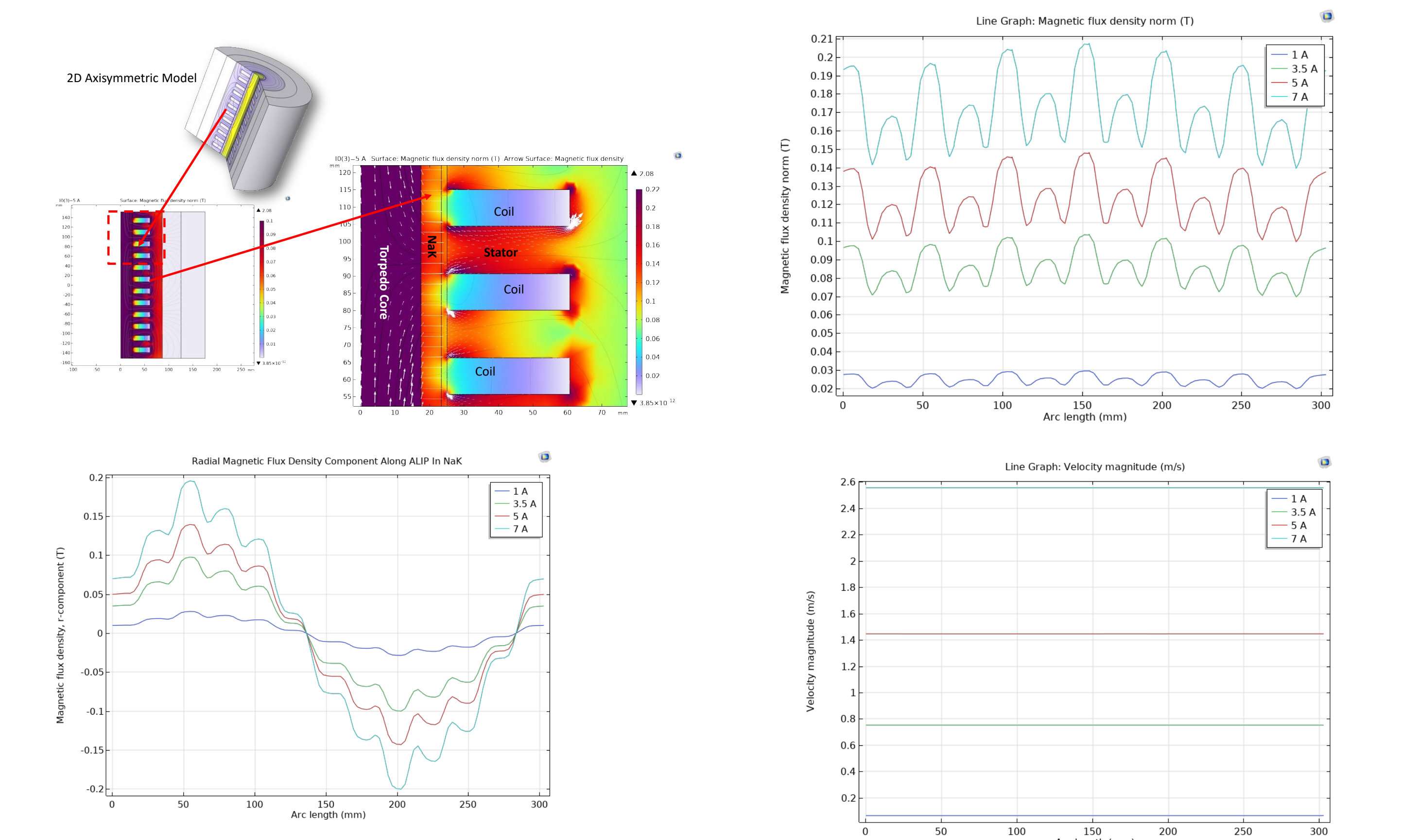
Modeling can be made more compact and self consistent using a multi-physics tools to couple EM and fluid equations in one package--COMSOL



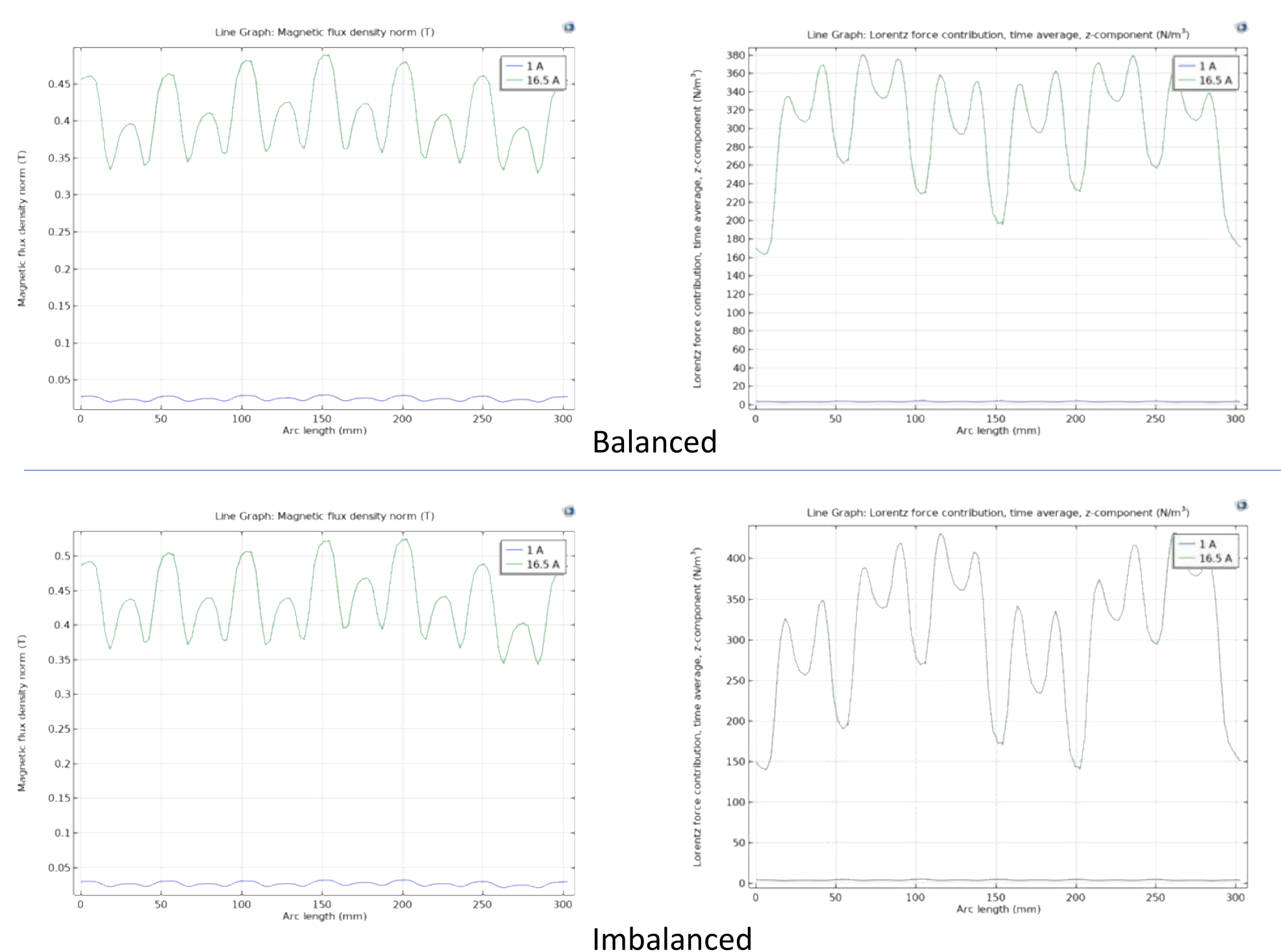
Saturation Effects



Multiphysics Effort



Current balance comparison (3 phase)



Acknowledgements

1. NASA Glenn Faculty Fellowship Program