**Mechanical and Thermal Modeling of a High Pulse Rate Pulsed Inductive Thruster**

**What is Electric Propulsion?**

- Electric Propulsion (EP) is the use of electrical energy to accelerate a propellant, often in the form of plasma.
- Pros/Cons of EP:
  - Pros: High exhaust velocity, high efficiency, lower propellant mass needed for mission success.
  - Cons: Engineering challenges when scaling for higher power, potentially expensive propellant.
- Current uses of EP: Keeping satellites in stable orbits over long periods of time.
- Long distance robotic exploration missions.

**Inductive Pulsed Plasma Thruster**

- Description: Form of electromagnetic propulsion using pulses through an inductor coil to ionize and accelerate a gaseous propellant using the Lorentz force.
- Advantages of IPPT:
  - Electrodeless design means that conductor does not come into direct contact with plasma.
  - Allows for use of more volatile propellants: water, nitrogen dioxide, ammonia.
  - Propellant flexibility allows in-situ resource utilization and cost benefits vs noble gas propellants.

**Research Problem and Objectives**

- Research Problem: How can mechanical and thermal modeling tools be applied to the early design process of a flight-ready thruster?
- Model Design Objectives:
  - Design thruster thermal management to maintain <200 W heat to the spacecraft for 5 kW thruster.
  - Design thruster structure to mass budget of <3 kg/kW.

**Thermal Modeling**

- Where does heat come from?
  - Electrical resistance.
  - Plasma heating.
  - Radiation.
  - Ion and electron collision.
- How to deal with heat in space?
  - Conduction away from sensitive electronics and instruments.
  - Radiation away from the spacecraft.
  - Radiative power scales as $T^4$ according to the Stefan-Boltzmann law.
- Computer Modeling:
  - ANSYS Mechanical steady-state thermal simulation used to set material, radiative, and conductive conditions to determine heat flow.
  - Shared topology used to model the connections between components.

**Mechanical Modeling**

- Solidworks applied to create mechanical model starting with higher-level assemblies.
- Refined over time to include detailed components and connections.
- Basic diagrams of system interconnects necessary for determination of specific connections and contact points.
- NASA NEPP handbook was key for determining options for electrical connections, wires, cables, and tubing that were applicable for vacuum environments.

**Results/Applications**

- Thermal Modeling Conclusions:
  - Best results for radiative power came from keeping the coil face as hot as possible.
  - Low conductivity ceramics in coil mounting and thruster connections was key in minimizing heat conduction to the spacecraft.
  - Vacuum gaps where possible also demonstrated positive results (<40W to spacecraft in ideal model).
- Future Work:
  - Insulating electrical connections in the coil and faraday cage is most promising area of future radiative gains.
  - Mechanical Modeling Conclusions:
    - Solidworks assemblies can effectively model the connections and interactions between components.
    - Future Work: Study feasibility of high voltage (500V+) connections in vacuum and reduce mass of component casings to stay within 15 kg mass budget.

**Mechanical and Thermal Modeling**

- Overview diagram of interfaces between a spacecraft bus designed by Avalanche Energy and the HiPeR-PIT.
- 3D rendered cutaway of HiPeR-PIT assembly created for thermal modeling.
- Test Image of an Electron Cyclotron Thruster (ECT), SPACE Lab.
- Vacuum chamber shot of HiPeR-PIT testbed, SPACE Lab.
- Labeled coil face of HiPeR-PIT testbed, SPACE Lab.
- Artist’s depiction of the Dawn spacecraft, a high-profile mission to Ceres and Vesta using electrostatic EP. [NASA/JPL, 2009]
- Summary diagram of system interconnects necessary for determination of specific connections and contact points.