Of course, a superconducting electrical motor is not without its challenges. "Our greatest obstacle will be managing the high AC losses produced by the stationary high temperature superconducting coils in the motor," Feldman said. "While superconductors do not produce resistive losses, they will produce AC losses when carrying alternating currents in an alternating magnetic field. These losses scale with frequency, magnetic field, flux density and size."

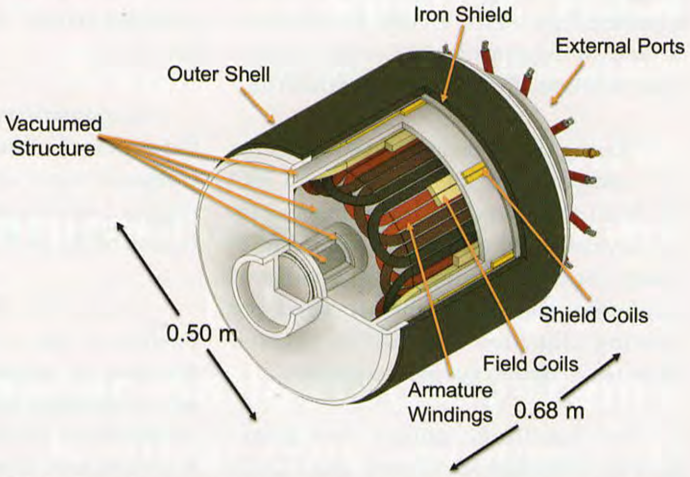
Haran Research Group, headed by Professor Kiruba Haran, front row, fourth from left, and Joshua Feldman, back row, fifth from left. *Image: Jianqiao Xiao*

While a commercial cryocooler may be able to handle low frequency applications like wind turbines, high frequency applications like aircraft propulsion require much more cooling consideration. "Our motor will spin at 3000 to 4500 rpm," says Feldman. "The losses are orders of magnitude higher than wind turbines and pose a significant challenge. At this frequency, we expect our motor to produce around 3000 to 4000 Watts of heat."

This presents Haran's group with two major challenges: how to design the electromagnetic components so as to minimize the AC losses and how to keep the whole system cold enough. Feldman is focused on the latter.

Liquid hydrogen has a boiling point of 20 K, which happens to be a suitable operating temperature for the motor. This allows the hydrogen to serve a dual purpose. "In addition to supplying power to the plane via fuel cells, the hydrogen will function as a cryogen to maintain the motor at superconducting temperatures," he said. "Since we will have to heat the hydrogen anyway for it to reach the required temperature of the fuel cell, we might as well heat it using the heat generated by the superconducting motor, cable conduit and power electronics. This essentially gives us 'free cooling,' meaning that we do not need an extra refrigeration or liquefaction system as would be needed in other superconducting applications."

In other words, the plane's supply of cold liquid hydrogen will absorb the heat produced by the superconducting coils in the motor, changing from liquid to gas in the process, before heading to the fuel cell. Feldman notes that there are different approaches they could take to achieve this. One he is evaluating is to use pipes containing forced liquid hydrogen flow. These pipes would contact a metal heat sink, which would contact the coils, which would then conduct heat from the coils into the pipes where the hydrogen would absorb it.



CAD drawing of superconducting motor. *Image: Joshua Feldman and Noah Salk*

This simplified overview minimizes the myriad of considerations Feldman's research must address: "How do we orient the pipes? How do we bond the coils to the heat sink? How do we size the pipes? How do we integrate such a design with our mechanical model, including the necessary vacuum chamber? How do we ensure mechanical integrity as the system experiences various forces and torques? The rotating field coils, while producing minimal losses, must also be cooled. Do we use liquid hydrogen pipes to cool these coils as well? If so, how do we couple stationary fluid flow to rotating flow?" he asks in rapid-fire succession. "These considerations should give you an idea of the design process we are undertaking."

That design process—and answering the questions surrounding it—is no small undertaking. Feldman says superconducting machine technology is "virtually nonexistent" today; he and his team are creating a considerable amount of the research that in other areas would be available for them to reference. While pioneering the research and development, the team must also account for the lack of infrastructure. The Haran group must reconcile the fact that large-scale hydrogen production, management and commercial storage means are not yet in place. Add to that the notorious reluctance of major industries to adopt new technologies and the obstacles begin to stack up.

But the CHEETA team remains undeterred. They plan on completing component designs for the airplane by Year Two and demonstrating system technologies by Year Three. For his part, Feldman says their plan is progressing. The team is constructing a 3D model of the system and running thermal and mechanical simulations over the course of the next year. After that, they will build a component-level model demonstrating the design's viability, then release papers or conference proceedings documenting their findings. ■