The Technological Development of Flux-Pinned Interfaces for Spacecraft

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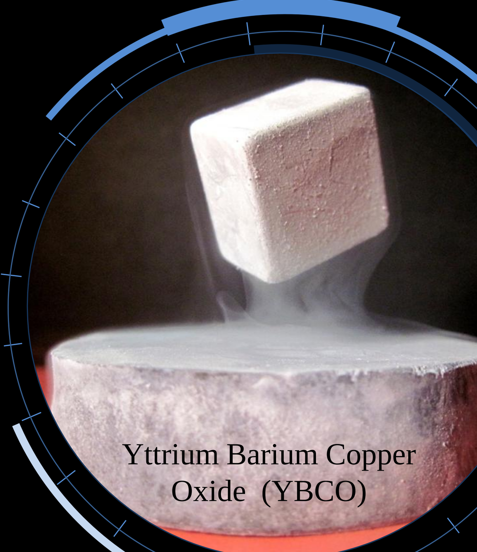
Basic Technology Research

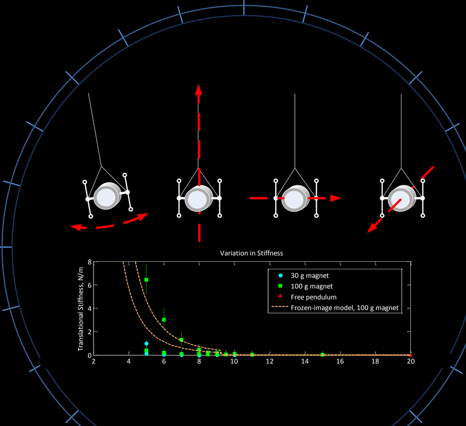
TRL 1–2

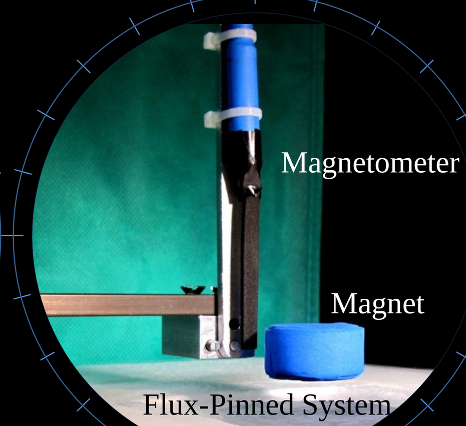
Observed scientific principles begin to be characterized and translated into applied research as the technology concept and application is formulated.

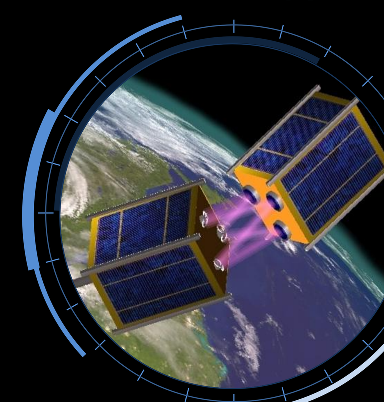


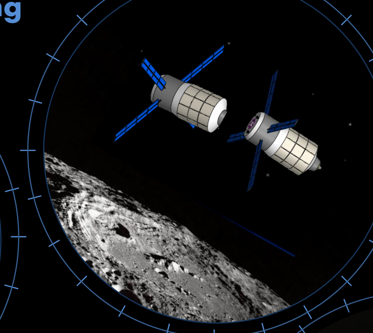
Magnetic flux pinning occurs when type-II superconductors are cooled in the presence of strong magnetic fields, establishing a non-contacting, stable six-degree-of-freedom equilibrium between the magnet (top) and superconductor (bottom). This equilibrium exists as long as the superconductor stays below its critical temperature (88K for YBCO).

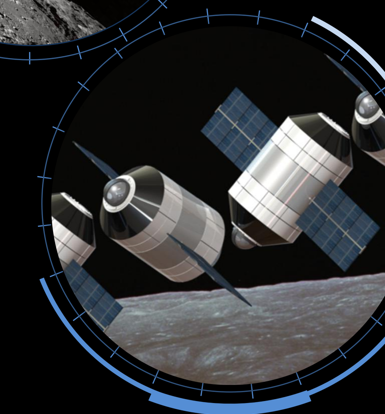
Characterizing flux pinning is the first objective of the technology maturation process. Pendulum tests (left) conducted in the lab have given values of stiffness, damping, and range for flux pinning. The precision lab translator and magnetometer setup (right) has aided in the characterization of the magnetic field strength produced by flux-pinned test articles.





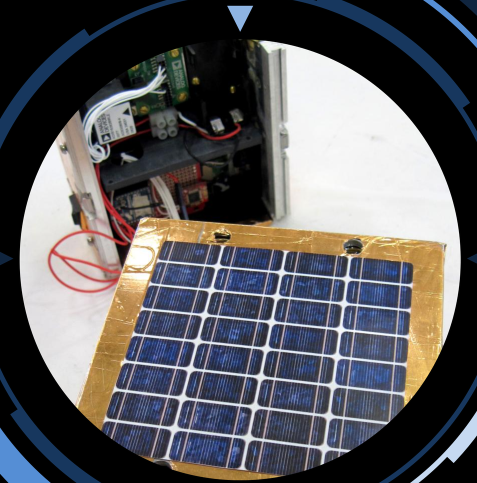






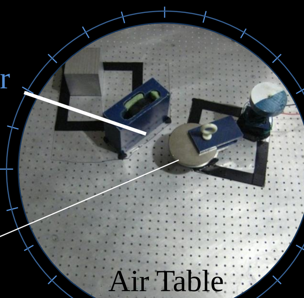
Flux pinning physics can assist spacecraft during a number of close-proximity operations, which motivates the development of flux-pinned interface (FPI) technology.

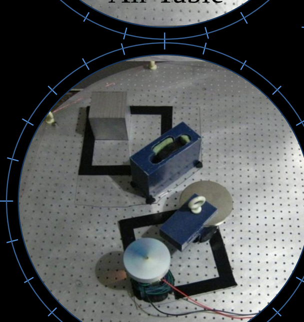
Technology Development

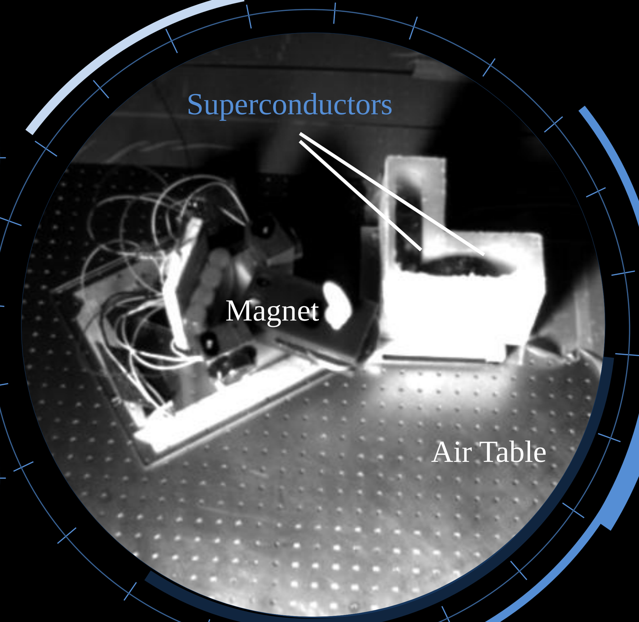


TRL 3–4

Experimental and analytical proof-of-concept demonstrations mature into component and breadboard validation testing in a laboratory environment.

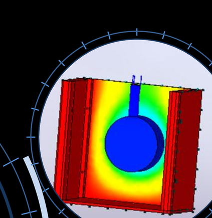


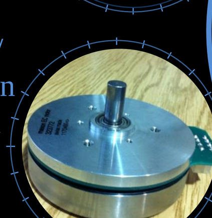


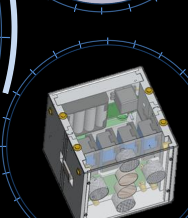


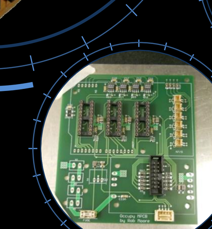
FPI applications are first proven with a combination of proof-of-concept experiments and analytical assessments of system performance. For example, a flux-pinned revolute joint that used electromagnets as actuators (a prototype for a reconfigurable FPI on spacecraft) was first demonstrated as component hardware on an air table (above).

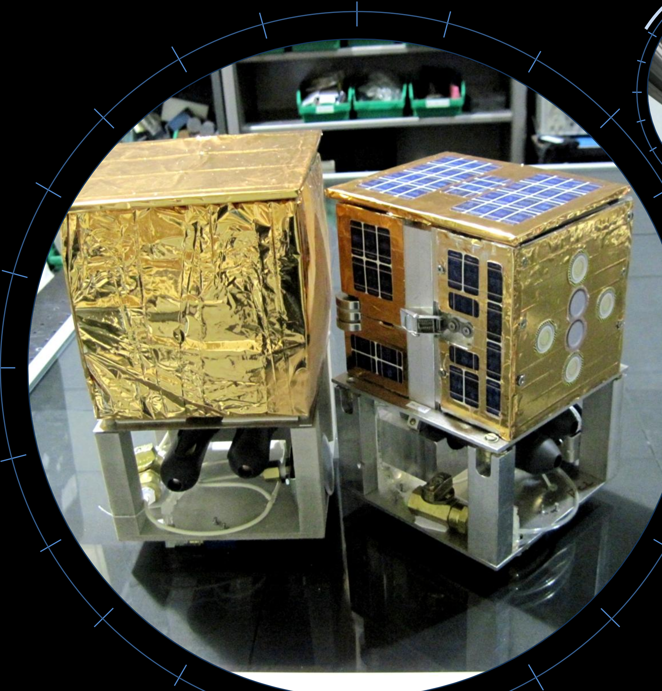
System-level laboratory testing enables FPI prototypes to improve their traceability-to-flight, by developing into higher-fidelity test articles such as the CubeSat-scale FluxCraft (below). FluxCraft integrate wireless communications, on-board sensing and actuating capabilities, and solid thermal and structural designs intended to mimic the flight requirements for an orbital CubeSat-scale FPI.









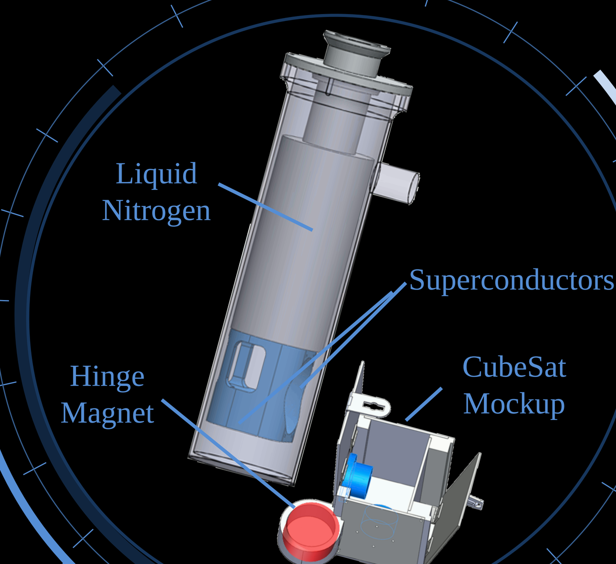


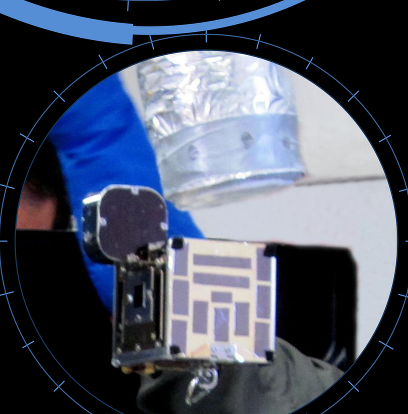
The FloatCube testbed consists of a structure with air feet bearings and CO_2 cartridges to provide a reduced-friction testing environment for the FluxCraft satellite mockups. An overhead camera system can collect real-time data from the platform.

Technology Demonstration

TRL 5–6

Component validation in a relevant environment progresses to a system model that is then demonstrated in a relevant environment.

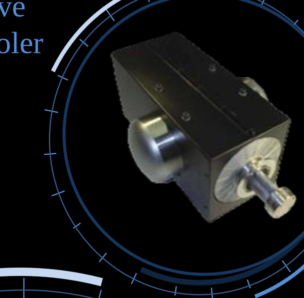


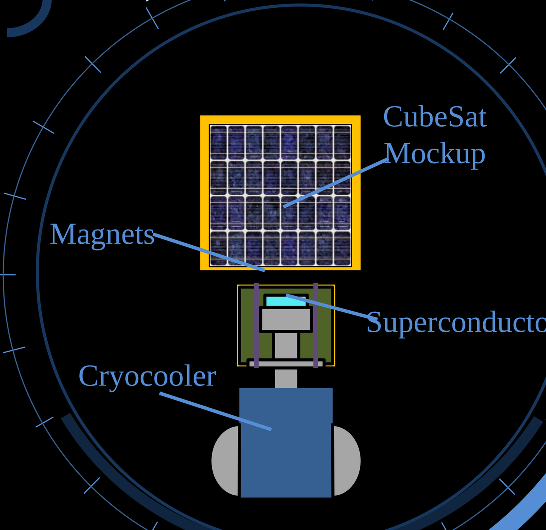


A 2009 NASA flight successfully demonstrated a flux-pinned revolute joint for the first time in microgravity using a prototype satellite mockup and a free-floating dewar of liquid nitrogen containing superconductors.

Ultimately, FPI component and system-level designs must be proven viable in a relevant environment before they can be tested on-orbit. In order to capture the nonlinear and coupled six-degree-of-freedom dynamics of a free-floating FPI, it is necessary to perform this testing in a microgravity environment. With over four flight days of testing to date, FPI technology has flown in over one hour of total microgravity time for various experiments

In 2010 members of the Flux Pinning Research Team successfully documented the dynamics of flux pinning with a superconductor disk cooled via a cryocooler on a microgravity flight.



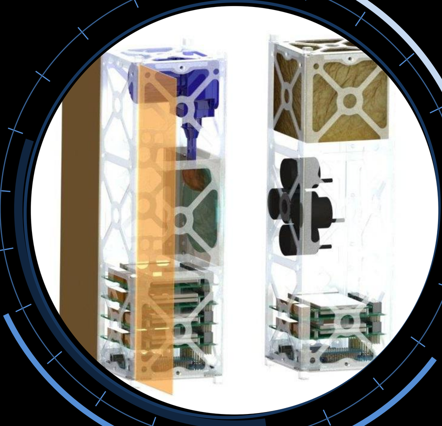


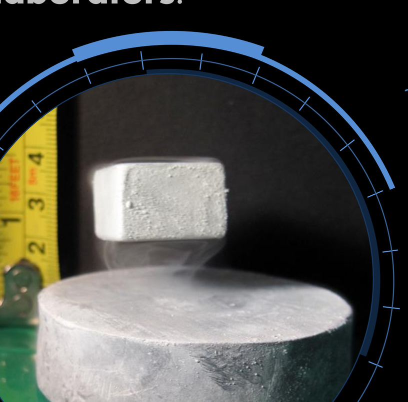
Orbital System Deployment

TRL 7–9

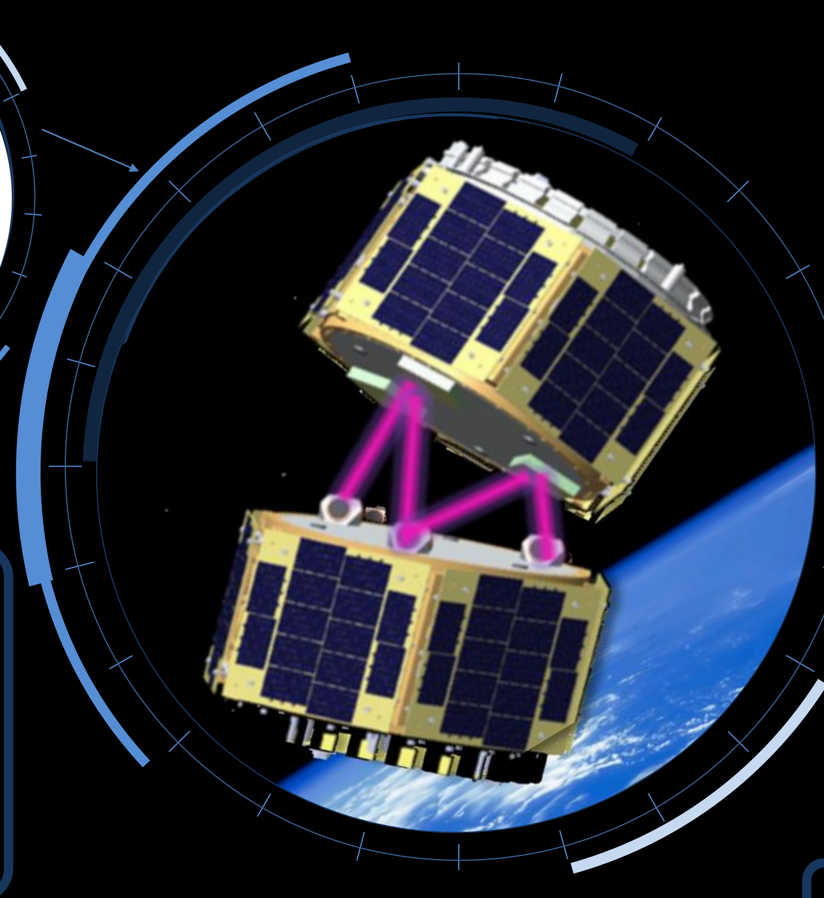
A system prototype demonstrated in a space environment develops into a flight-proven system with repeatedly successful missions.

The final phase of FPI technology development starts with an orbital demonstration of a system prototype. Several proposals to design, build, and launch an orbital FPI demonstration mission are underway with industry, government, and academic collaborators.





One proposed orbital FPI demonstration would use the CUSat nanosatellite bus with two non-contacting segments whose relative dynamics are influenced by flux-pinning physics.



A successful orbital validation of FPI technology will enable novel solutions to close-proximity operations in space. The last phase of the development process at that point is to repeatedly fly FPIs on useful missions. FPIs can be applied to rendezvous and docking operations, close-proximity formation flying, magnetic grappling for satellite servicing, and the on-orbit assembly and control of structures. These key technologies will be critical to future space systems.