



WHITE PAPER: CALNETIX ADVANCED HIGH-SPEED TECHNOLOGIES FOR MISSION-CRITICAL DEFENSE AND AEROSPACE APPLICATIONS

Calnetix Technologies, LLC, headquartered in Cerritos, Calif., specializes in high-performance, high-speed motor generators and advanced magnetic bearings and control systems. The company's overall technology portfolio and system integration capabilities have led to development and production contracts with original equipment manufacturers (OEMs) and the start of successful subsidiaries that focus on unique niche markets.

The company's proven, mature technologies are intrinsically adaptable for defense and aerospace industries, providing lower-cost solutions, faster implementation timelines and increased system reliability for the lowest overall life-cycle costs.

Calnetix and its subsidiaries have developed a suite of cutting-edge high-speed technologies that apply to a wide variety of applications across many industries. These technologies have been proven already in commercial and industrial applications, such as compression, pumping, air/gas movement and control, turbocharging, turboexpansion and power generation. They can be easily adapted for defense and aerospace applications.

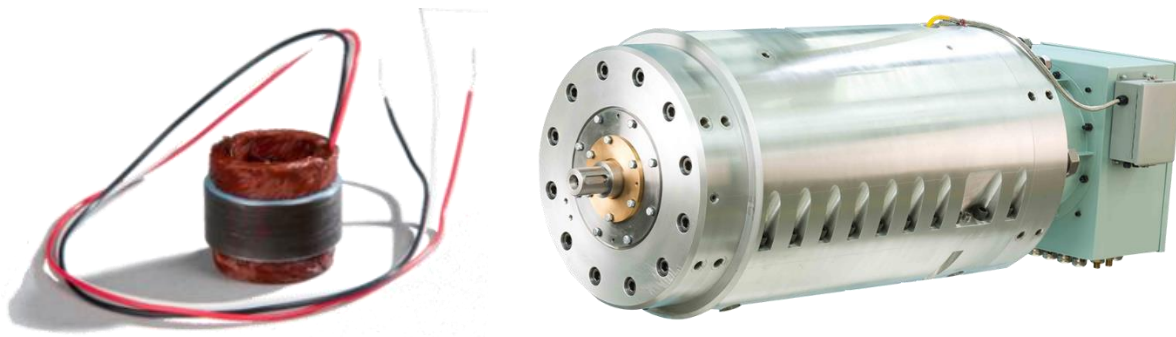
In this White Paper, we describe Calnetix's basic underlying technologies and field applications across a wide spectrum of industrial segments. We also provide examples showing how Calnetix and its technology partners are currently solving problems for defense and aerospace programs and look briefly at a few potential applications for these technologies in the future.

Core Technologies

Permanent Magnet Motors & Generators

Designed with the smallest volume and weight, Calnetix's high-speed Magnaforce™ permanent magnet (PM) motors and generators achieve increased efficiency and power density over traditional gear box motors due to the use of PM rotors supported on advanced oil-free frictionless magnetic bearings.

Calnetix has developed custom PM motors and generators for OEM products ranging from large compressors, blowers, vertical pumps, auxiliary power units and large industrial power generation systems down to subminiature PM motors for artificial hearts and other blood pump applications.



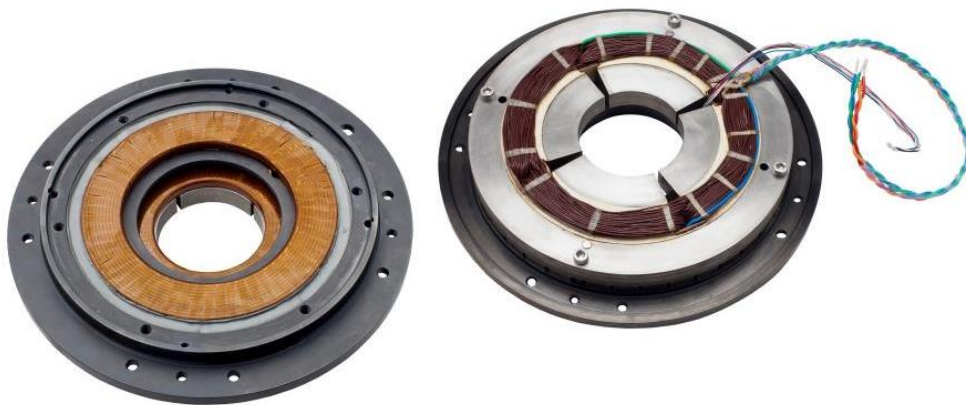
Magnaforce™ Permanent Magnet Motors and Generators

Active Magnetic Bearings

Calnetix specializes in high-speed rotating machinery supported by patented active magnetic bearings (AMB), which help optimize system efficiency and enhance reliability and sustainability.

Calnetix's Powerflux™ active magnetic bearings present unique advantages over conventional roller or fluid-film bearings for high-speed rotating machinery. Unlike conventional bearings, AMBs suspend the target rotor in a magnetic field. The result is a non-contact rotor support system with extremely low friction and no contact wear.

Calnetix magnetic bearing systems are used in a wide variety of commercial and industrial systems, including high-efficiency blowers, high-speed compressors, Organic Rankine Cycle (ORC) systems, turboexpanders, flywheels and many more.



Powerflux™ Active Magnetic Bearings

Power Electronics

Variable speed drives (VSDs) or variable frequency drives (VFDs) regulate the rotational force and speed of electric motors by changing the frequency of the input power to the motor. Currently, Calnetix utilizes both sensor-based and sensorless motor drive technology based on the needs of the system.

By utilizing cutting-edge technology in motor drives and inverters, Calnetix is able to take full advantage of the latest technology in permanent magnet motor generators. Calnetix's low and medium voltage VSDs deliver energy efficiency and reliability to drive profitable operations in a wide range of industrial applications.

Calnetix Vericycle™ variable speed drives consist of a simple two-level architecture, which has a low parts count and high reliability compared to multilevel inverter topologies. The current harmonics are minimized by operating at higher inverter Pulse Width Modulation (PWM) switching frequencies. Calnetix inverters utilize both Insulated Gate Bipolar Transistor (IGBT) and Silicon Carbide (SiC) switching devices, providing significantly higher switching frequencies at lower operating losses.



Vericycle™ Variable Speed Drives

Relevant Commercial and Industrial Experience

Calnetix's core high-speed technologies have been deployed into many commercial and industrial applications, leveraging their light weight, high power density and efficiency. We will focus on three representative market segments that are relevant to defense and aerospace crossover.

Motorsports

Calnetix has extensive years of experience in designing and developing high-speed, high-performance lightweight motor generator units and components for motorsports customers. For instance, the company's proven expertise has been used to develop kinetic energy recovery motor generator units (MGU-K) and heat recovery motor generator units (MGU-H), with the latter design matching turbo speeds as high as 135,000 rpm.

Calnetix's Magnaforce™ motors and generators are designed to provide maximum power density while maintaining high operating efficiency and optimum thermal performance and meeting the most stringent light weight requirements. For example, Calnetix designed and manufactured a power-dense

machine for a motorsports customer rated at 100 kW and weighing just 7.7 kg in a 1.2-liter volume. This is equivalent to a machine power density of 13 kW/kg and 43 Kw/liter.

This technology and expertise could meet many aerospace requirements and applications where maximum power density and lowest weight are paramount.



Magnaforce™ High Power Density Motor Generator

Heat Recovery

Calnetix was one of the first to bring to market a self-contained, fully integrated expander solution for industrial waste heat recovery and subsequently licensed the technology to General Electric and other OEMs.

Since 2005, Calnetix has been working with Mitsubishi Heavy Industries Marine Machinery and Engine (MHI-MME) Company to improve the energy efficiency of marine vessels without impacting vessel operation or performance through highly efficient and cost-effective pressure and heat recovery systems. The two companies collaborated to develop the Hydrocurrent® Organic Rankine Cycle (ORC) system that uses Calnetix's proprietary turbo-generator power conversion technology to convert thermal energy from the ship's engine jacket water into mechanical power to generate grid-quality electric power. The system can produce up to 125 kW of electric power from a temperature source as low as 80 degrees C. This translates into fuel savings of up to 200 tons and reduced carbon monoxide emissions by 18 tons per year.

At the heart of the shipboard ORC system is Calnetix's Carefree® Integrated Power Module (IPM), which makes small-scale heat recovery systems viable and economical. The IPM is a high-efficiency maintenance-free, hermetically sealed module that consists of a radial turbine and a permanent-magnet generator. The magnetic bearings enable frictionless operation, eliminating energy loss, wear and maintenance associated with traditional lubricated bearings.

We foresee numerous applications for ORC turboexpander-generator technology for a wide range of waste heat conversion to utility-grade electricity in defense and aerospace operations.



Hydrocurrent® ORC Module

Flywheels

Calnetix has designed and developed flywheel-based energy storage systems for a wide range of commercial and industrial applications. These highly reliable, environmentally friendly and compact flywheel systems provide an alternative to battery technologies for critical backup power for mission-critical applications. Over 1,200 flywheel systems have been delivered and are operating around the world for backup and microgrid applications, such as hospitals, universities, data centers, manufacturing plants, broadcast studios and casino gaming centers. Other applications include energy recycling for rail and industrial equipment.

The Calnetix flywheel energy storage systems combine a high-speed electromechanical kinetic energy storage device with a bidirectional power conversion system. Key components include a Magnaforce™ permanent magnet motor generator and Powerflux™ active magnetic bearings to levitate and sustain the rotor during operation. These innovative technologies enable the flywheel systems to charge and discharge at high rates for countless cycles, making conventional technologies like lead-acid batteries obsolete.

Flywheels provide proven, reliable high-capacity backup power with instantaneous response in the event of a power failure at mission critical data centers and operation centers.



Flywheel Energy Storage System

Current Defense and Aerospace Programs

Calnetix's core technologies have been employed to meet the stringent functionality and reliability requirements for a variety of aerospace and defense applications. Here are two examples of current programs.

High-Performance Shipboard Chillers for the U.S. Navy

Calnetix worked with Johnson Controls to design, develop, test and deploy a new high-efficiency, super-capacity (HES-C) shipboard chiller system for the U.S. Navy. Calnetix's Magnaforce™ power dense rotating machines provide an ideal direct drive solution to meet the increased power demands of existing Navy vessels within limited footprints. The new HES-C ruggedized chiller compressor drive system, introduced to the fleet in 2017, uses Calnetix's Magnaforce™ drive systems to increase the ship's existing cooling capacity by 75 percent within the same value and footprint, while also improving reliability and reducing chiller fuel consumption, resulting in reduced ship acquisition and life-cycle costs.

Calnetix's high-speed permanent magnet motors, active magnetic bearings and power electronics are fully tested to MIL-STD-167 mechanical vibration and MIL-S-901D high-impact shock standards for shipboard equipment.

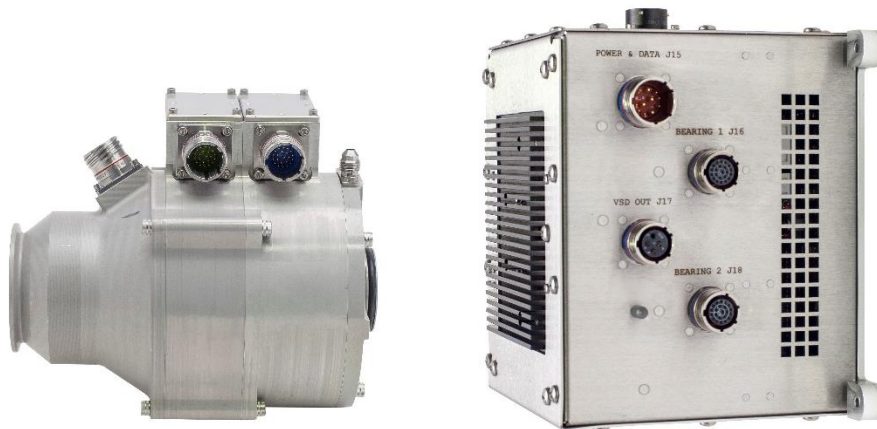


U.S. Navy Floating Shock Platform (Photo courtesy of the U.S. Navy)

High-Speed Blowers for NASA International Space Station

Calnetix's high-performance motors driven on magnetic bearings are a good fit for many aerospace applications due to their small-size, high efficiency, high reliability, variable speed, high torque system capabilities, long-term maintenance-free operation, reduced noise and ability to reach high rotational speeds.

In one of the projects, Calnetix was asked by NASA to design a next-generation blower for a CO₂ removal system, which will be installed and tested on the International Space Station (ISS). Calnetix's ISS blower system includes a compact Momentum™ in-line blower on magnetic bearings and an integrated Continuum™ dual controller. The blower consists of a centrally located five-axis Powerflux™ AMB system, backup bearings, an overhung Magnaforce™ permanent magnet motor and a centrifugal impeller in a very compact package. The magnetic bearings significantly increase the performance, reliability and lifespan of the system due to its frictionless operation. It fits into the same length, width and height envelope as the foil-bearing supported blower it replaces.



Momentum™ In-line Blower and Continuum™ Dual Controller

Potential Future Defense and Aerospace Applications

Based on the numerous successful deployments of Calnetix's core technologies across multiple commercial, industrial, defense and aerospace applications, we foresee many potential applications where Calnetix's proven permanent magnet motors and generators, non-contact active magnetic bearings and power electronics technologies can be deployed. These three core technologies can meet

the most demanding operational and form-factor requirements for high-speed, high-efficiency, high-reliability and lightweight machinery. Here are just a few areas that Calnetix is actively pursuing.

Electric Hybrid Aviation

Direct Drive Turbine Generators. Traditionally, airborne turbine generators utilize gear reduction systems to drive synchronous or induction electric generators. Calnetix's high-speed direct-drive PM generators can eliminate the gearbox, significantly improving efficiency while reducing required maintenance. Also, the size and weight of the generator can be significantly reduced, improving fuel efficiency.

Electric Propulsion. Next-generation hybrid electric aircraft and new types of urban air mobility platforms will require new integrated propulsion systems. To increase the fuel efficiency and flight times for these applications, the weight, volume and power density of the electric motors need to be considered. Adoption of Silicon-carbide (SiC) technologies will help achieve high power density, high-temperature operation, high efficiencies and smaller drive size. Calnetix is developing lightweight air- or liquid-cooled electric motors with the combination of SiC-based drives that will significantly reduce the system mass and subsequently boost fuel efficiency and flight times. The integrated system can reduce energy consumption and meet stringent emission standards while improving reliability and operational flexibility.

More Electric Aircraft (MEA). New MEA technologies will decrease operating and maintenance costs and increase aircraft availability by reducing mean time between failures (MTBF). The MEA aircraft also will reduce exhaust gas emissions and noise levels because they are lighter, more efficient, and have fewer bulky systems on board. There are two main elements to the more electric concept – extracting power from the engine and activating the various controls and utilities electrically rather than hydraulically. Calnetix will be developing variable-frequency starter/generators that can provide electric power to eliminate pneumatically driven environmental controls and cabin pressurization systems, simplify onboard hydraulics and optimize wing-ice protection functions.

Ground Vehicles

Next-generation unmanned ground vehicle (UGV) payloads will require high power density motor generators to ensure long periods of operation in the field. Calnetix's Magnaforce™ PM generators provide the best combination of size, power, cost and reliability for these missions. They are customizable for special applications and provide excellent energy efficiency, minimal footprint and low maintenance requirements.

Turbine-based range extender power generation systems are being considered as a viable option to give ground vehicles efficiency and reliability in a compact package while providing additional power acceleration and auxiliaries. Gas turbine range extenders with Calnetix high-speed PM motor generators provide the highest power-to-weight ratio, ultra-low emissions, ability to operate on alternative fuels, low sound and vibration levels, low maintenance and greater reliability.

Satellites

Calnetix motor generator systems are compact and lightweight with minimal maintenance requirements, making them well suited for space-based applications. They provide freedom from

lubricants and other contaminants. In orbit, solar panels can charge the flywheel systems, which store energy for release when solar charging is unavailable.

Marine

Similar to the aviation industry with its MEA initiative, military vessels will increasingly adopt more electric-based equipment, for which reliability and quality of onboard electric power will be critical to ship operations. Calnetix's flywheel energy storage system is an attractive solution to provide increased stability and peak-power capability to the main electrical network on the ship. Higher power output and energy storage capacity values can be obtained by connecting several flywheel systems in parallel.

The Calnetix flywheel energy storage system stores energy in the form of kinetic energy in a rotor spinning at a high rate of speed in a vacuum. The rotor is supported on frictionless magnetic bearings, offering long life and charge/discharge rates, many times higher than those achievable with electrochemical batteries.

Calnetix's proven ORC heat recovery systems and high-efficiency super-capacity chiller systems will continue to move into more widespread use on naval warships and auxiliary vessels.

Summary

Calnetix brings to the table the core technologies and depth of expertise for next-generation high-speed machinery in the defense and aerospace industries.