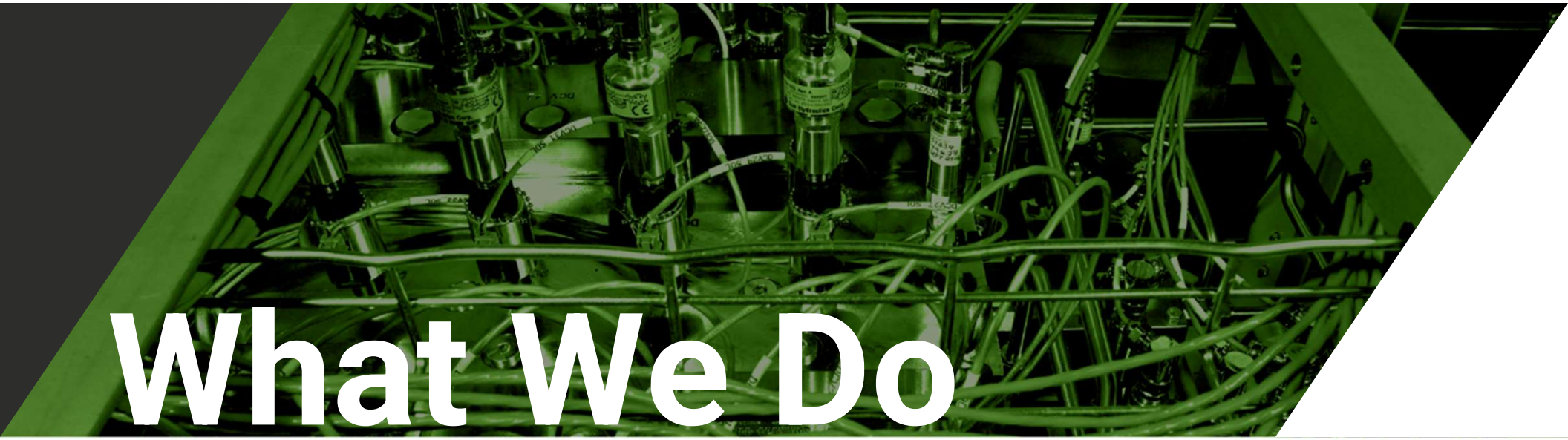
Czero®
ENGINEERING TOMORROW

Czero – Engineering Services Overview & Partial Portfolio

Updated 2023-08-21
Czero-solutions.com



What We Do

Czero
ENGINEERING TOMORROW

Czero innovates designs and advances technologies for energy conversion, use, and storage.

Improve Efficiency

Increase Performance

Reduce Manufacturing Costs

Enhance Sustainability

Easy For You

Creative Insight

Broad, experienced team – the power of diversity to finding creative solutions to your toughest challenges.

Quality Service

Exceptional up-front engineering saves you time and money later.

Flexible Engagement

Close collaboration or fully autonomous delivery.

Responsive Engineers

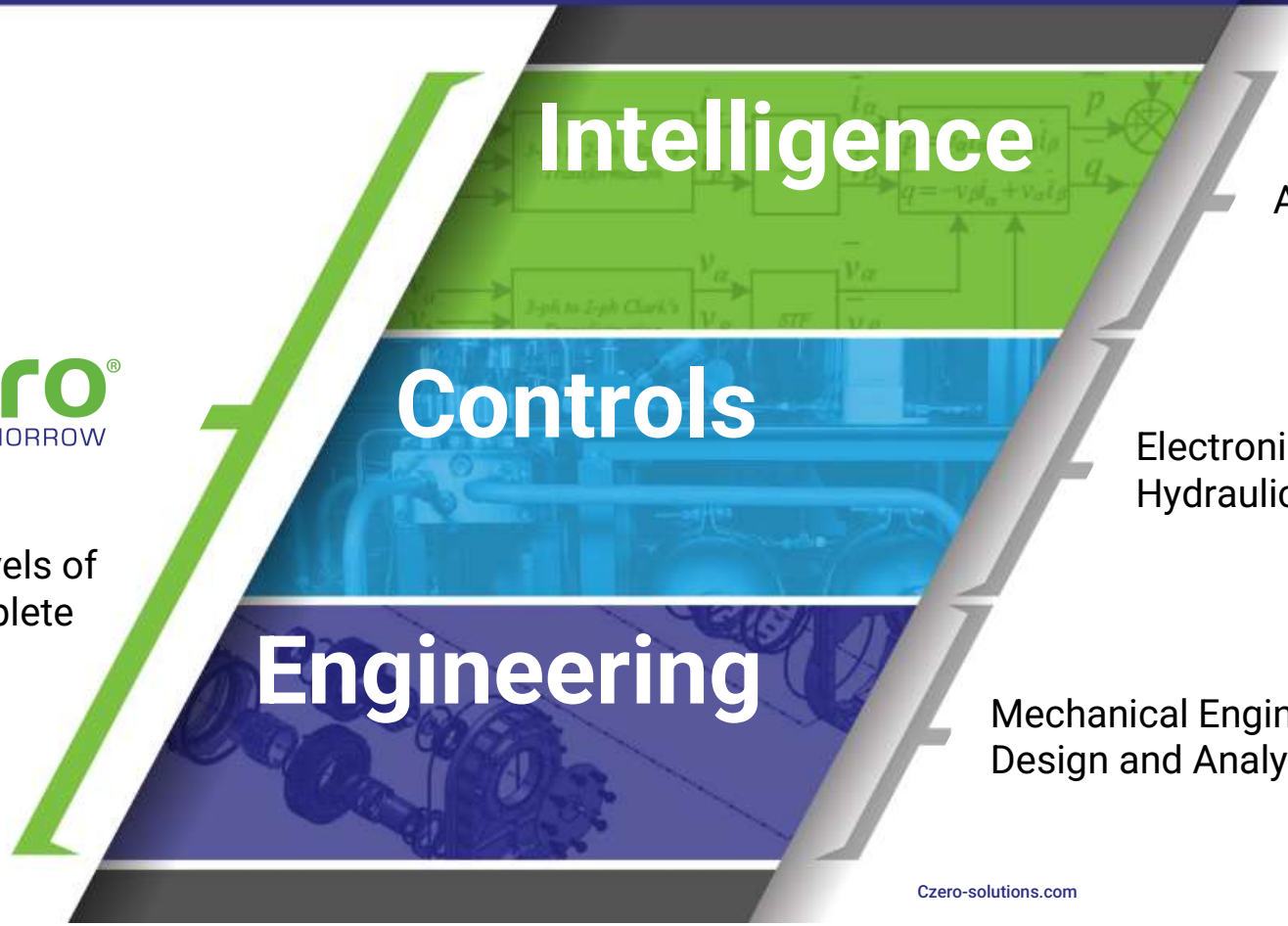
You benefit from Czero's agility and thorough processes synonymous with R&D teams in large global corporations.

Disciplined Execution

You benefit from our proactive project management culture which ensures the project is delivered on time and within budget.

Integrated Solutions

Czero integrates all levels of engineering for a complete one-source solution.



Algorithms

Electronics and Hydraulics

Mechanical Engineering, Design and Analysis

Focus Areas

Focus

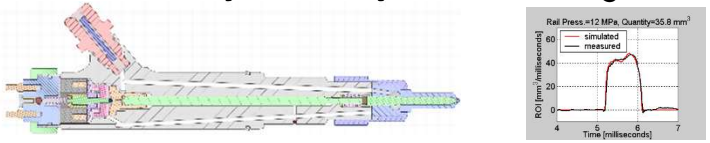
- **Advanced mechanical systems, hydraulic power systems, and energy-conversion systems**
  - Engines/transmissions
  - Hybrid systems
  - Fuel systems
  - Renewable energy
  - Hydraulics

- **Proven track record**
  - Rapid design and development of new technologies
  - Readying technology for high-volume manufacturing

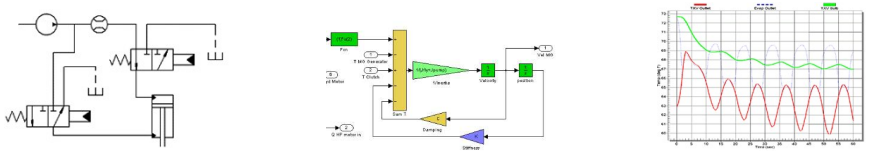
Core Expertise

Mechanical Design – Solid Modeling, GD&T, Structures & Mechanisms

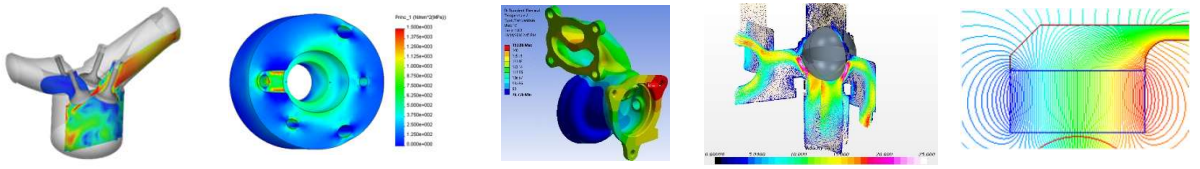
High-bandwidth Hydraulic Systems – Design and Analysis



Dynamic & System Modeling and Controls



Analysis – Thermodynamic, Structural, Thermal, CFD, Magnetics



Mechanical Engineering and Analysis Software Tools & Expertise

Solid Modeling & Design

3D Modeling

Layout Studies

Tolerance Stack-ups

Detailed Drawings (GD&T per ASME Y14.5)

P&ID Drawings

Analysis

Thermodynamic Analysis

Finite Element Analysis

Computational Fluid Dynamics

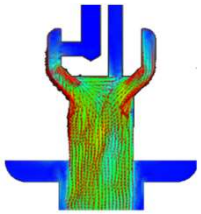
Magnetic Modeling

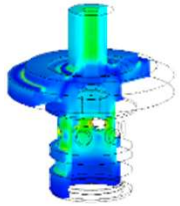
Dynamic System Modeling

Hydraulic Simulations

Refrigeration Cycles

Engine Combustion





Controls Engineering Software Tools & Expertise

Rapid Prototyping of Real-Time Control Systems

Programming

- Matlab/Simulink
- C, C++, C#, JAVA, Python, etc.
- CODESYS, (IL, SFC, CFC, FBD, ST)
- LabVIEW

Communication Protocols

- TCP/IP
- Modbus (RTU and TCP), PROFIBUS
- CAN, XCP, CCP, J1939, J1587
- I2C, SPI

Instrumentation and Data Acquisition

- Measurement Computing
- SCADA

Expertise

- System modeling and identification
- Rapid controls prototyping
- MIL, SIL, PIL, and HIL testing
- Supervisory control and telemetry
- Industrial controls and automation
- All levels of embedded software development

Advanced Controls Algorithm Development

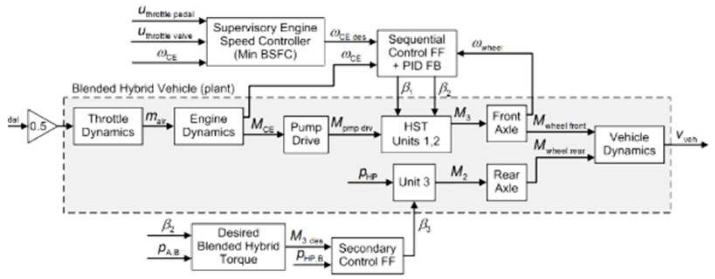
- Dynamic programming
- Non-linear, optimal, and adaptive control
- Neural networks

NATIONAL INSTRUMENTS
dSPACE
WOODWARD
MotoHawk
Particle
RaspberryPi
ARDUINO
SIEMENS
WAGO
ABB
BOSCH

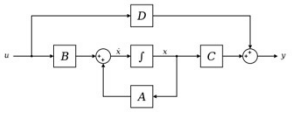
Algorithm and Control Strategy Development

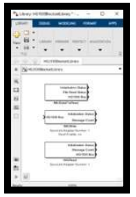
Czero develops component and system level algorithms and control schemes for a wide range of applications, such as:

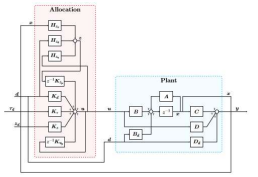
- Control of electromechanical and electrohydraulic camless engine valve actuation systems
- Robust control strategies and prognostics for sub-sea electrohydraulic oil and gas equipment
- Motion control of automated agricultural equipment
- Automated end-of-line testing for hydraulic components
- Power management of a MW scale hybridized genset
- Globally optimal control and power management of hybrid on-road/off-highway vehicles and industrial equipment
- LPG metering algorithm for pay-per-use dispenser for third world countries
- Control of combined IC engine and gas turbine in advanced turbo-compounded reheat cycle



Controls Expertise







Embedded and PLC Controls

- Controller model development for use on embedded targets
- Development of custom Simulink blocks (S-functions) and corresponding TLC files for utilizing external hardware and 3rd party software tools
- Integration of legacy C/C++ code into new code generatable Simulink blocks

Digital Controls

- Evaluation of stability and robustness of discrete physical models and control systems

Developed controls through such techniques as loop-shaping, predictive control, Kalman filter design, and frequency-shaped control allocation

Digital Signal Processing

- Utilize FFT and PSD techniques for vibration studies of vehicle ride properties and feedback control
- Real time analysis of engine combustion data for timing control of fuel injection and hydraulic valve actuation
- Post process analysis of fluid pressure within hydraulic rail to understand impact of standing pressure waves on timing control of hydraulically actuated engine valves
- Real time analysis of utility grid power demand to determine the appropriate power source within a hybrid power generation unit to meet said demand

Implementable Power Management

- Neural Networks can be trained to generalize the DP control strategies and then use this knowledge to predict the near optimal control of hybrid vehicles for new and untrained drive cycles, yielding considerable fuel savings over baseline controls

State Space Analysis

- Extensive experience in applying state space analysis to understand physical systems and within control/estimator development
- Experienced in stochastic state space model development and analysis as well as eigen-value and eigen-vector analysis
- Developed iterative state space models for use within model predictive control and model reference adaptive control

System Identification

- Use of MATLAB System Identification toolbox for both linear and nonlinear plant identification
- Use of machine learning to identify road friction parameters in real time
- Written algorithms that identify transfer function coefficients from data using various regression algorithms

Laplace/Z Transform

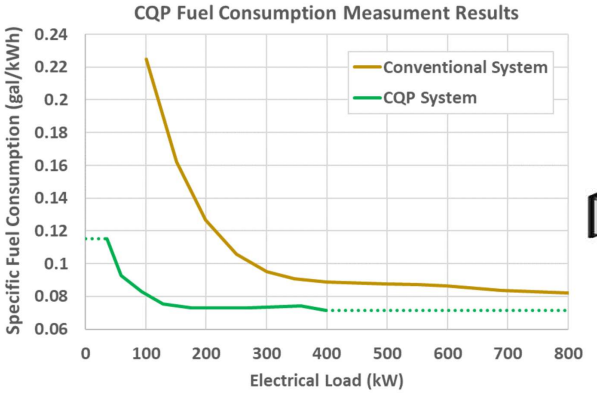
- Extensive use of Laplace variable in analyzing linear systems and developing controls

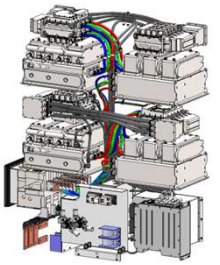
Transfer Functions

- Experience developing transfer functions from fundamentals and evaluating those transfer functions for physical system insight
- Used transfer functions in the development of both SISO and MIMO controls using traditional and more sophistical techniques, like Smith-McMillan and Singular-Value Decompositions
- Experience using MATLAB to develop and evaluate both numerical and symbolic transfer functions

Fully Containerized, High Efficiency, Grid-Ready, Hybrid Genset

- Complete systems engineering, integration and controls
- Detailed design, development, prototype build and test
- Fully integrated control system (1 master & 5 slave controllers)
- Full power management to maximize system efficiency
- Local and remote operation capable
- Grid tie and island mode capable
- Dual 60 kW electric vehicle chargers integrated





Machine Design, Build and Test

Rhizosphere Observations Optimizing Terrestrial Sequestration (ROOTS)

ROOTS supports development of new technologies and crop cultivars to improve soil, increase water productivity, and reduce atmospheric buildup of the greenhouse gases carbon dioxide (CO2) and nitrous oxide (N20), an ozone precursor

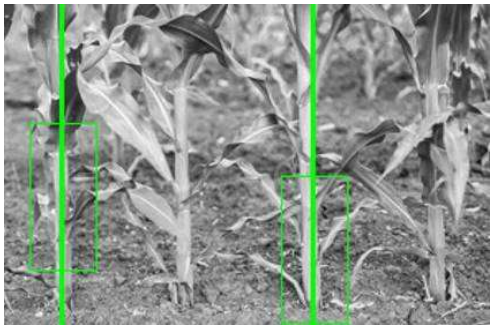
Its ambitions goals for the technology and cultivar development ROOTS funds include:

- 50% increase in soil carbon accumulation
- 50% reduction in N2O emissions
- 25% increase in water productivity

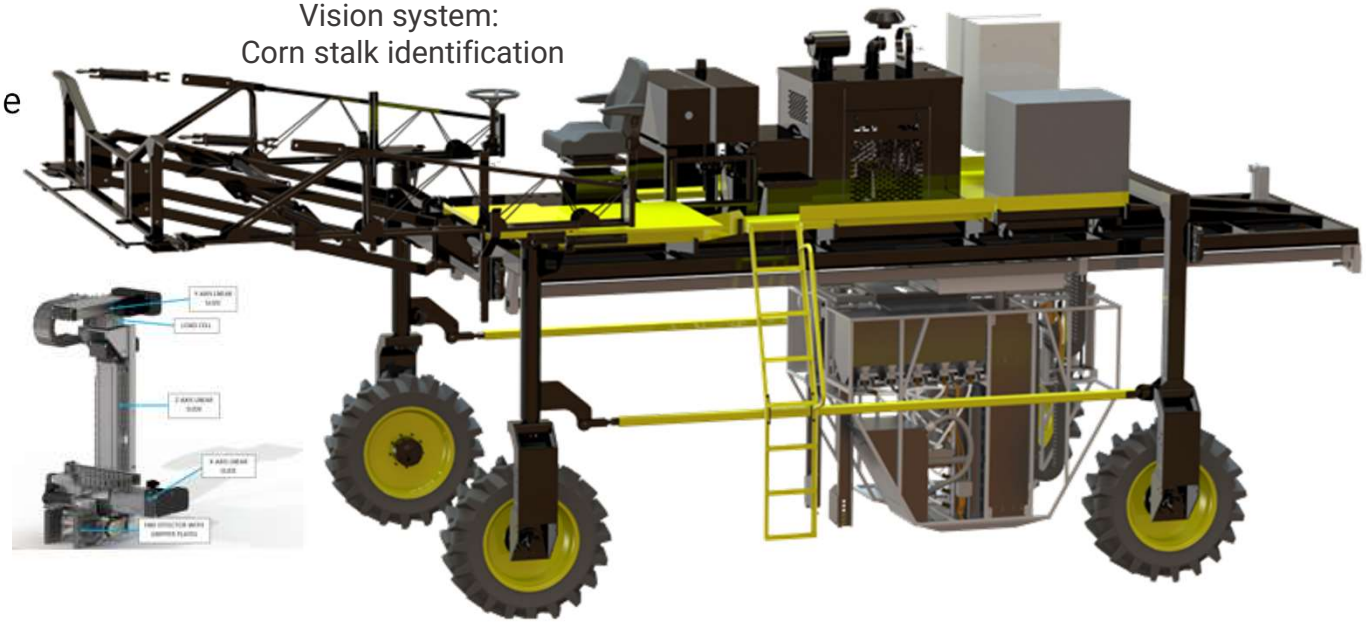
Czero was contracted by Colorado State University to design and develop an automated system for agricultural field research. This system was assembled in house and has been running for several years now.

ROOTS Crop Phenotyping Control System

- Developed an automatic corn phenotyping machine as part of the ARPA-E ROOTS program
- Designed and implemented motion control on Bosch PLCs to control sampling system on dynamically moving platform
- Implemented vison system to automatically locate and sample corn stalks



Vision system:
Corn stalk identification

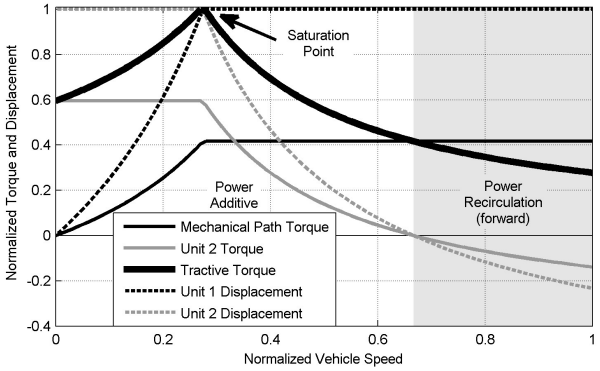


arpa·e
CHANGING WHAT'S POSSIBLE

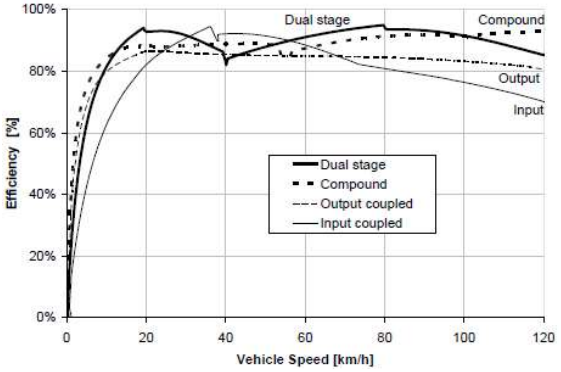
Colorado State University

Czero's Design of Hybrid Powertrains

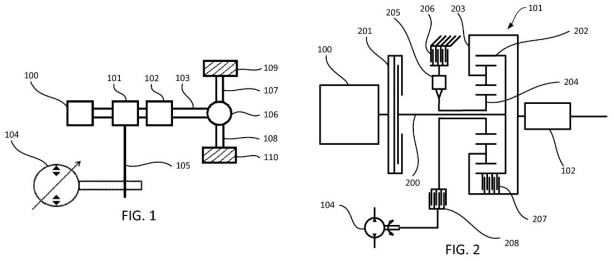
Czero personnel have a long history of designing and analyzing innovative hybrid powertrain architectures for on-road and off-highway applications. This includes a variety of power-split/IVT configurations



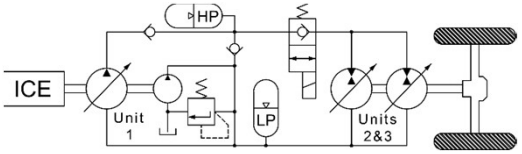
Torque-Split Operation



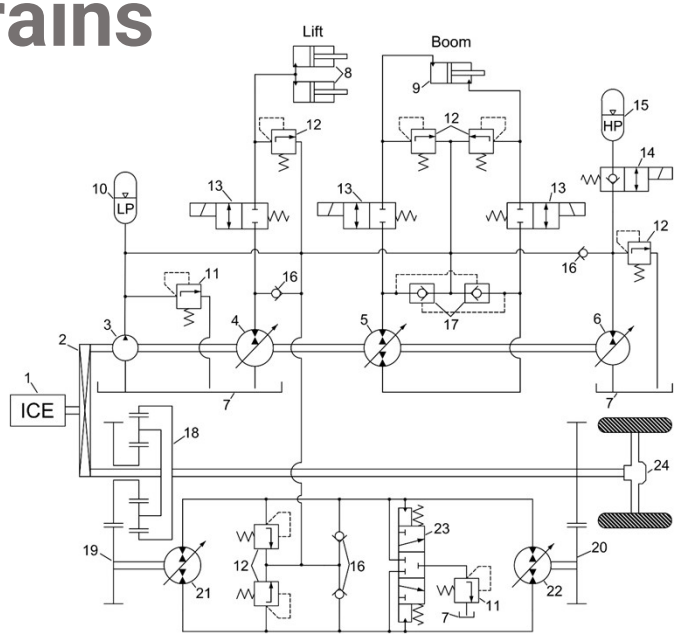
Comparison of Torque-Split Configurations



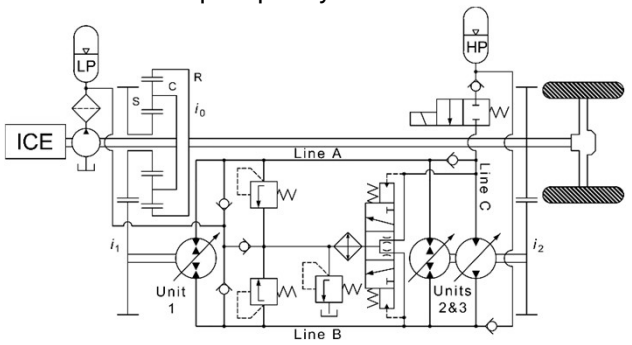
Czero U.S. Patent 8622859 Figures



Series Hybrid



Torque-Split Hybrid Reach Stacker



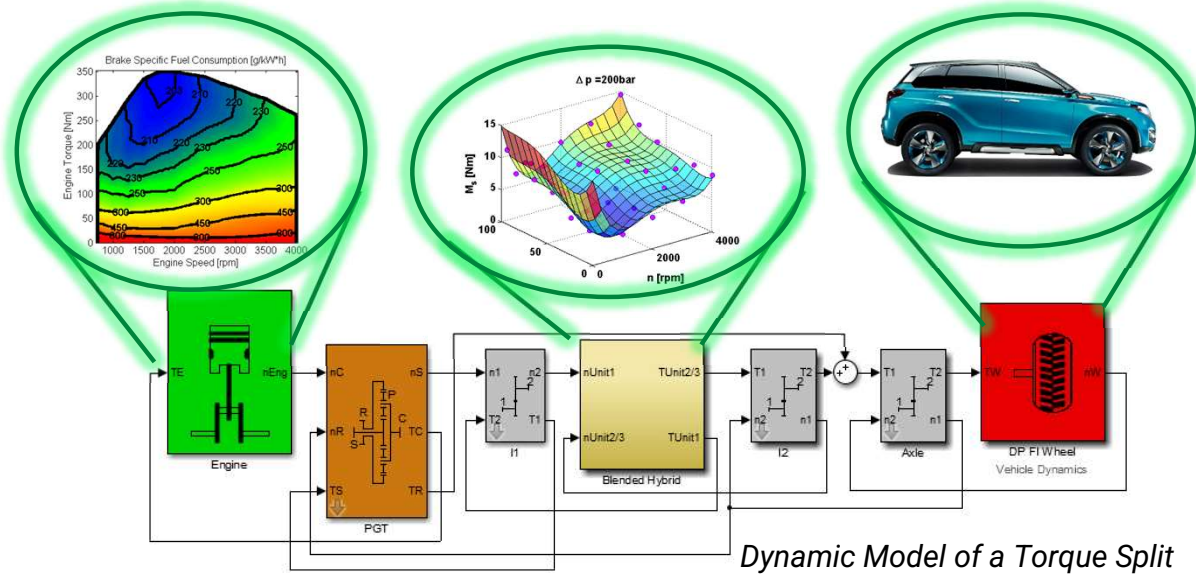
Blended Hybrid

Dynamic Modeling of Hybrid Powertrains

Czero uses a suite of modeling tools, which have been customized and validated over many years, to analyze hybrid powertrains at all stages in the production cycle

Benefits of this dynamic modeling includes:

- Predicting performance and efficiency before any hardware is built
- Saving time and money by identifying problematic configurations and conditions before they occur in the field
- Optimizing system design and component sizing to maximize performance and efficiency
- Enabling the design and evaluation of more efficient control algorithms



Dynamic Model of a Torque Split Hydraulic Hybrid Transmission

Select modeling tools include:

MATLAB SIMULINK

GT Gamma Technologies

ANSYS

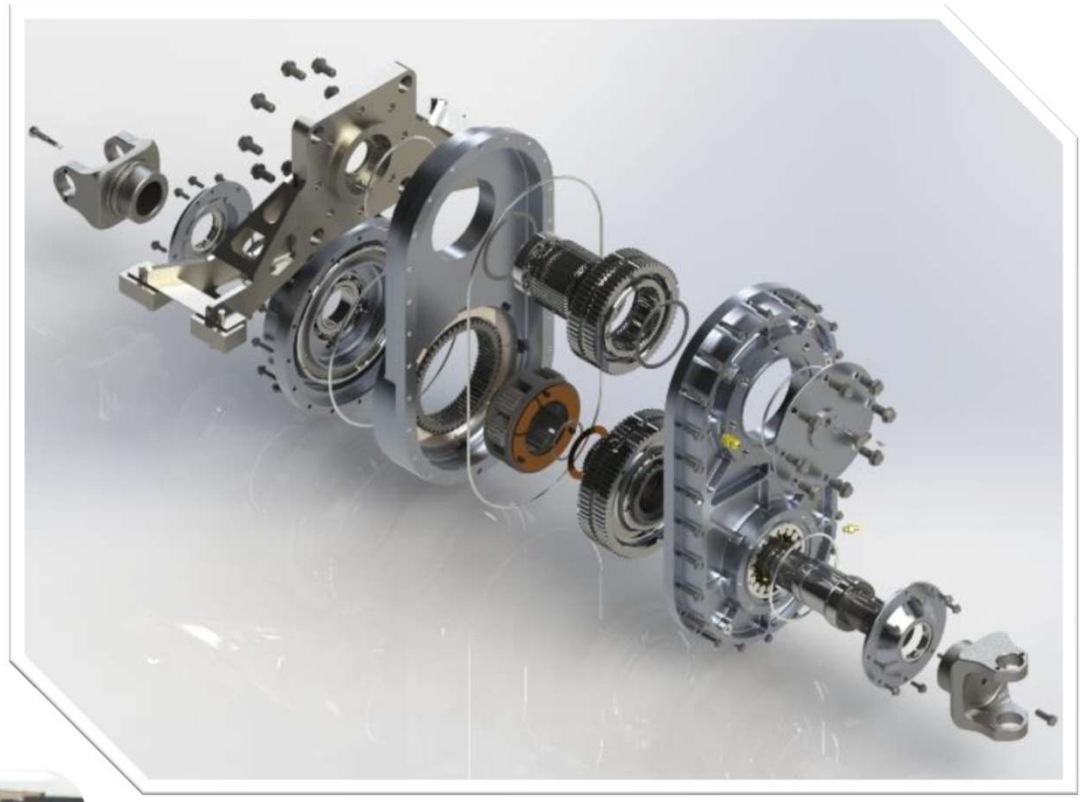
LMS ENGINEERING INNOVATION

CONVERGENT SCIENCE

Hydraulic Hybrid

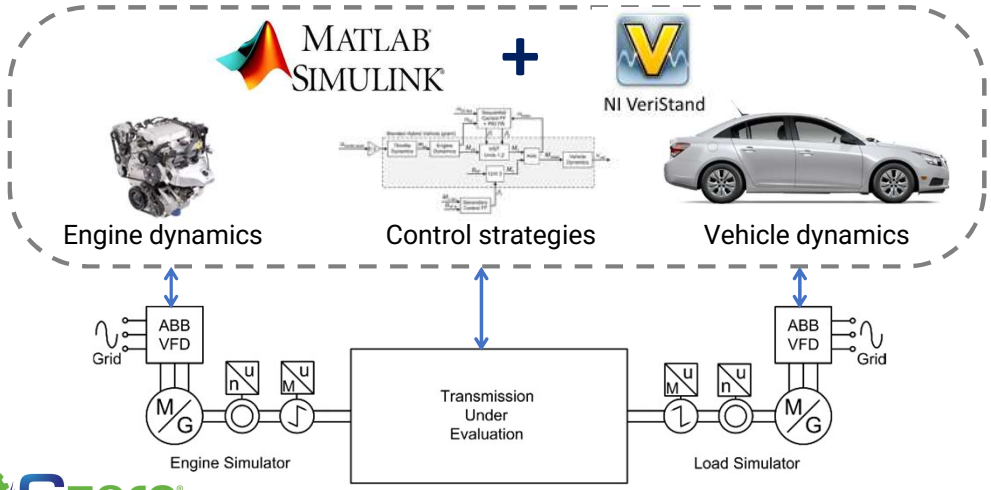
Czero completed an in-house project to design and develop a hydraulic hybrid retrofit system for medium duty trucks

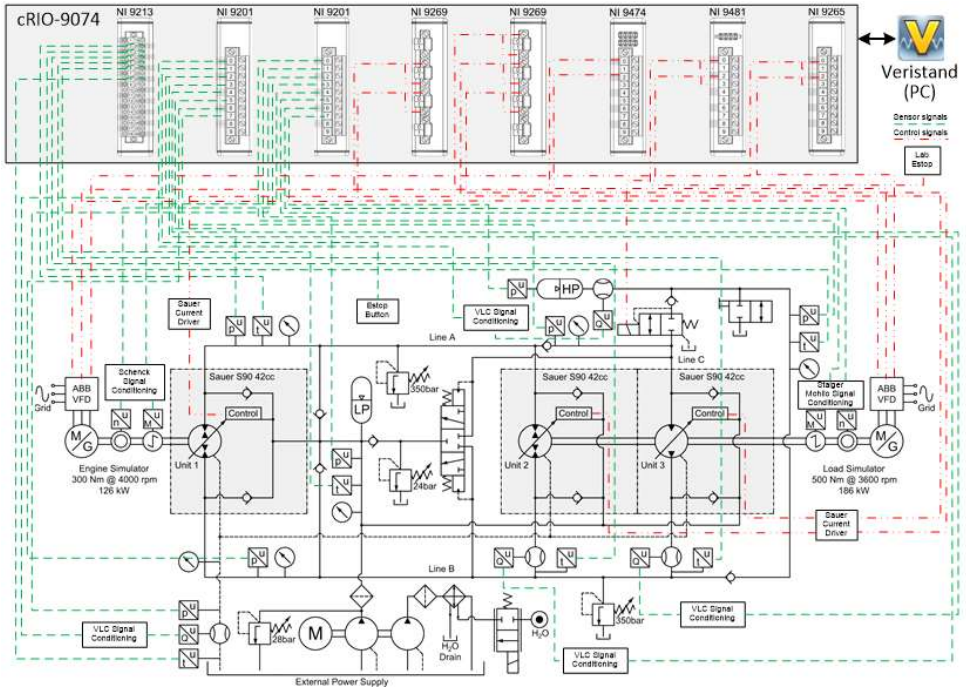
- ~5 months from concept to installation
- Tested in Class 6 truck for 2 years with only minor seal leak and no appreciable wear or degradation



Hardware-in-the-Loop Transmission Testing

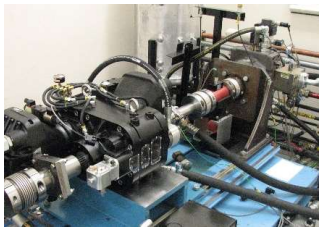
- Czero personnel have experience developing and implementing HIL based transmission test rigs using NI Veristand, xPC Target, and other real time control systems
- Control strategies originally developed and validated in MATLAB Simulink were transferred to HIL test rig and evaluated on hardware with minimal modification
- Full data acquisition systems were also implemented on each of these HIL test rig





Hydraulic Hybrid Transmission HIL Test Rig with **Electric** Engine and Vehicle Emulators

Hydraulic Hybrid Transmission HIL Test Rig with **Hydraulic** Engine and Vehicle Emulators



Algae Bioreactors for Solix Biofuels / Solix Biosystems

Czero worked with Solix Biosystems

- Started by augmenting their small engineering team (2007)
- Took on Engineering Director role and helped fill out engineering team
- Executed on project and helped secure A and B series funding
- Czero acted as virtual engineering team at first, they are bringing more in house
- Multiple patent applications filed

Pilot scale bioreactor designed by Czero

> Guy understands technology development from the back-of-the-napkin stage to the product launch stage. I've never met someone who is more capable of keeping the end-product vision in his mind during the early stages of engineering.
>
> —Sam Jaffe - CEO
> Panea Energy
> (Formerly Solix)

> Guy and Czero were an insightful and very technically proficient group that were instrumental in helping us develop our technology. They were very quick studies to understand the fundamental challenges we faced and design/build solutions around them. Top qualities: Great Results, Personable, Good Value.
>
> —Doug Henston - Former CEO, Solix Biofuels

Solix AGS 4000 portable bioreactor and support equipment designed by Czero

Monetizing By-products of Natural Gas Production

- Czero worked with the Gas Technology Institute (GTI), Oregon State University (OSU) and EcoCatalytic Technologies
- Developed a small-scale reactor engine for converting the longer-chain alkanes from oil and natural gas into more commercially desirable forms
- Czero's engineers modeled gas reaction temperatures, evaluating multiple concepts and architectures. This led into detailed design work and making the first system prototype.

Czero's work…has been instrumental in developing a completely new, innovative system. The in-depth simulation and analysis of the various concepts that Czero did ahead of time has built tremendous confidence that we are going down the right path.

– Devin Halliday, Principal Investigator
Gas Technology Institute

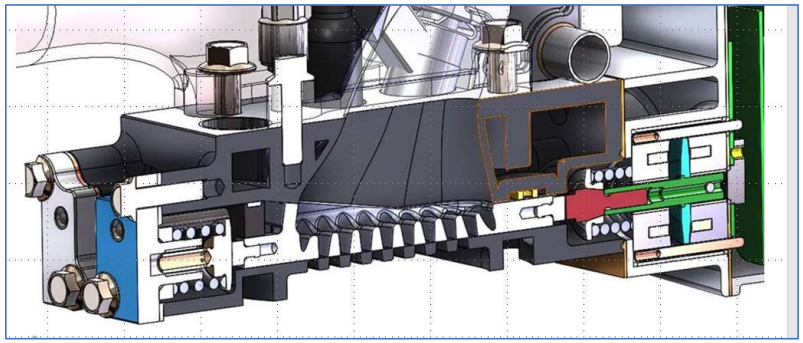
Fully Variable Valve Actuation System for Four Cylinder Test Engine Head

Full Analysis led Mechanical and Industrial Design

- CAD, FEA, mechanical and thermal stress/distortion, thermal modeling
- Dynamic and magnetic modeling of the actuator
- CFD and engine performance modeling
- Capable of sub 2 millisecond travel times
- Upwards of 7000 RPM operation

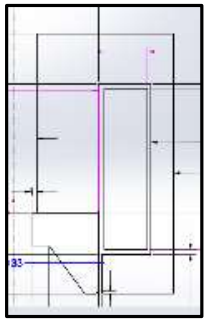
Project Included Custom Engine Dyno Capable of 8,000 RPM, 100 HP

- ABB PLC SCADA for supervisory control and management
- SCADA responsible for control and management of all dyno subsystems
- LabView based front end for operator control
- Integrated NI hardware for data acquisition

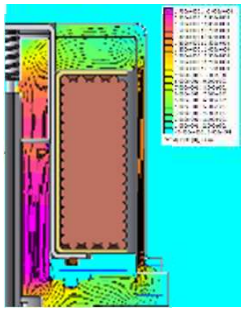


Babbitt et al / SAE Int. J. Engines / Volume 10, Issue 3 (June 2017)

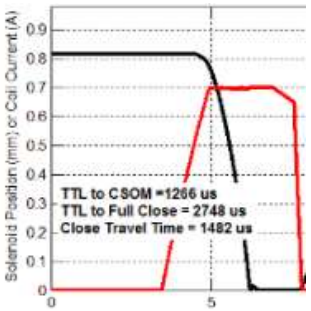
Solenoid & Injector Optimization



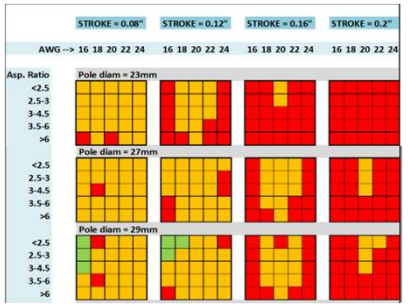
Generate large number of solid models from file of parameters automatically



Data imported into magnetic analysis software. Force maps created for each case

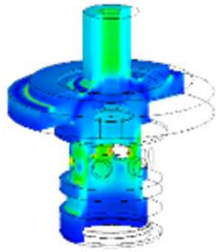


Magnetic data files used in simulation for each case to see how the actuator AND system perform

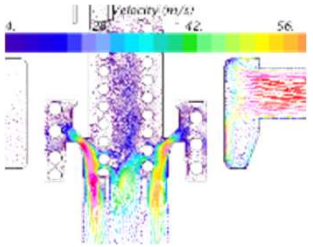


Performance metrics automatically plotted and rated allowing various trades to be quickly identified

Detail CAD Design

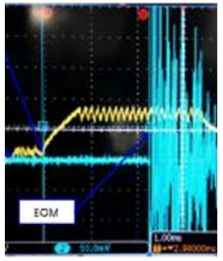


Structural Analysis



Fluid Forces and Internal Losses

Iteration as needed to get final design



Test

500-1000 design iterations day

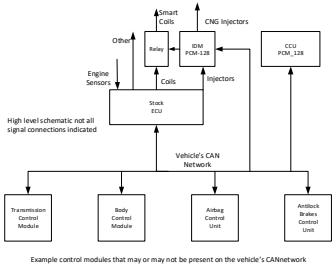
Optimal designs arrived at very quickly, saving time and money

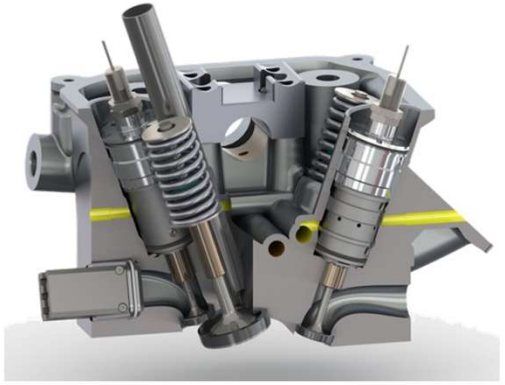
Dual-mode CNG Engine & Multi Unit Control System

Onboard Dynamics, Inc.
Self-refueling anywhere.

In 4 months, Czero went from a production cylinder head to an assembled prototypes. This modified dual-mode CNG engine can propel the vehicle as well as refuel the onboard tank using commonly available low-pressure natural gas supplies. In the trailer configuration, it can be used to safely empty remote natural gas pipelines for servicing and repairs.

- Redesign the cylinder head for natural gas compression in addition to normal combustion mode:
  - CNG porting design
  - Custom check valve for CNG metering
  - Deactivation system for the standard valvetrain
  - Revised PFI intake and exhaust ports
  - Simulation of check valves and combustion system
  - Control system for fueling and pumping modes



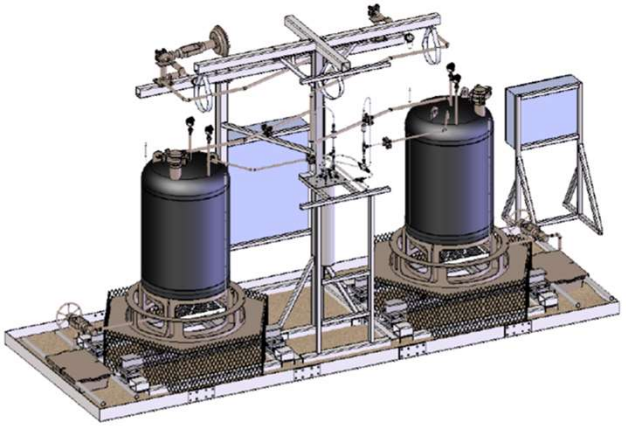


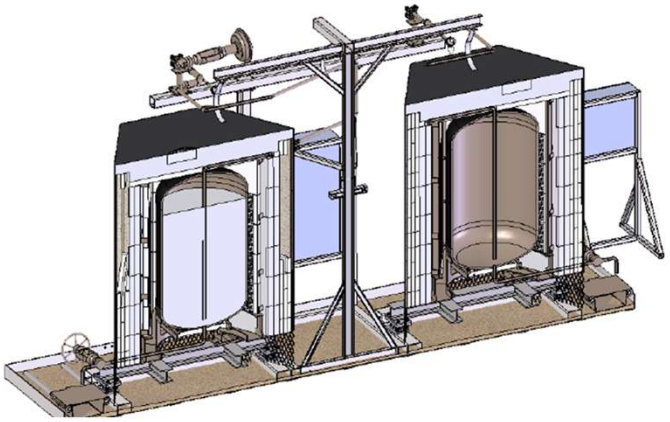
- Paired two rapid development engine controllers with stock ECU to achieve dual mode operation
- One rapid development controller functioned as an Injector drive module for both modes of operation while the other functioned as a master controller during compression mode.
- Utilized model based controls development on both controllers
- Both controllers accessed stock engine OBD2 bus for monitoring health of stock ECU and vehicle sub systems

arpa·e U.S. DEPARTMENT OF ENERGY

Test Rig for 800º C Molten Salts

- Springs Fab and Czero won a competitive research project with the NREL SunShot program to push the boundaries of energy storage for solar power concentration.
- Czero designed the test rig to evaluate thermal energy storage components for higher-temperature molten salt systems.
- The system components needed to withstand sustained temperatures of 1,500 °F (815°C) created by an array of mirrors concentrating sunlight on a heliostat that heats salt to a molten state to store the sun's energy.





NREL NATIONAL RENEWABLE ENERGY LABORATORY

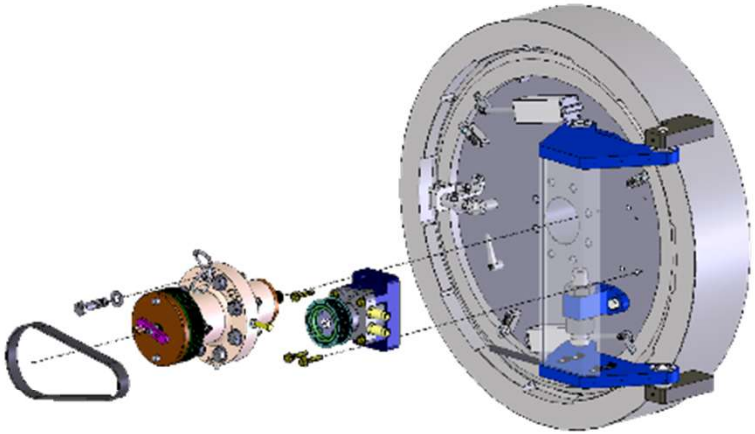
SPRINGS FABRICATION

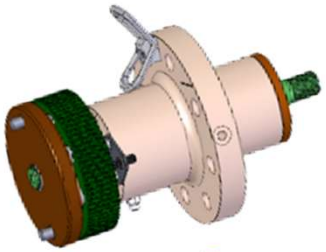
This technology represents an important step in making solar-powered energy plants more competitive with those powered by fossil fuels.

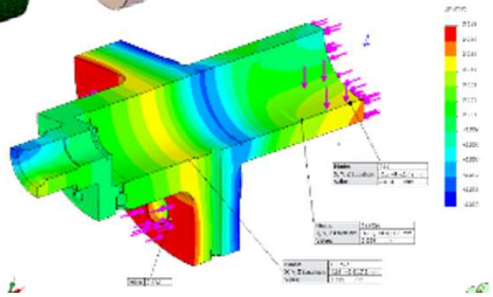
CO2 Based Cleaning Machines

Czero supported the design and development of a novel CO2 based garment cleaning system

- Designed and built first double door commercial laundry system (2011) as virtual Engineering team
- Responsible for full drum design and development as well as closed loop process system for CO2
- Czero continues to support CO2Nexus Engineering
- Multiple patent applications filed





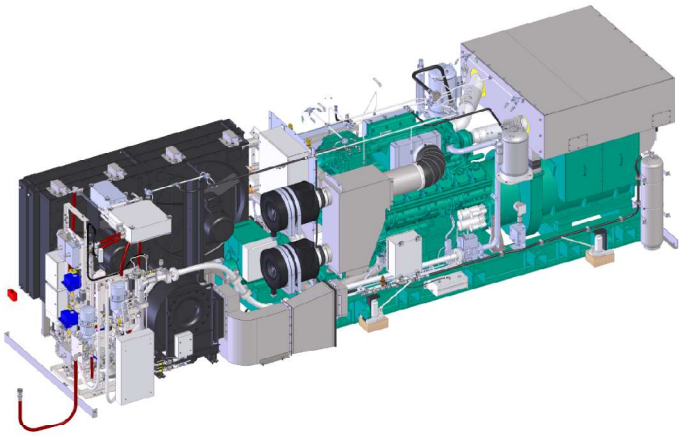


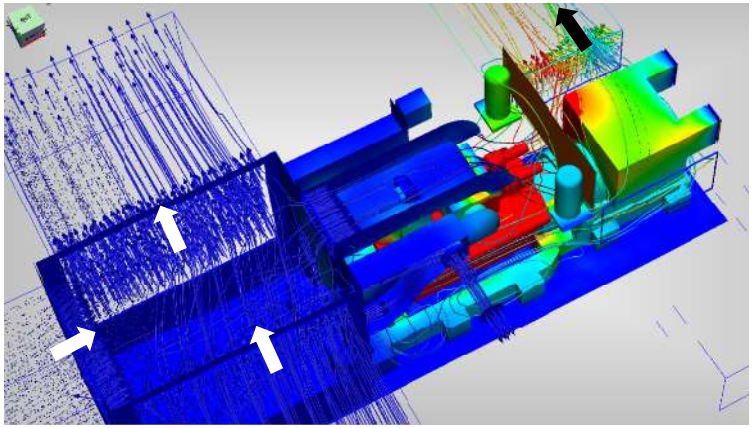
TERSUS SOLUTIONS

Natural Gas Genset

Czero designed a novel CNG tender car system for diesel-electric locomotives:

- Developed containerized custom genset, with a Cummins QSK60 (1.5MW) engine, to supply electrical power fueled by bank of CNG tanks
- Designed and analyzed thermal management system
- Designed and developed control system to manage locomotive operation and auxiliary power input





- Complex systems integration and packaging of custom genset and all ancillary systems into 30’ ISO container
- Successfully operating in field tests with Bright Rail Energy

Thank you for your time!

Please contact us:

GuyBabbitt
Chief Executive Officer
(970) 372-5775
(719) 331-9662 (cell)
guy.babbitt@czero-solutions.com
www.czero-solutions.com

1306 Blue Spruce Drive, Fort Collins, CO 80524
(970) 325-5735

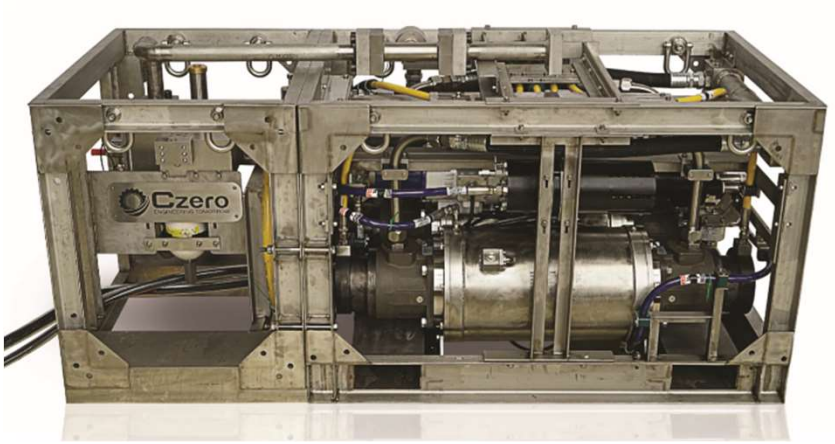
ADDITIONAL CZERO PROJECTS

Subsea Hydraulic System

Czero was enlisted to design a prototype subsea pump assembly for oil drilling systems.

- Integrated pumps, valves, and regulators with control system:
  - Subsea environment
  - Extremely high-pressure demands
  - Redundant system for fail-safe operation

- The system has been successfully tested and is undergoing evaluation for next steps.

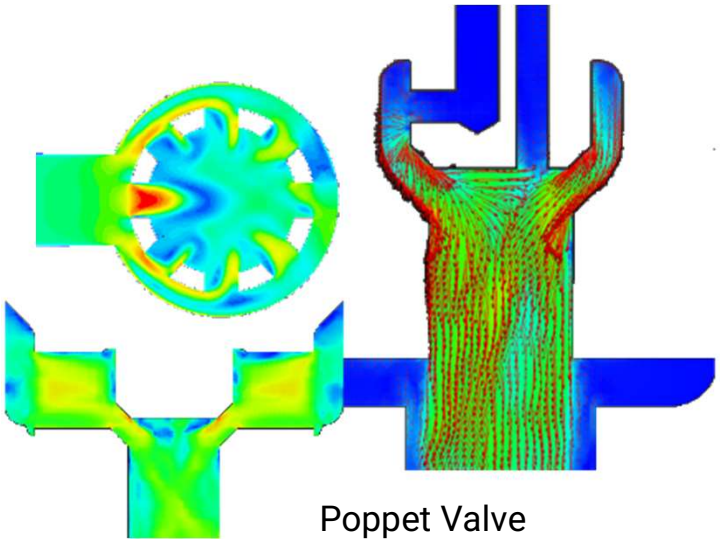


Hydraulic Valve CFD

Czero utilizes CFD to model flow characteristics/forces within hydraulic valves. Results are integrated into higher level dynamic models and used to inform the final valve design

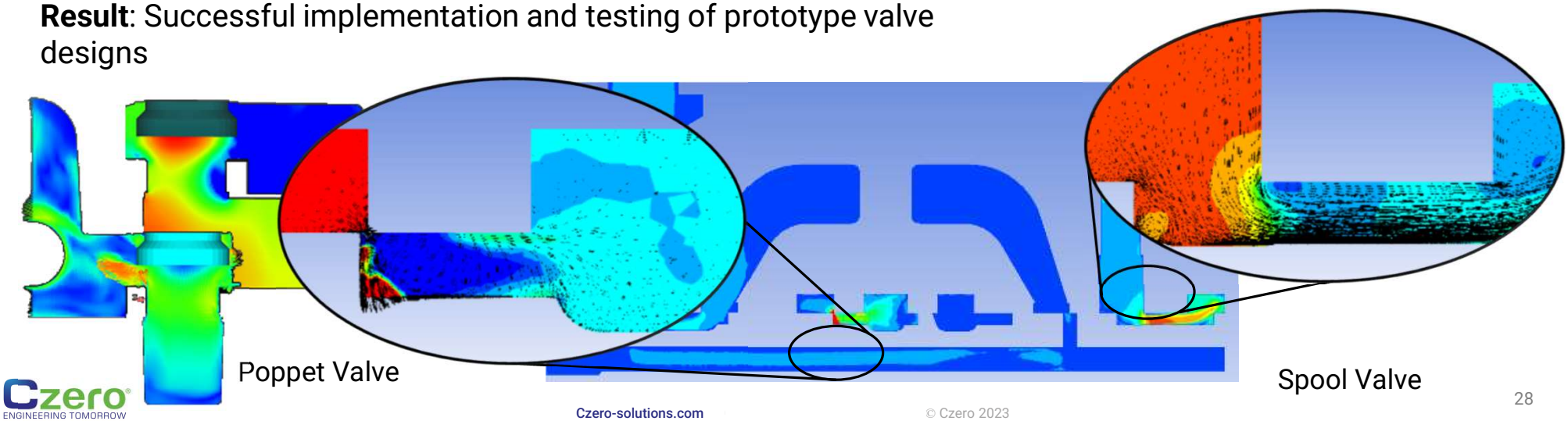
Design Challenges:

- Seek resolution of detrimental performance factors (oscillating/high flow forces, instabilities, cavitation, etc.)
- Provide modeling and test recommendations to correlate analytical and empirical data.



Poppet Valve

Result: Successful implementation and testing of prototype valve designs



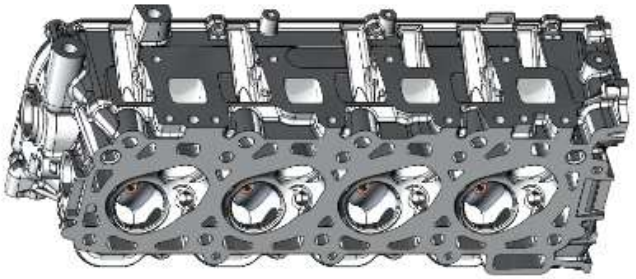
Poppet Valve

Spool Valve

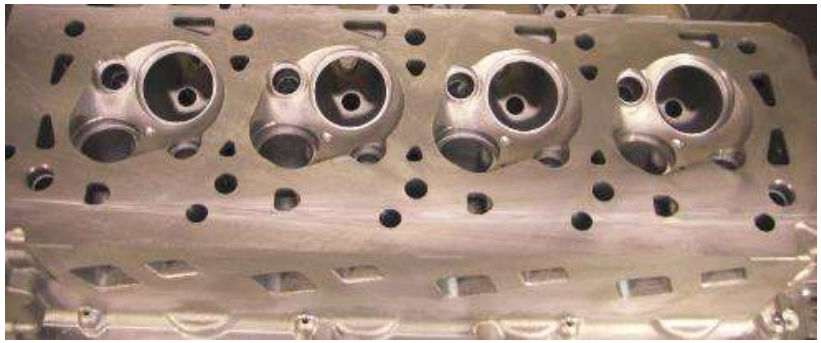
Custom Cast Cylinder Head

Baseline Part

Scanned Model



Detailed Model



Machined Part

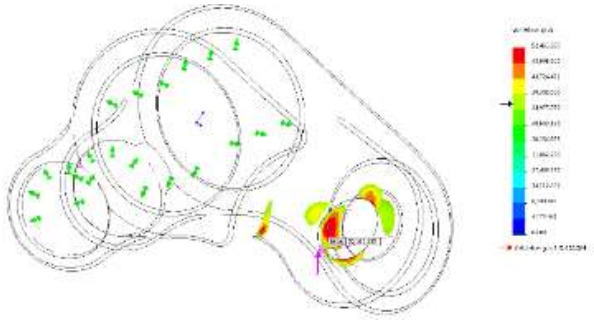
Assembled Head

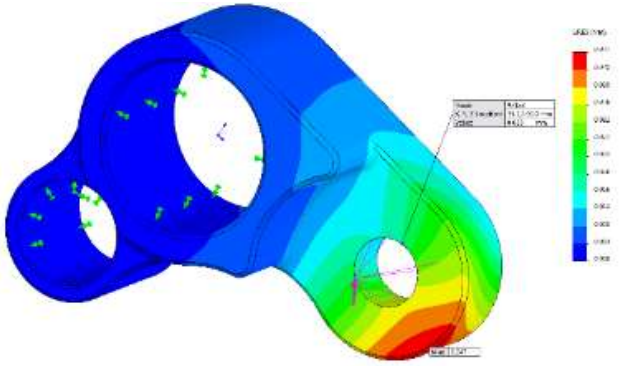
Custom Valve Deactivation System

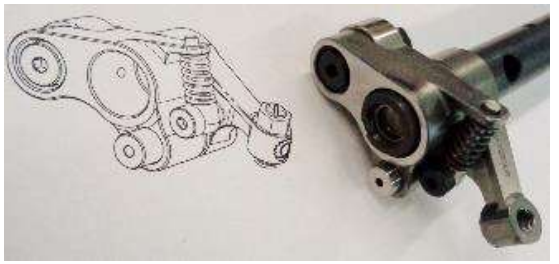
Design Challenge: Redesign the valve rockers to allow deactivation of the inlet and exhaust valves

- Rocker arm design
- Hydraulic actuation system
- Shaft mounting
- Integration into cylinder head

Result: Success demonstration of the system on the prototype Phase 2 engine, accumulating run time without failure



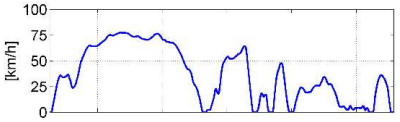




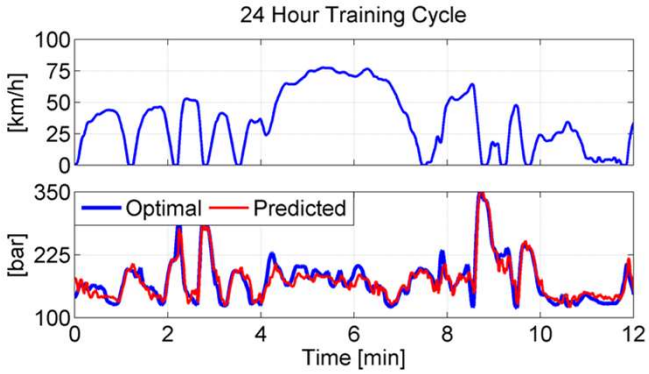
Implementable Power Management

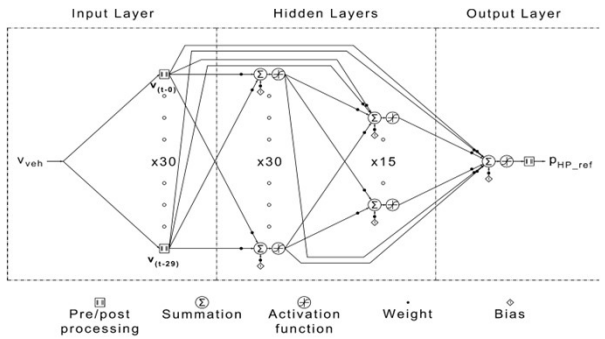
Neural Networks can be trained to generalize the DP control strategies and then use this knowledge to predict the near optimal control of hybrid vehicles for new and untrained drive cycles

This NN strategy was evaluated on a HIL test rig and demonstrated considerable fuel savings over baseline controls

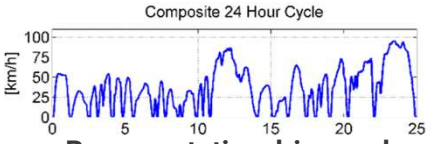


Training cycle velocity

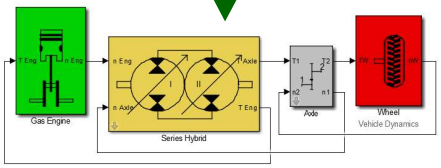




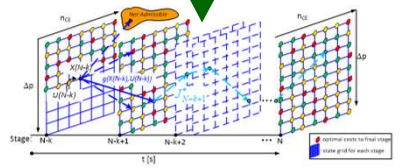
Predictive neural network



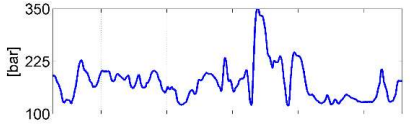
Representative drive cycle



High fidelity simulation model



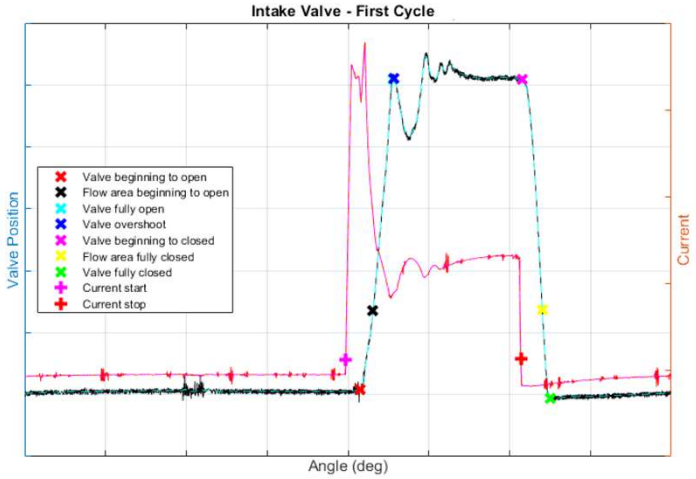
Optimal control via DP

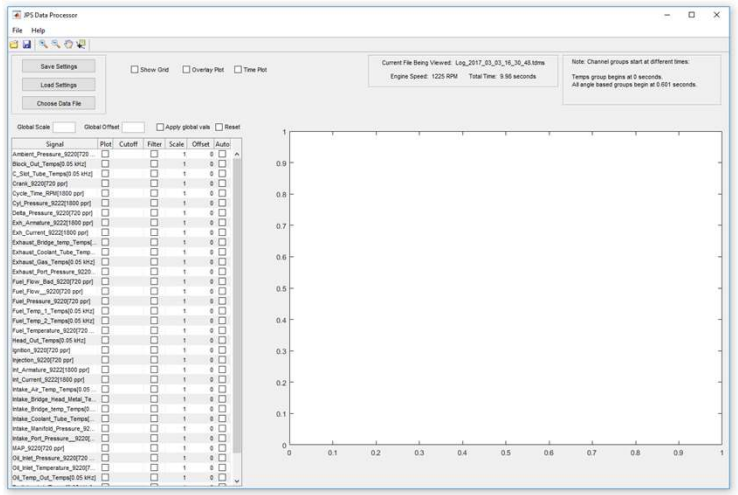


Training cycle optimal pressure

Engine Dynamometer Data Reduction, Analysis, and Visualization

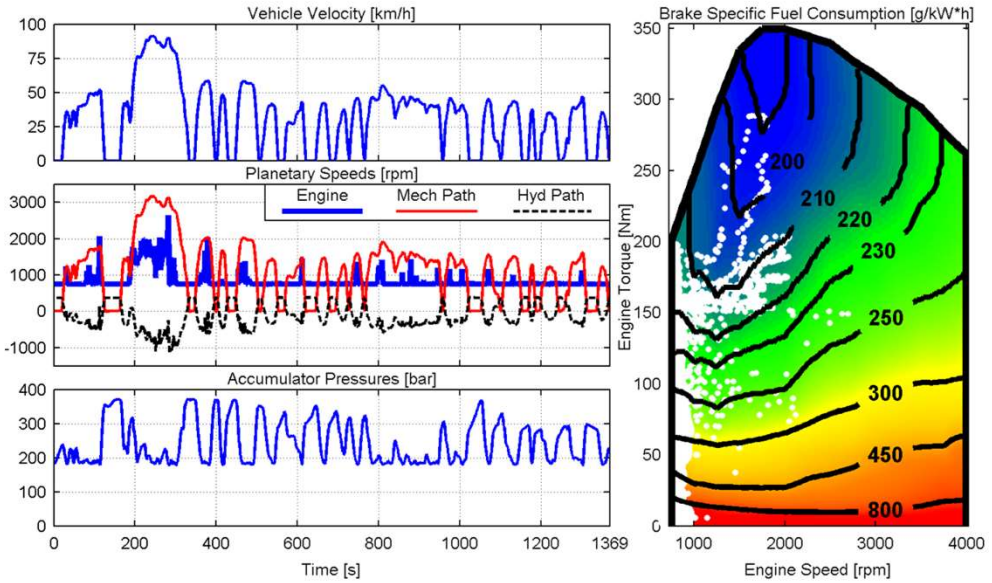
- Developed a standalone executable for a client using MATLAB to process, analyze, and visualize data collected on engine hardware and dynamometer (also developed by Czero)
- Standalone executable allowed engineers without MATLAB on their computer to process and evaluate dynamometer data
- Graphical User Interface simplified workflow and increased productivity



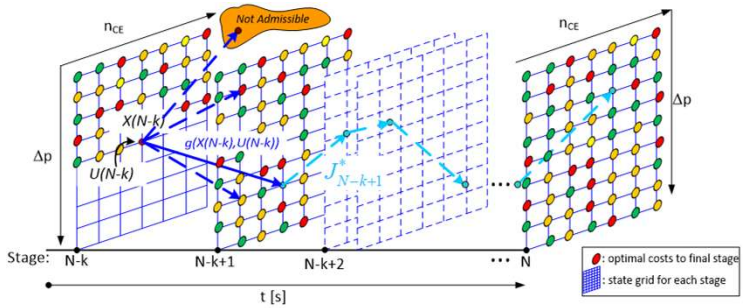


Globally Optimal System Control via Dynamic Programming

- Remove the influence of control on system performance enabling an unbiased comparison of multiple system architectures and component sizings
- Help ensure that the system with the greatest inherent potential is selected early in the design process
- Determine a system's maximum possible performance
- Discover effective, but perhaps counterintuitive, control schemes
- Provide a baseline for comparing implementable control strategies



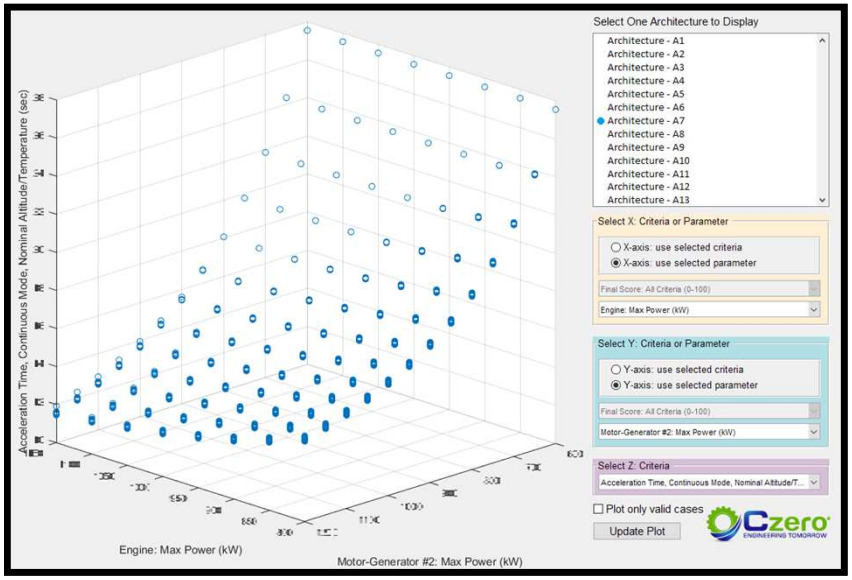
Globally Optimal Control Trajectories generated by Dynamic Programming



Powertrain Architecture Trade Tool for Heavy Tracked Vehicles

Czero developed a powertrain architecture trade tool to evaluate the next generation of hybrid powertrains for heavy tracked vehicles for GDLS (presented at SAE in 2019)

- Modular structure permitted rapid evaluation of 10+ powertrain topologies
- 50+ dynamic evaluations and 100+ weighted outputs
- Plant models developed in MATLAB Simulink
- All models controlled using instantaneous optimization algorithms
- Trade tool, data reduction, and visualization routines all developed in MATLAB



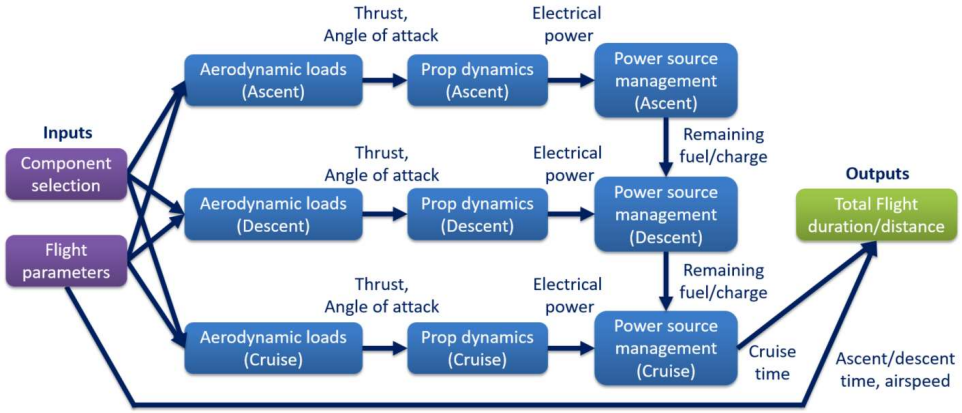
Joint Tactical Aerial Resupply Vehicle (JTARV) Range Extension Study

Czero performed study as a third-part subject matter expert for a prime contractor for Army Research Laboratory

Scope of Work:

- Industry COTS Powertrain Survey
- Aerodynamic Load Study
- Prop Dynamics Analysis
- Power Management Study and Algorithm Development
- Powertrain Evaluation

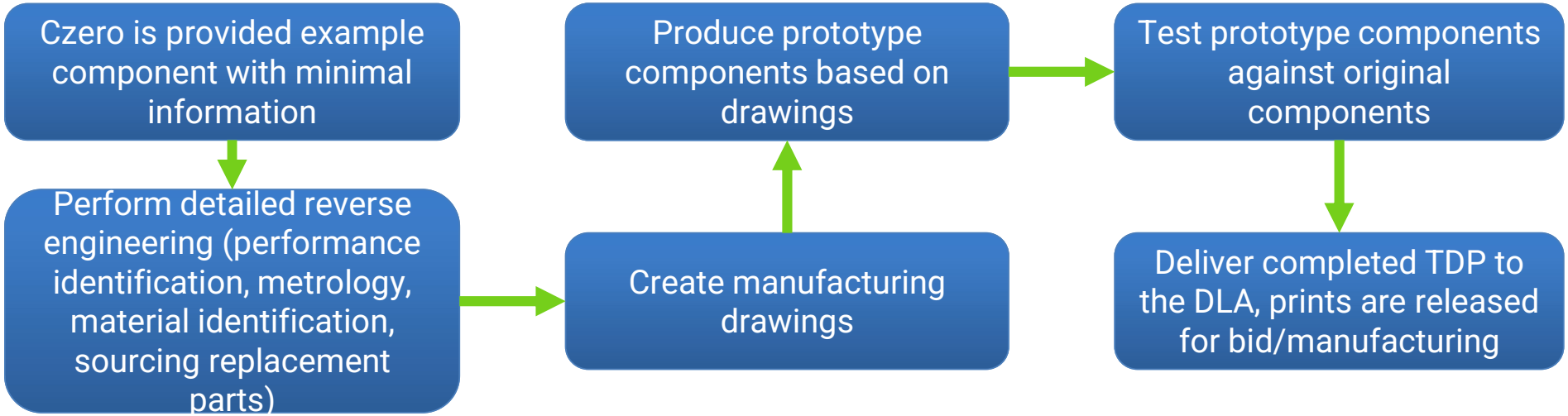
Result: Established performance benchmarks with respect to range and endurance and achieved other SOW objectives



Aerospace Components Sustainment Engineering

Czero provides reverse engineering services to the **Defense Logistics Agency**

With minimal starting information Czero can create full manufacturing prints for components which cannot be procured by other means



Sustainment Engineering

Czero provides reverse engineering services to the DOD through the Defense Logistics Agency (DLA)

Reverse Engineering

Czero reverse engineers aircraft parts for the DoD through the Defense Logistics Agency (DLA)

Natural Gas Fuel Skid

The Bright Rail Energy system required a custom fuel skid to accommodate a wide range of temperatures and flow requirements.

Czero was responsible for design and build of the entire skid:

- Fuel Inlet Conditions:
  - Gas temperature: -30°C to 40°C
  - Gas pressure: 300psi to 3,250psi
- Fuel Outlet Requirement:
  - Fuel Flow: 2,210SCFH to 14,500SCFH
  - Fuel Pressure: 4.8psi to 6psi
  - Fuel temperature: 5°C to 50°C

BRIGHT RAIL ENERGY™
NATURAL GAS LOCOMOTIVE POWER

Parametric Table

Valve Sizing | HX Design | Table 2

	Q [ft3/hr]	$Perc_{open1}$	$Perc_{open2}$	$Perc_{open3}$	$Perc_{open4}$	$T1_{Ci}$ [C]
Run 1	14500	5.439	10.58	32.1	85.61	-15
Run 2	8170	3.065	5.964	18.08	48.24	-15
Run 3	4420	1.658	3.226	9.784	26.1	-15
Run 4	2210	0.829	1.613	4.892	13.05	-15

Equations Window

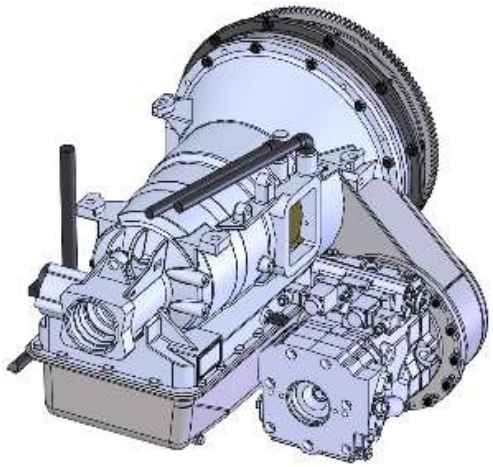
```
PROCEDURE Valve_Fun(P1,P2,T1_C,Q,Cv_valve:T2_C,C_v,Perc_open,P2_cr)
    "Define the variables called from the main function"
    $Common C_f, Fluid$

    "Preliminary calcs"
    DELTAP = P1-P2

    "Calculate y"
    IF (1.63/C_f*sqrt(DELTAP/P1) < 1.5) THEN
                                        y := 1.63/C_f*sqrt(DELTAP/P1)
    ELSE
                                        y := 1.5
    "Choked flow case"
    ENDIF

    "Calculate temperatures"
    T1 = ConvertTEMP(C,R,T1_C)
    h = Enthalpy(Fluid$,T=T1,P=P1)
    T2 = Temperature(Fluid$,P=P2,h=h)
    T_ave = (T1+T2)/2
    T2_C := ConvertTEMP(R,C,T2)

    "Calculate gas specific gravities"
    rho = Density(Fluid$,T=419.67[R],P=14.7[psia])
    rho_air = Density(Air_ha,T=419.67[R],P=14.7[psia])
    SG = rho/rho_air
    {SG = 0.8}
    mw = MolarMass(Fluid$)
    mw_air = MolarMass(Air_ha)
    SG2 = mw/mw_air

    "Calculate the flow coefficient for the valve in the current state of flow"
    C_v := Q*sqrt(SG*T1)/(834[ft^3*R^0.5/hr*psia]*C_f*P1*(y-0.148*y^3))
                                        "Q [SCFH]"
                                        "T [R]"
                                        "P [psia]"
```

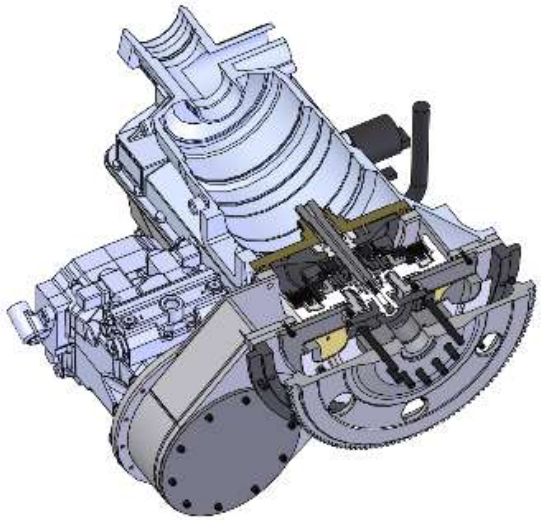
Detailed analysis of gas flow and temp across a wide operating range

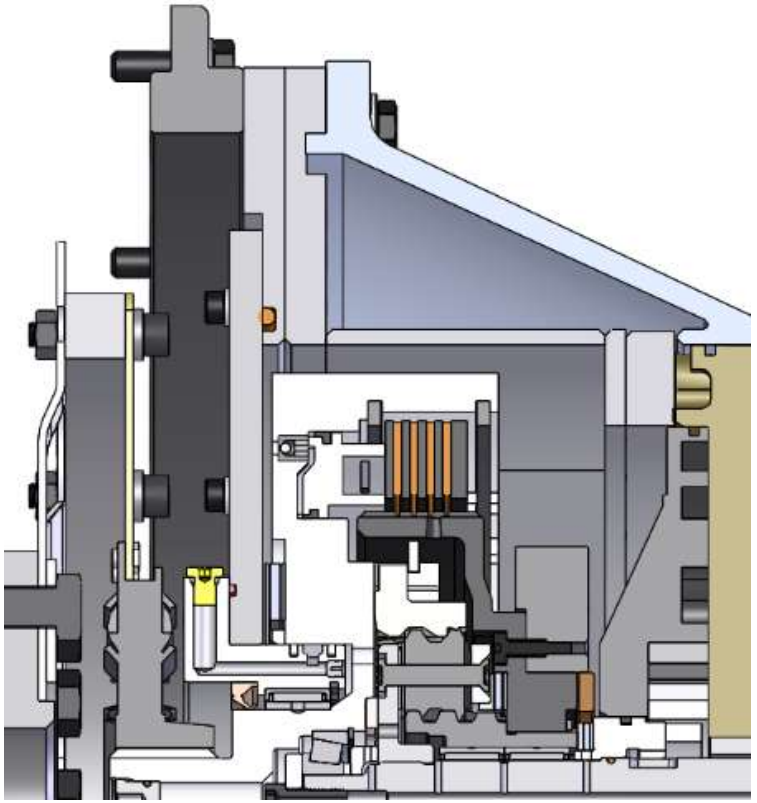
Hydraulic Hybrid - Gen II

Modification to Allison transmission only required new case and oil pump housing. Other custom-made components resulted in elimination of the torque converter and split torque hybrid operation (only design work done to prints, not manufactured)

(Patented)







Fuel Injectors