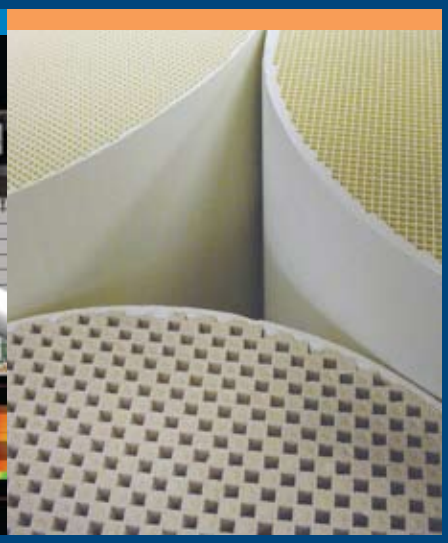
Diesel Engine Emissions Experience and Capabilities

Donaldson®



Donaldson utilizes advanced emissions technologies in the areas of model-based transient control, on-board dosing, system diagnostics, thermal management, acoustic performance, flow distribution, product durability and system integration.

We have high efficiency and cost-effective solutions for a wide range of applications.

Donaldson has the knowledge and capability to be your single resource for tailpipe and crankcase diesel engine emission solutions.

Donaldson®

History of Innovation

1950s

When exhaust was about silencing -- we led the way! Frank Donaldson sold enough mufflers in 1951 to open an exhaust manufacturing facility in Grinnell, Iowa in 1952.

1960s

In the 1960s, sound meters were used to measure noise levels (see image on right). Donaldson is one of the first manufacturers to introduce the use of aluminized steel in exhaust systems.

1970s

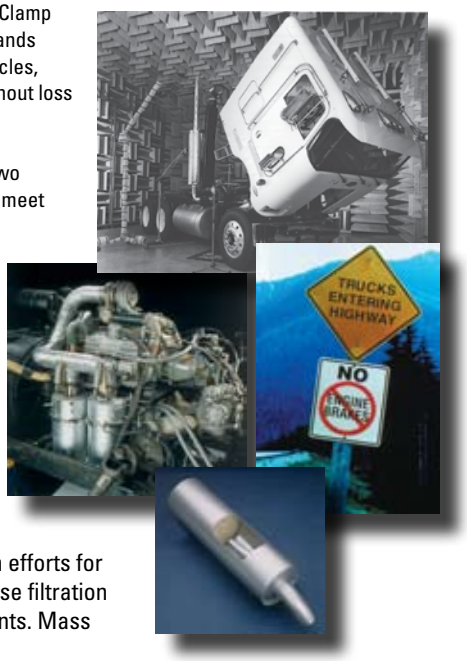
Donaldson introduces mufflers with integrated ejectors and wrapped mufflers. Wrapped mufflers reduced the overall exhaust system noise and the exterior body temperature. Donaldson SealClamp band-style exhaust clamp launched into the marketplace. Donaldson expands to Japan. In 1973, U.S. noise regulations went into effect for on-road vehicles, Donaldson offered a muffler line that was effective at noise reduction without loss of horsepower.

1980s

In 1981, Donaldson opened a new technical center. The center included two anechoic chambers which expanded our technical capabilities. Mufflers meet 1988 U.S. EPA truck noise regulations (sonic chokes and floating baffles)

1990s

When engine manufacturers needed help to meet the first U.S. Emissions regulations, innovations continued. In the early 1990s, we pioneered the design of integrated catalytic converter mufflers and diesel particulate solutions for three major U.S. engine and truck manufacturers. In the late 1990s, Silent Partner was the first muffler that effectively reduced engine brake noise without loss of power or fuel economy. During this decade, Donaldson expands exhaust manufacturing in Europe (France); Mexico (Guadalajara); and the United States (Alabama).



Since the early 1990s, Donaldson has sold more than a million DOC Mufflers.

2000s

2001 Donaldson forms a group dedicated to emissions reduction efforts for diesel engines; begins retrofit projects; Spiracle™ crankcase filtration introduced to eliminate emissions from open crankcase vents. Mass production of CCM for on-road OEs begins.

2002 First of many CARB and EPA verifications for Donaldson retrofit emissions solutions; first company to verify tailpipe and crankcase solution.

2003 Donaldson expands exhaust manufacturing in Aguascalientes, Mexico.

2004 Donaldson upgrades and expands heavy-duty engine test cell capabilities; U.S. MSHA accepts Donaldson high temp exhaust filter. New web-based Emissions Resource Center (www.donaldson.com/en/erc).

2005 DPF Cleaning System and DMF Muffler launched for retrofit market. Donaldson introduces an active, smart DPF emissions solution for the most difficult duty cycles; low temperature, transient and extended idling.

2006 Donaldson expands European emissions staff and Mexico exhaust manufacturing to Monterrey; Donaldson selected as emissions packager for medium-duty diesel OE; Donaldson improves Stepped SealClamp.

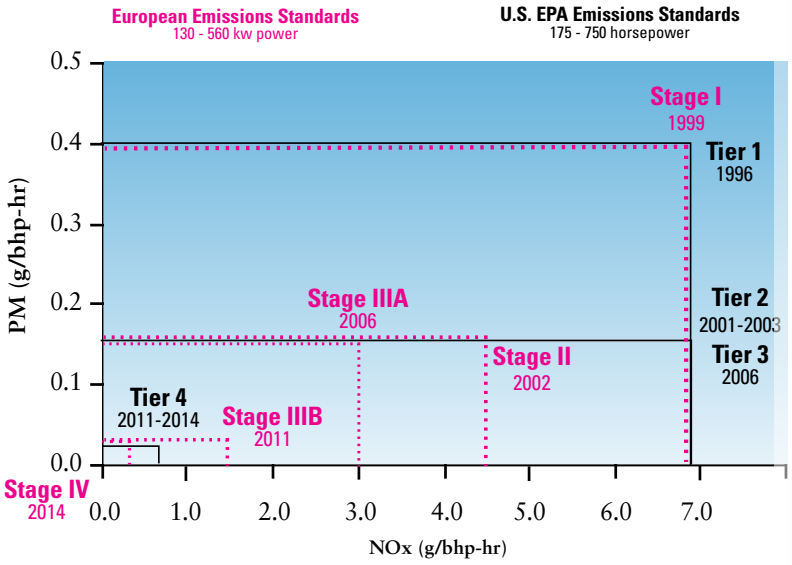
2007 Donaldson expands OE emissions support with production of an active system to meet 2007 emissions regulations.

Donaldson
your one-stop **Emissions Solutions Provider**

When looking for a supplier that understands heavy-duty diesel engine aftertreatment and knows what it takes to package emissions devices, Donaldson is a powerful resource.

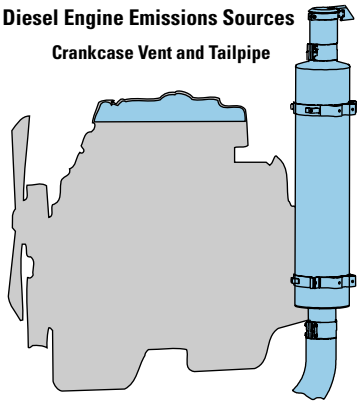
Now that on-road vehicle manufacturers have rolled out their 2007 solutions, off-road vehicles are the next industry challenge.

U.S. & European Off-Road Emissions Standards



Diesel Engine Emissions Sources

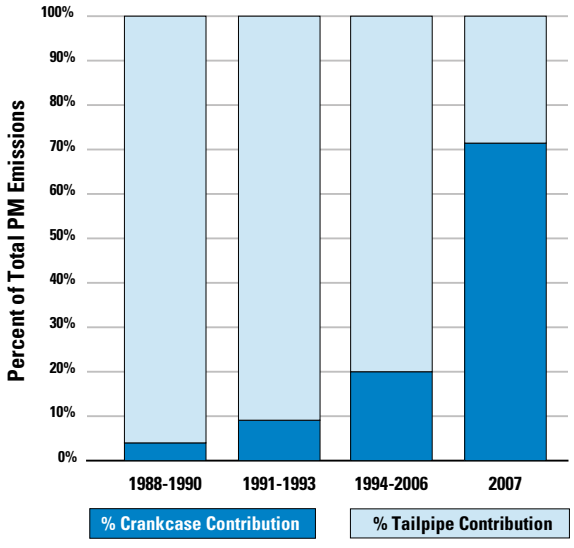
Crankcase Vent and Tailpipe



As tailpipe emissions are reduced, the crankcase emissions become the larger percentage of the two sources.

Patented* Tailpipe and Crankcase Solutions

There are two emissions sources in diesel engine applications - the crankcase ventilation system and the tailpipe. Independent tests on on-road engines have shown that 10-25% of engine emissions are generated from the crankcase. In 2007 model year engines, the crankcase emission contribution accounts for more than 70%!



* Reference: Donaldson Jan 03, 2008 announcement

Original Equipment Experience

Markets Served

- Medium- and Heavy-duty Truck and Bus
- Construction
- Industrial
- Mining
- Agriculture
- Military/Defense

Technology

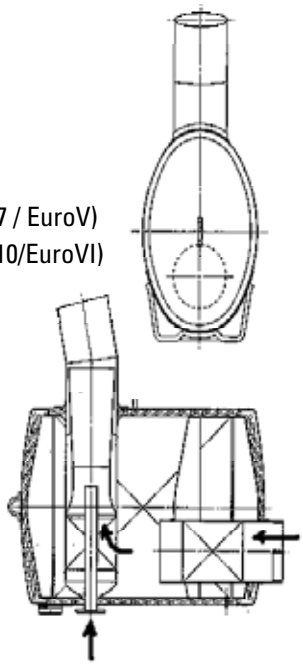
- PM and NO_x Control
- Emission Reduction Control Integration - SCR NO_x and DPF PM
- Active and Passive Filter Regeneration
- Filter Loading Characteristics
- Model-based, Adaptive Active System Control
- Active Dosing Systems
- Component Development
- Flow Distribution
- Thermal Management

Products

- Emission Control Systems
  - EPA 2007 /EuroV complete active DPF system including: controller, fuel injection system, catalyst/ muffler and wiring harnesses
  - EPA 2010 / Euro VI Active DPF system and system integration for SCR
- Emissions Products
  - Heavy- and medium-duty DOC's
  - EPA 2007 DPF packaging
- Spiracle™ Crankcase Filtration System
- DPF Cleaning System
- Acoustic
  - mufflers, resonators, ejectors, spark arrestors
- Exhaust Systems
  - stanchions, heat shields, clamps, mounting brackets and exhaust tubes

Experience

- Emissions Packaging
  - DOC's
  - Active DPF's – 2007-forward
- Emissions Systems
  - Active DPF System (EPA2007 / EuroV)
  - Integrated DPF/SCR (EPA2010/EuroVI)
- Acoustics
  - Noise-compliant mufflers
  - Low frequency attenuators
  - In-cab noise reduction
  - Insulated mufflers
  - Structurally enhanced designs for off-road
  - Scavenged systems to enhance air filter life

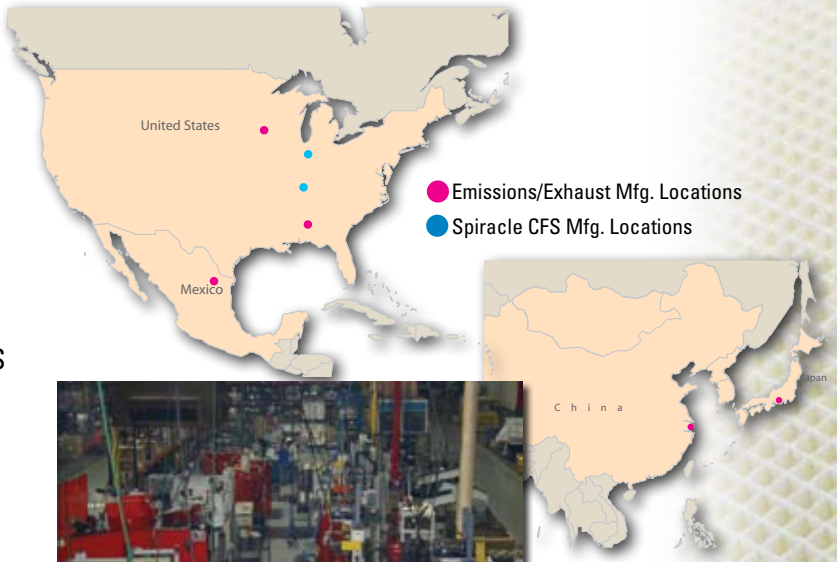


Emissions Manufacturing

N. America, Europe and Asia

Global Production Facilities

- United States, Mexico, Europe, China and Japan
- TS16949 & ISO9000 Certified facilities



Base Component Materials

- Built for long-life, durability and corrosion resistance
- Aluminized and non-aluminized 409 SS plus other materials

Quality Controls

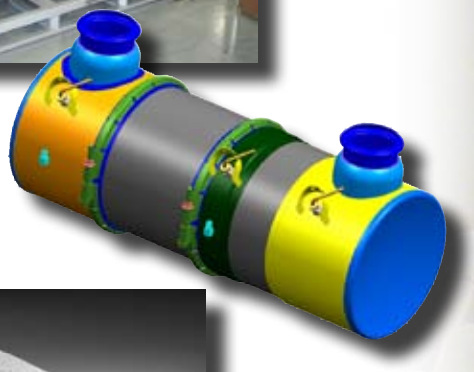
- Consistent, reliable product
- PLC controls are part number specific
- Each assembly is identified with manufacturing dates and lot codes (or serialized) for tracking and warranty purposes.

Packaging Options

- Returnable packaging
- Heavy-duty packaging, bulk or individually boxed
- Pallets ISPM-15 compliant for international routing

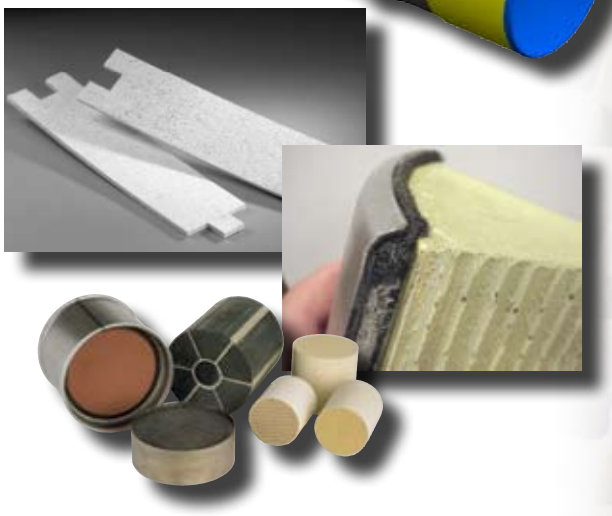
Filters/Substrates

- Diameter ranges from 7.5" to 12.5" with capability for smaller and larger sizes
- Experience with ceramic (standard and thin wall), SiC and metallic substrates



Filter Packaging

- Unique manufacturing techniques that hold, seal and insulate the filter within the can.



Product Identification Options

- Serialization
- Pin-stamping
- Metal tagging
- Bar coding

Development Tools

Prediction & Simulation

Filter Regeneration Model

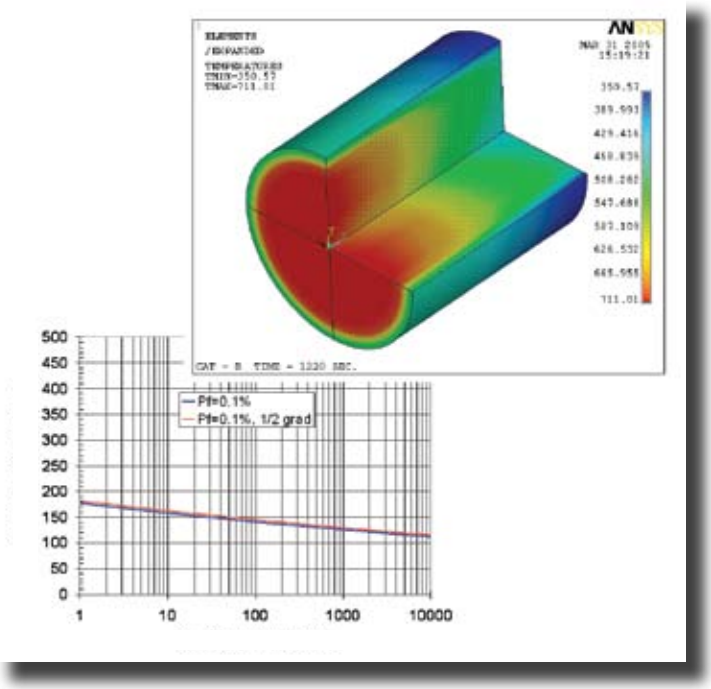
- Enables accurate simulation and prediction of the DPF regeneration process
- Models heat transfer, fluid flow and species reactions in multi-dimensional, time-dependent fashion

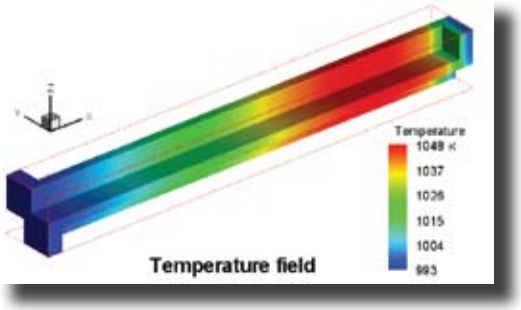
Filter Durability Model

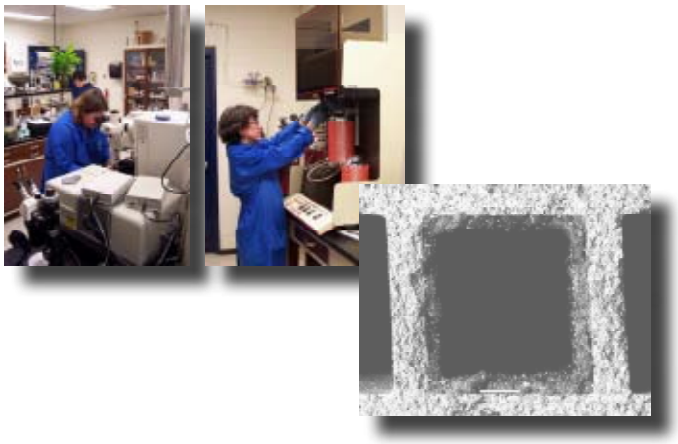
- Used to determine filter life and reliability
- Use ultrasound to assess filter integrity

Chemical Analysis Test Benches

- NO_x bench conducts dynamic evaluation of NO_x loading and regeneration
- Ammonia (NH_3) bench used for dynamic evaluation of NH_3 loading and regeneration
- Sulfur dioxide (SO_2) bench performs dynamic evaluation of SO_2 loading and regeneration.
- Volatile Organic Compounds (VOC) bench dynamic evaluation of NO_x loading and regeneration
- Temperature Programmed Desorption (TPD; TGA-MS) - catalyst activity, loading and desorption profiles as a function of temperature







SEM of Soot Cake inside filter channel

Engine Test Cells

Product Performance

Engine Test Cells

- Measurement of gaseous and particulate emissions
- Measurement of on-engine aftertreatment and acoustical performance
- Component durability
- Multiple Test Cells - Europe and U.S.

Test Cell Capability

- Computerized steady state and transient test cycles
- Up to 2000 hp absorbing dynamometer
- Multi-channel data acquisition in each test cell
- 24/7 durability testing
- Web-based test cell monitoring

Exhaust Gas Benches

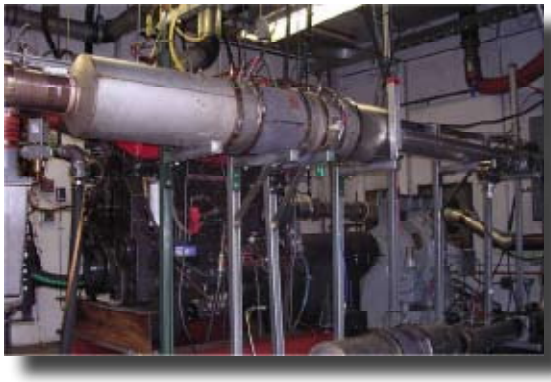
- Measurement of CO, CO_2, NO_x, O_2 and HC

FTIR Analyzer

- Allows transient speciation of gases for aftertreatment development
- Quantifies multiple gas species including NO, NO_2, N_2O, and NH_3

Sierra Instruments BG-3 PM Sampler

- Measures steady state and transient particulate matter emissions



Development Tools

Product Durability

Prediction and Simulation

Finite Element Analysis

- Models stress on components and assemblies
- Capable of dynamic analysis to determine resonance frequencies and modes

Experimental Modal Analysis Software

- Determines modal properties of structures

Test and Evaluation

Vibration Tables

- Use shakers to excite hardware to assess durability
- Can apply sine, random, or shock vibration input
- Capable of running hot or cold tests
- Multiple tests cells - U.S. and Europe

Thermal Aging Test Bench

- Allows transient flow and temperature control for thermal aging and durability analysis
- Ability to simulate full flow engine conditions
- Multiple benches - U.S. and Europe

Ultrasound Analyzer

- Allows non-destructive evaluation of filter integrity

Tensile/Compression Tester

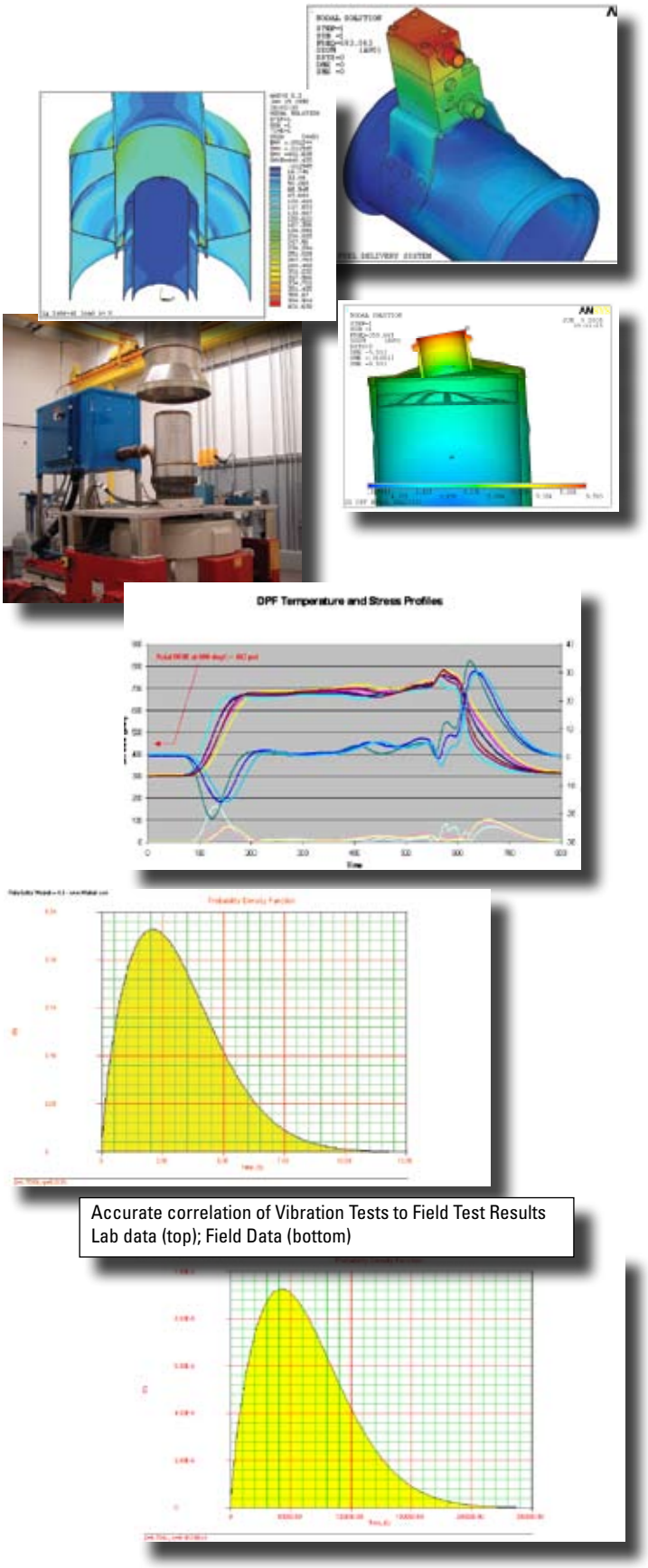
- Used to test material properties

Environmental Chambers

- Allows testing at hot or cold temperature, with humidity control and salt spray

Field Data Acquisition System

- Collects data from field tests
- Allows analysis of acceleration, strain and pressure to develop vibration test profiles



Accurate correlation of Vibration Tests to Field Test Results
Lab data (top); Field Data (bottom)

Development Tools

Flow and Thermal

Prediction and Simulation

Fluid Modeling

- Predicts performance of components
- Predicts fluid flow, pressure loss, flow distribution, velocity ranges, thermal gradients and dispersion

Fluid Flow

- Predicts performance of systems by component
- Predicts fluid flow, pressure loss, flow velocity, flow rates and heat transfer rates
- Considers transient and steady-state flow

Backpressure Modelling

- Predicts pressure drop of muffler designs due to internal component changes
- In-house proprietary software

Test and Evaluation

Flow Test Bench

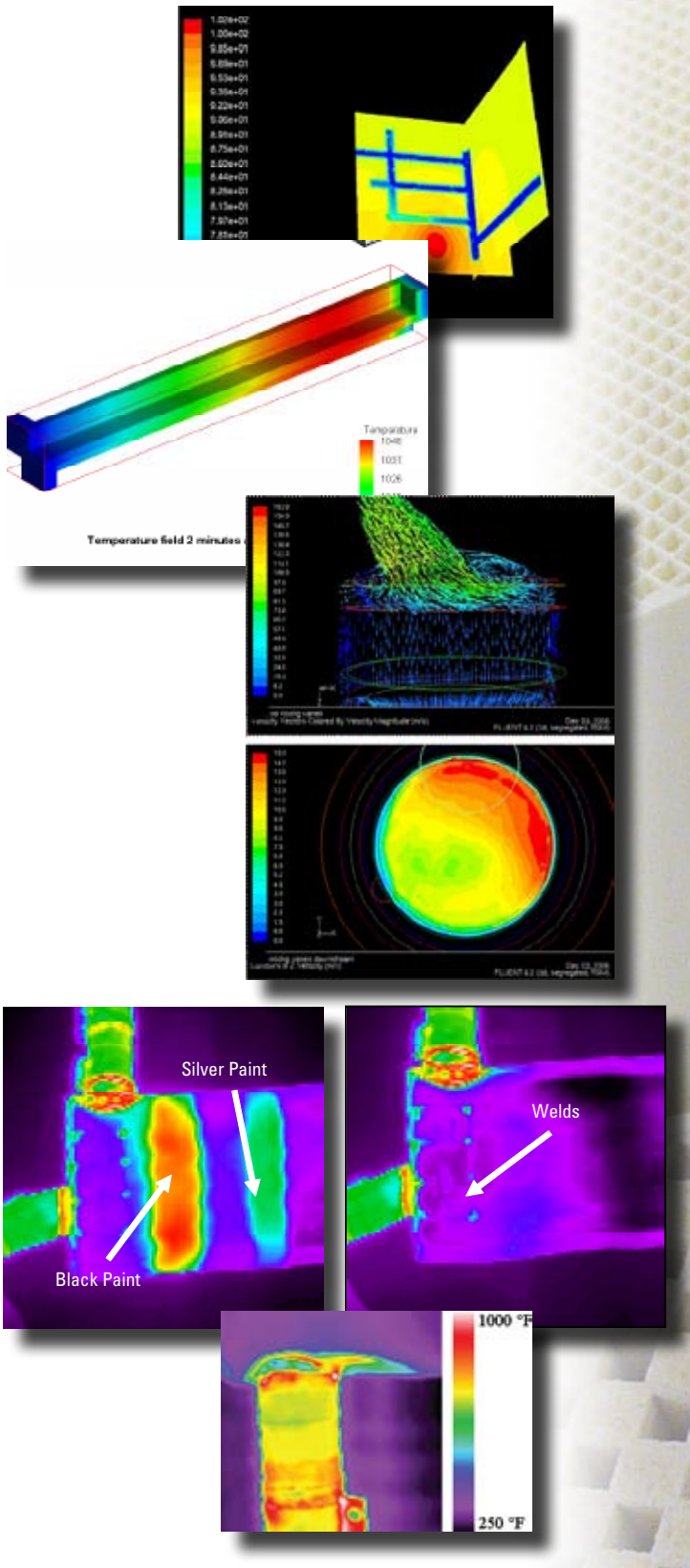
- Allows measurement of the flow distribution or backpressure for an emissions device
- Allows calculation of device backpressure at varying flows and temperatures

Vehicle/Engine Dynamometers

- Used to validate performance and durability

Infrared Imaging

- Analyzes effect of insulation on surface temperatures
- Allows thermal analysis of an object's surface



Development Tools

Acoustic

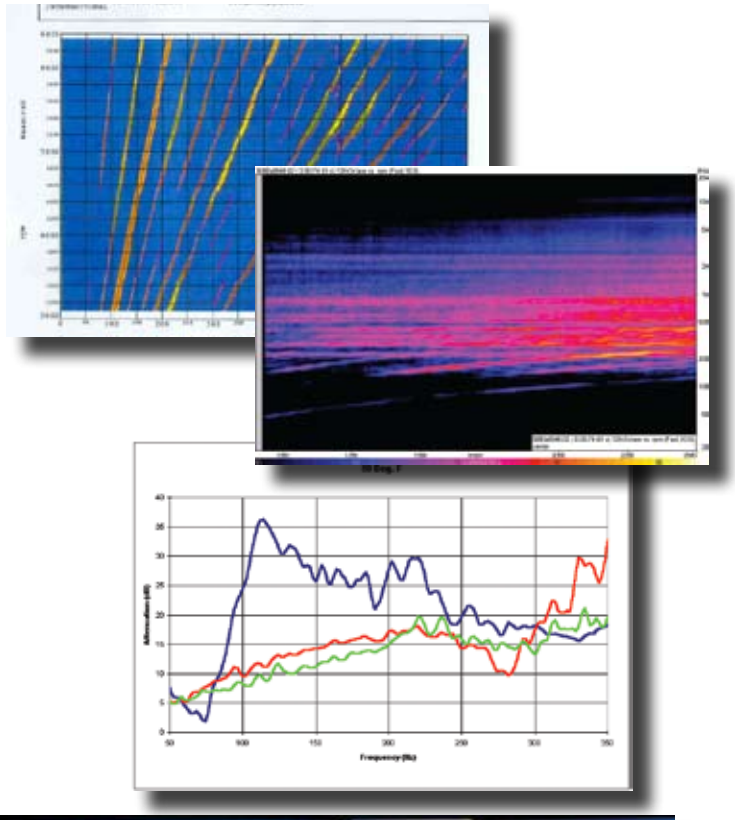
Prediction and Simulation

Linear Acoustic Analysis

- Engine simulation tool
- Enables prediction of transmission loss (noise reduction) of a given design
- Reduces development time and prototype costs

Finite Element Acoustic Analysis

- Enables prediction of transmission loss of a given design
- Includes the impact of shell noise from muffler surfaces
- Works in conjunction with ANSYS for 3D analysis



Test and Evaluation

Hemi-anechoic Chambers (2)

- Used for transmission loss analysis
- LMS sound quality software

HEAD® Acoustics

- Used for sound quality analysis
- Evaluates sound for human hearing subjective noise analysis
- Allows analysis of in-cab noise based on cab design
- Considers affects of noise frequency

Acoustic Test Cell

- Evaluates “on engine” performance of acoustic products
- Simulates SAE J366 Drive-by Test
- Accommodates customer engines
- Offers steady-state or transient control

Design Validation
Field Testing

Experience with a Wide Variety of Vehicles

- U.S. and European on-road medium- and heavy-duty trucks
- Refuse Haulers
- Special municipality vehicles; i.e., sewer vacs
- Off-road equipment

Extreme Operating Conditions

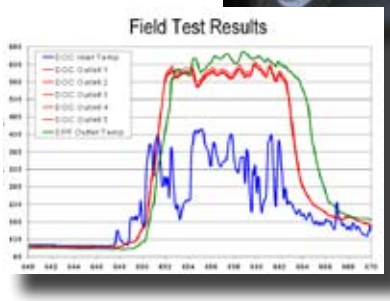
- Hot to cold climates (California, Minnesota and Canada)
- High and low altitudes

Data Collection

- Filter weight
- Visual and mechanical inspection
- Collect real-time data from data logger
- Operational check

Performance Monitoring

- Rapid data collection rate to collect temperature, backpressure and other system performance parameters
- Review daily, weekly and monthly reports to analyze operational trends
- Telemetry data acquisition with GPS for real-time data collection



Retrofit/Aftermarket Experience

Markets Served

- On-and off-road
- Mining
- Military/Defense
- Original Equipment Manufacturers
- Regulatory agencies/ influencers

Products

- Emission System Retrofit Kits
  - DPF Cleaning System
  - Passive: diesel oxidation catalysts (DOC), diesel particulate filters (DPF), diesel multi-stage filters (DMF) for tailpipe emissions
  - Active diesel particulate filter with fuel delivery and adaptive controls; Semi-active Exhaust Filter Muffler and active NO_x–SCR systems (in development)
  - Spiracle™ filtration system for crankcase emissions reduction
  - System accessories: backpressure monitor, mounting kits, clamps, brackets, adapters, ejectors and tubing
  - Disposable exhaust filter for mines
- Acoustic
  - mufflers, resonators, ejectors, resonators
  - clamps, stacks, tubing, heat shield, mounting brackets, reducers, connectors

Experience

- Semi-active Exhaust Filter Muffler (electric)
- Emissions Packaging
- Retrofit Emissions Products
  - DOC, DMF, LTF, LNF, DPF, Spiracle™ CFS
  - U.S. CARB and EPA Verification Procedures
- Fleet Assessment
- Retrofit Programs / Grants

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