Combustion Research Facility

SAND2018-5140C

Engine Combustion Research

Paul C. Miles
Manager, Engine Combustion Research Program
Sandia National Laboratories, Livermore, CA

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Program Overview

- Mission: Provide the combustion and emission knowledge-base needed by industry to develop high-efficiency, clean engines adapted to future fuels
  - Research spans needs from 5 to 20+ years out
- Primary sponsor is DOE Office of Vehicle Technologies (VT)
  - Program managers: Gurpreet Singh, Leo Breton, Kevin Stork, Mike Weismiller
- Supports VT engine and fuels program goals
  - Greatly improved efficiency & fuel economy (30% to 35% by 2020)
  - Emissions compliant (Tier 3, Euro 5/6 particulate number)
  - Fuel effects on conventional & advanced engine combustion
- Strong collaborations with industry, universities, and other national labs (since the start in the mid-70s)

Program Overview (cont.)

- Program research directions are aligned with DOE/industry, USDRIVE, and 21st Century Truck (21CTP) roadmaps and directions
  - Detailed research directions are modified annually in response to roadmap updates, VTO input, discussions with industry in various forums:
    - USCAR ACEC Tech Team
    - Advanced Engine Combustion MOU
    - Frequent PI to PI exchanges with partners, site visits
    - DOE VTO Annual Merit Review
- Additional sponsors (SPP) - complementary, precompetitive research: Caterpillar, Toyota, Chevron, the Spray Combustion Consortium and internal funding (LDRD)
- >30 staff, technologists, post docs, and visiting researchers
  - World experts, selected for strong fundamentals
  - Staff deeply engaged in leadership roles in the field

The Sandia program has had significant impacts on engine technology over the last 40 years

Energy crisis of the early 70s

DOE ECUT begins engine research.

Light-duty engine working groups with industry/ national labs /universities (DISC, DHC, Knock)

Heavy-duty diesel working group

Congress establishes DOE's Tech Transfer Initiative. Many CRADAs with industry established over next decade (e.g., GM, Ford, Caterpillar, Cummins, ...)

Sandia led Advanced Engine Combustion MOU – 21 industry and national lab partners

Industry engages CRF in WFOs

Engine Combustion Network - Global collaboration and leveraging

Retrospective study – $70 billion return

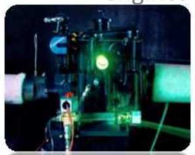
1975	1985	1995	2005	2015

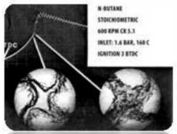
Laser diagnostic development and application in engines begins

Combustion Research Facility (CRF) opens to researchers

Alternative fuels research begins

Introduction of realistic optical engines

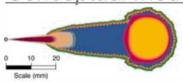




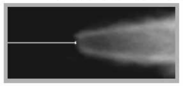
New understanding of SI engine processes developed (knock and flame propagation)

New conceptual model developed and mixing physics clarified for heavy-duty diesel combustion

Conceptual model

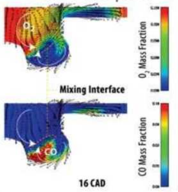


Flame lift-off

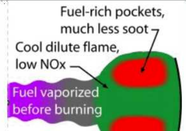


High-efficiency, clean Low- Temperature Combustion (LTC) research initiated

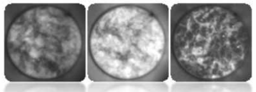
Comprehensive understanding of light-duty diesel combustion developed



Cummins develops first computationally designed engine



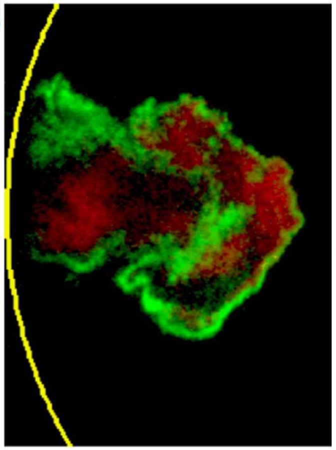
Conceptual model for diesel-LTC developed



Pathway to full load range gasoline LTC revealed

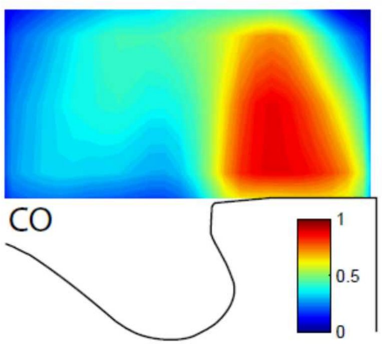
Combustion Research Computation and Visualization (CRCV) opens

Our optical diagnostic capabilities and physics-based quantitative analysis are unmatched



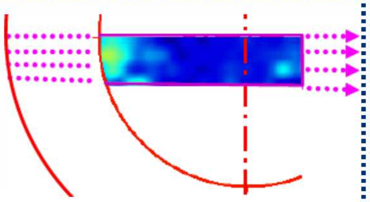
Simultaneous imaging of soot & OH (J. Dec)

RISTRA OPO technology promises 3X signal level



$$N_{CO,B} = f_v N_{CO,X}\,\sigma^{(2)}\left(\frac{I}{h\nu}\right)^2 \frac{A_{B^1\Sigma^+\to A^1\Pi}}{\sum_i Q_i + \frac{I}{h\nu}\sigma^i}$$

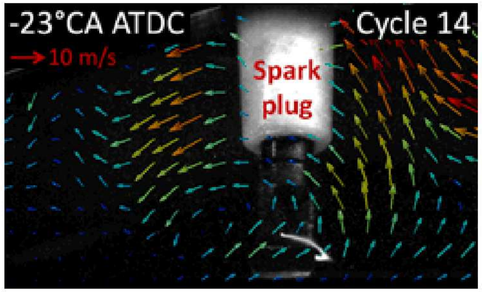
2-photon quant. CO Imaging (P. Miles/I. Ekoto)

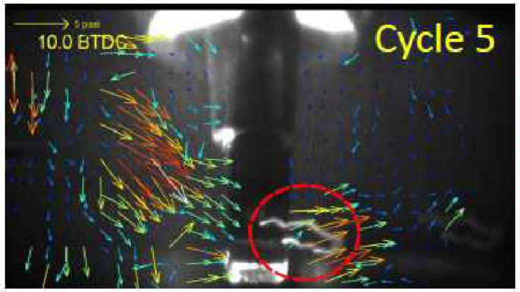


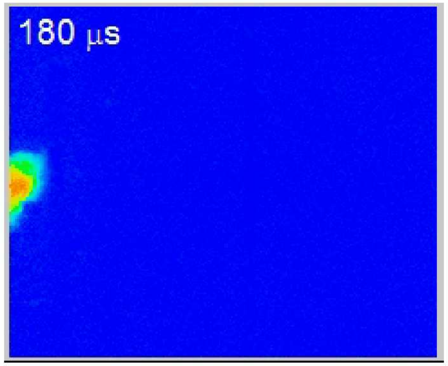
Qualitative CO imaging (OEM)

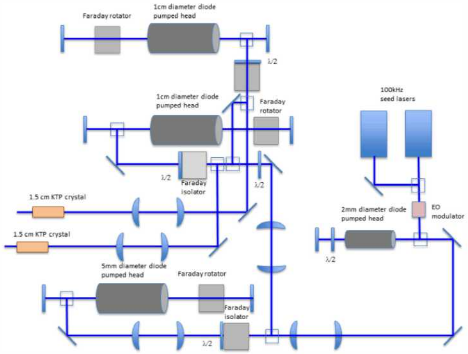
Simultaneous flow & spark channel imaging

(M. Sjöberg) (OEM)

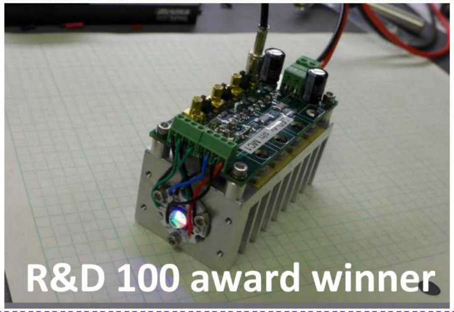








Quantitative 100 kHz mixture fraction imaging (L. Pickett / J. Frank)

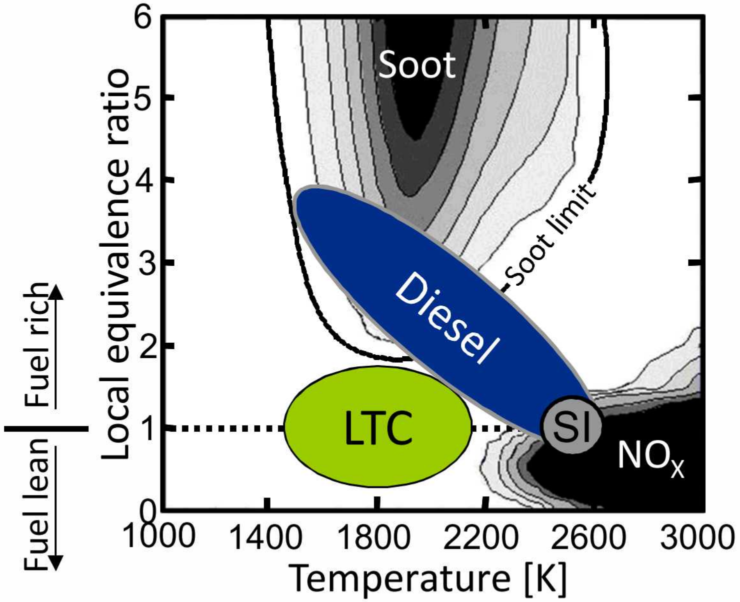


High-speed, high intensity, multi-wavelength illumination yields:

- High-resolution, frozen motion imaging
- Analysis of transient processes (soot formation & graphitization)

Research focuses on key USCAR ACEC technology pathways to increased efficiency

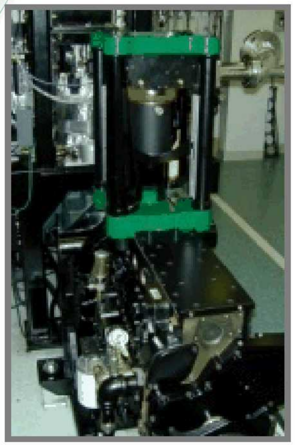
- Stoichiometric, stratified charge & dilute homogeneous spark ignition: Fuel-air mixing, ignition, knock suppression, stochastic processes (misfire) …
- Advanced diesel combustion: Fuel-air mixing, high-pressure and multi-pulse injection, lifted-flame combustion, asymmetry, bowl geometry …
- Low-Temperature Combustion (LTC):



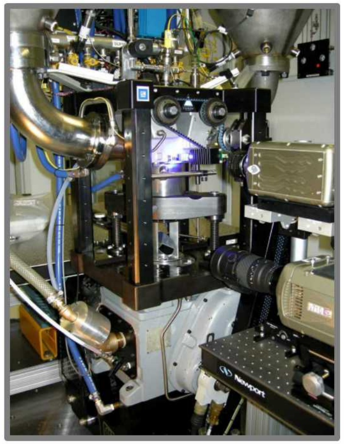
  - Diesel LTC (PPCI, RCCI, MK, …)
  - Gasoline LTC (HCCI, LTGC, GCI)
  - *Challenges:*
    - Combustion phasing
    - Load range
    - Heat release rate
    - Transient control
    - HC and CO emissions

- Fuel effects on conventional and advanced combustion strategies (**Co-Optima**)

Current laboratories/projects (research portfolio)

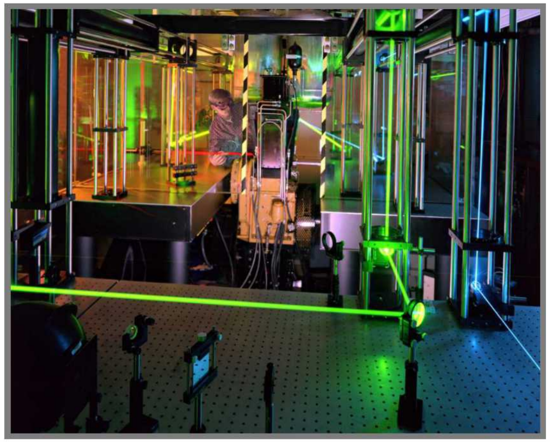


Low-temperature gasoline combustion
PI – John Dec

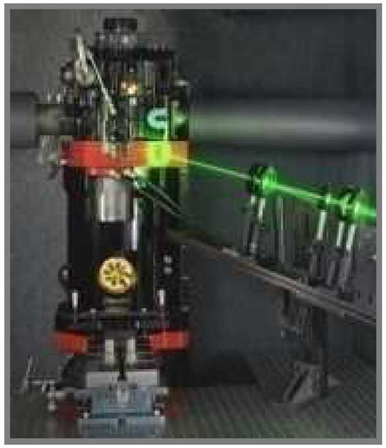


Alternative fuels – light-duty DISI
PI – Magnus Sjoberg

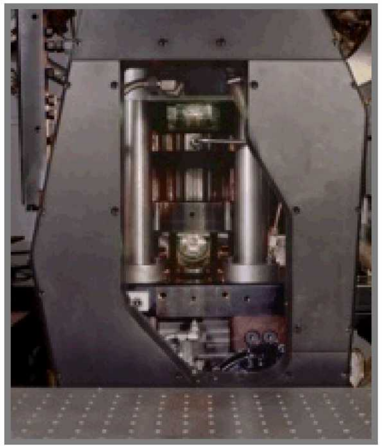
SI ignition & com-bustion fundamentals
PI –Isaac Ekoto



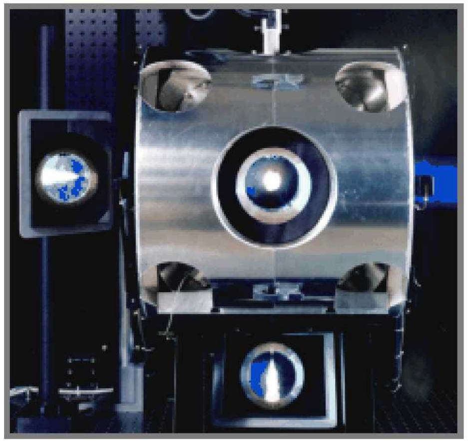
Alternative fuels – Heavy-duty CI:
PI – Chuck Mueller



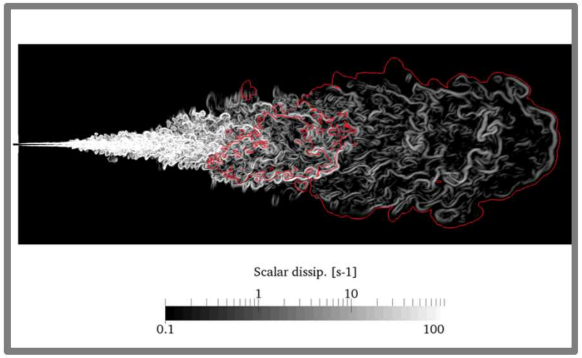
HD Diesel/LTC diesel combustion
PI – Mark Musculus



LD Diesel/LTC diesel combustion
PI – Steve Busch



Fuel sprays:
PIs – Lyle Pickett and Scott Skeen



Large Eddy Simulation
PI – Joe Oefelein

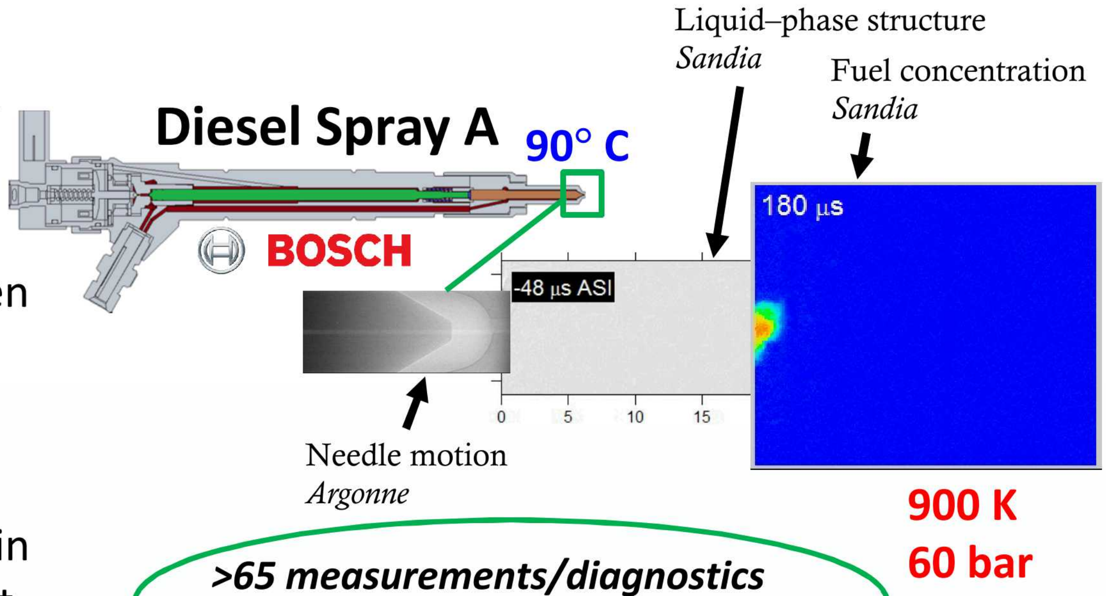
Sandia formed and leads the Engine Combustion Network – accelerates CFD model development

Approach

- Investigate both diesel and gasoline injectors with emphasis on CFD modeling shortcomings
- Comprehensive comparison between experimental and modeling results
- Multiple injector geometries investigated
- Results, *with uncertainty*, collected in an online archive tailored to support CFD simulations

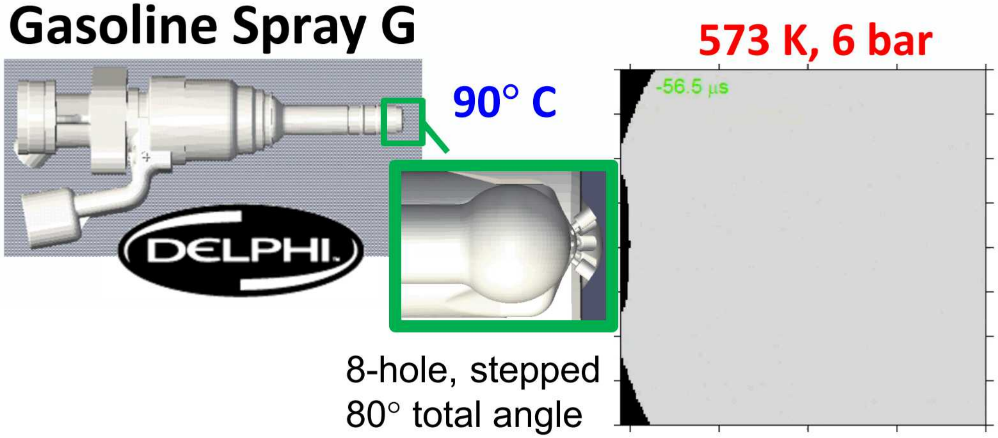
Impact

- Established in 2009, there are already 1400 citations of the ECN data archive
- **ALL** US OEMs (light- and heavy-duty) use the ECN archive to test their CFD methods



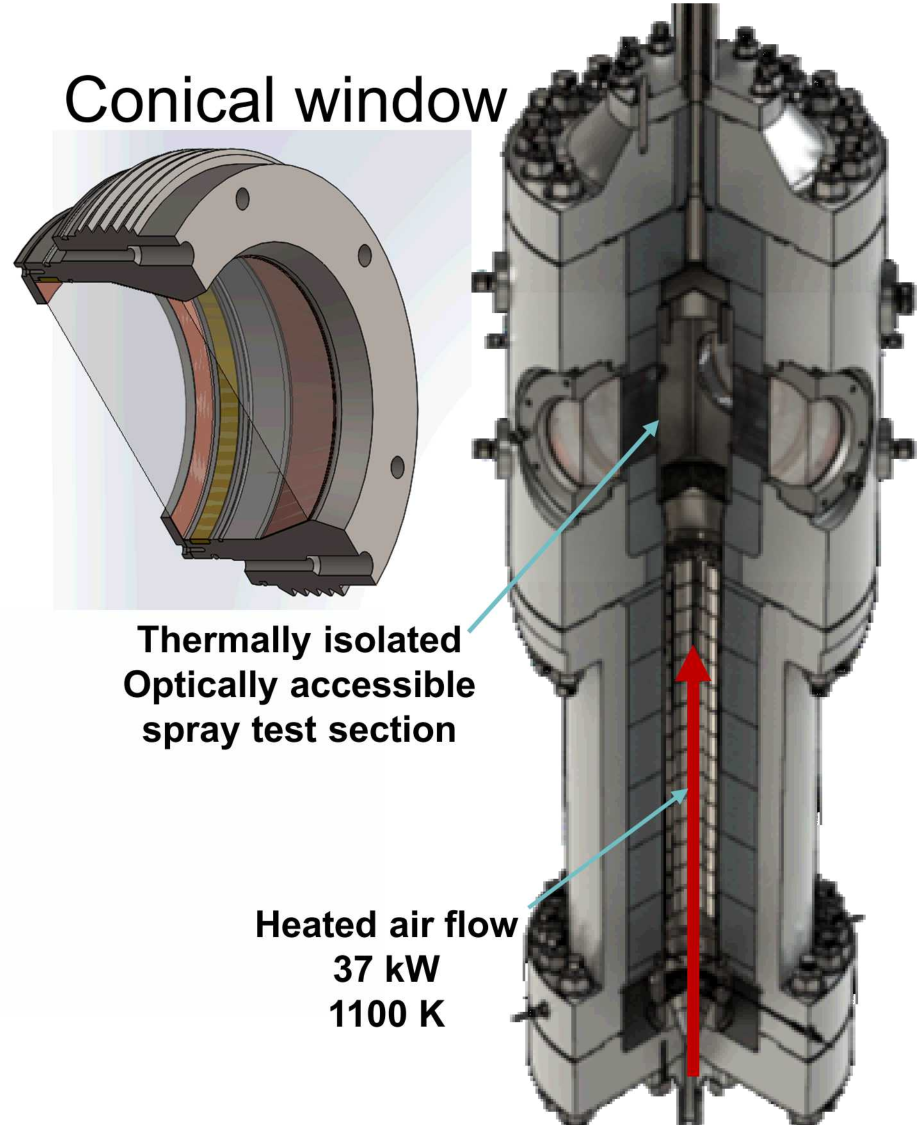
>65 measurements/diagnostics contributed from >15 institutions

Gasoline Spray G



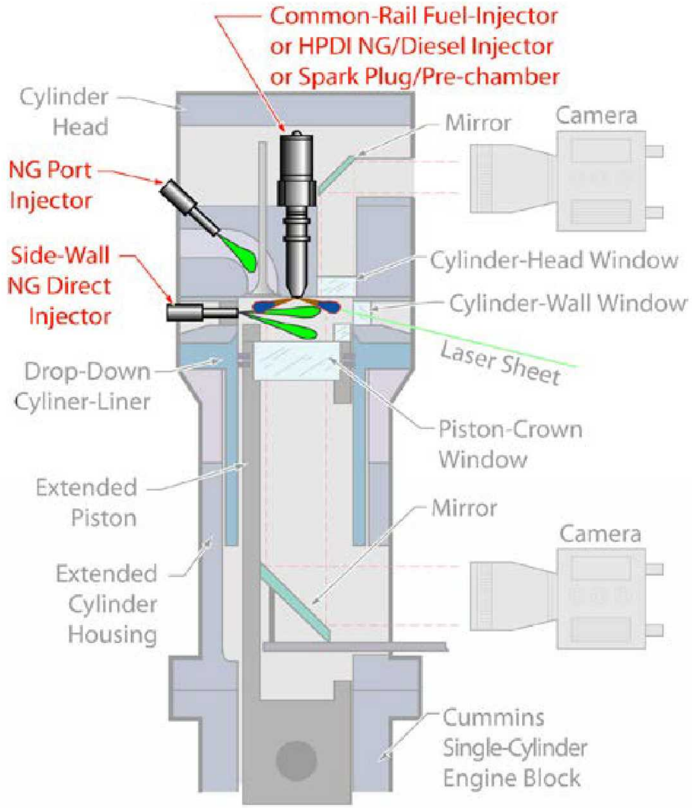
New Capability development –
High-throughput spray research laboratory

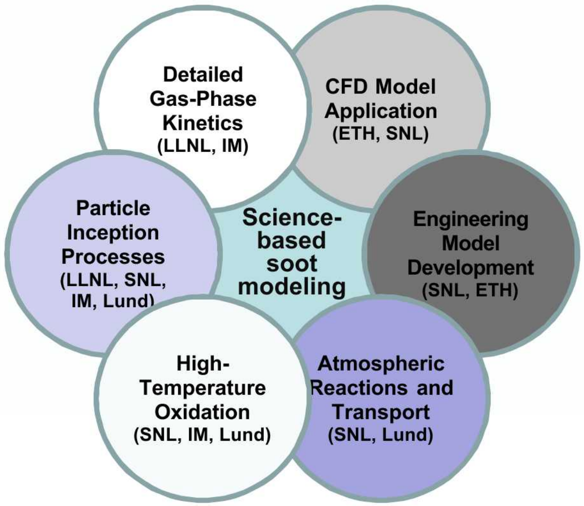
- Develop a continuous flow spray chamber that reproduces engine conditions (T & P) and enables a 300X data throughput improvement
- New design includes:
  - Windows with smaller working distance but the same clear aperture
  - Laser access ports
  - Efficient thermal isolation with maximum charge-gas temperature of approximately 1100 K
  - Rated pressure of 150 bar
  - Safety features for window ports
  - Small-volume (50 mL) syringe pump up to 2000 bar for work with small test samples



Additional capability development areas

- **Heavy-Duty Dual Fuel or NG Combustion**
  – Solid industry interest in dual fuel (4 sessions in WCX17, 21 CTP 55% BTE concepts)
  – High pressure (650 bar) NG injection capability supports all major NG combustion systems





- **Soot Modeling** (LDRD – Skeen)
  – Key area identified by industry partners (PreSICE, CFD workshop)
  – New IEA Combustion Program task (Sandia led, leverages work in 5 other countries, cross-disciplinary)

Questions?

TIM GILBERTSON

OVERVIEW FOR
JOURNEYMAN MACHINIST
AND
MECHANICAL TECHNOLOGIST
OCCUPATIONS

MECHANICAL TECHNOLOGIST

A MECHANICAL TECHNOLOGIST WILL PERFORM A WIDE VARIETY OF TASKS FROM MECHANICAL ASSEMBLY, DESIGN AND ASSEMBLE HIGH PRESSURE PLUMBLING , INSTALL MACHINERY, DESIGN HARDWARE USING CAD SOFTWARE, MANAGE FABRICATION AT MACHINE SHOPS, MACHINING OF PARTS, SETTTING UP TEST APPARATUS, TO OPERATING EXPERIMENTS .

JOURNEYMAN MACHINIST

A JOURNEYMAN MACHINIST UTILIZES PRECISION MACHINE TOOLS THAT REMOVE MATERIAL FROM A WORKPEICE TO FABRICATE PRECISION MACHINE PARTS. THE REFERENCES USED TO MAKE THE MACHINE PARTS ARE BLUEPRINTS, 3D "CAD" MODELS, SKETCHES, VERBAL INSTRUCTIONS OR FROM PRECISELY MEASURING AN EXISTING PART. PARTS ARE MADE FROM MANY DIFFERENT MATERIALS-FROM METALS TO PLASTICS

MECHANICAL TECHNOLOGIST TASKS

Engine modification: fabrication of temporary support stand on left.

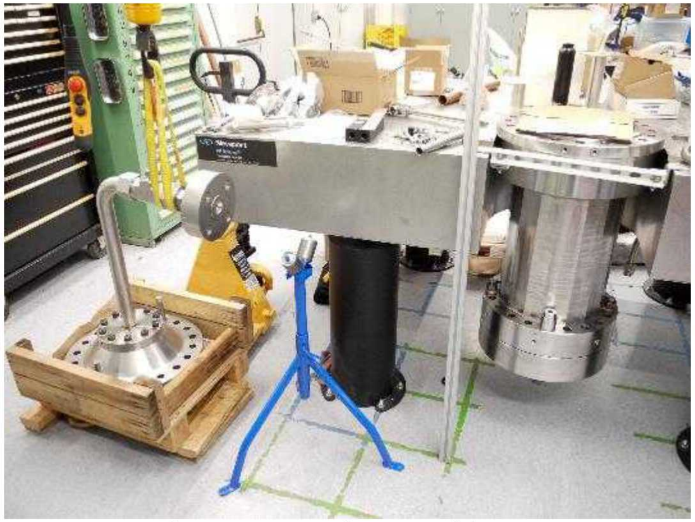
High pressure plumbing requires design and build and documentation of system for liquids and gasses

Cummins diesel engine modified for Lab research projects.

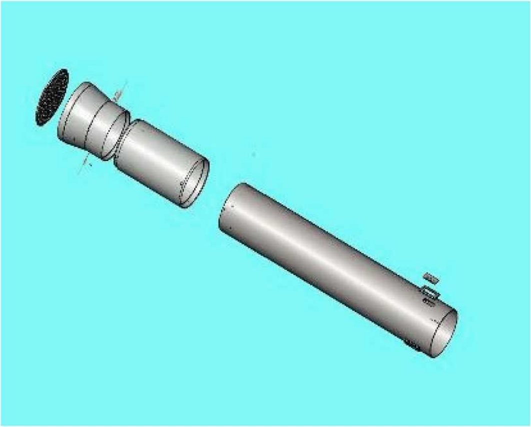
Assemblies such as engines require dis-assembly and modification to suit the current research.

Engine lab

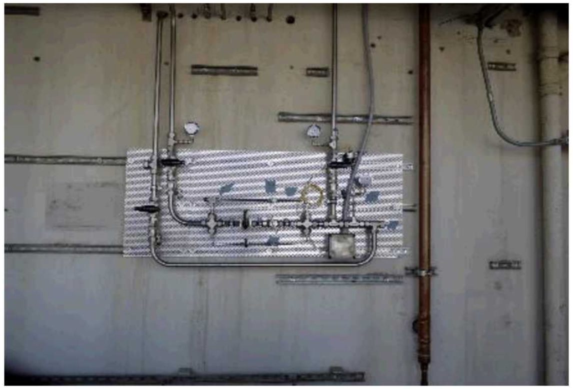
Mechanical Technologist



Large vessel assembly



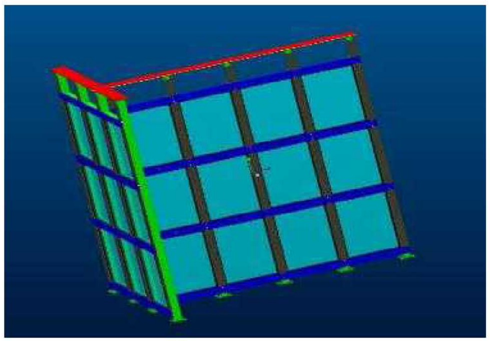
Design components, insert in to full assembly on computer, machine or send out to local machine shops



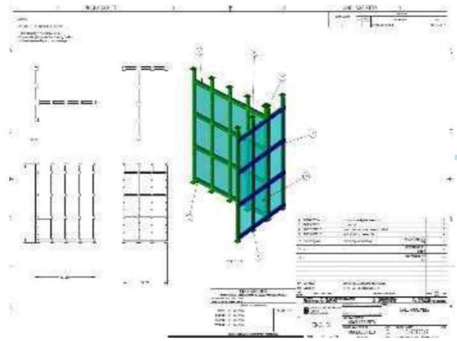
Pressure system design, assemble, test and prepare supporting documentation

Example of a project from concept through assembly

Below is a “blast wall” which was designed to protect operators in the event of a catastrophic failure of an experiment. This required Collaboration with the project lead Scientist , project team members and other groups within our site as well as outside vendors. The design required careful tolerancing and drawing notes in order for the assembly to fit together.

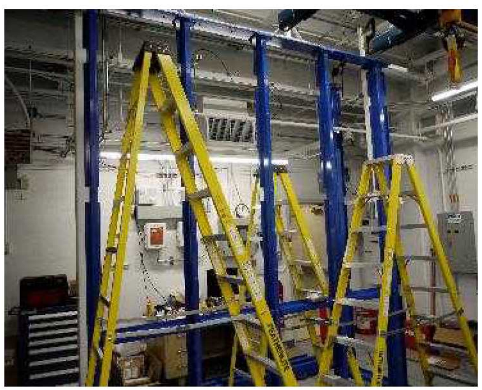


Concept is Designed and analysis performed on structure from cad models



Drawings produced from CAD models sent To shops for fabrication.

Finished assembly shipped to site



Assembly in lab space

Control room

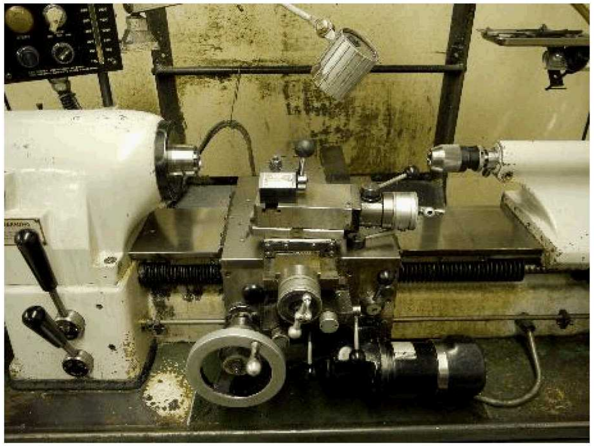
Modification - Machine shop

Mechanical technologists need to fabricate and repair components used in experiments in order to support the project scientists. Below are both manual and computer controlled machine tools. The shop is fully equipped for machining, welding and Sheetmetal work - modification or build from stock material. On many occasions experiments need modification or repair and technologists need to react in a timely manner.

Lathes, milling machines, saws

Computer controlled lathe

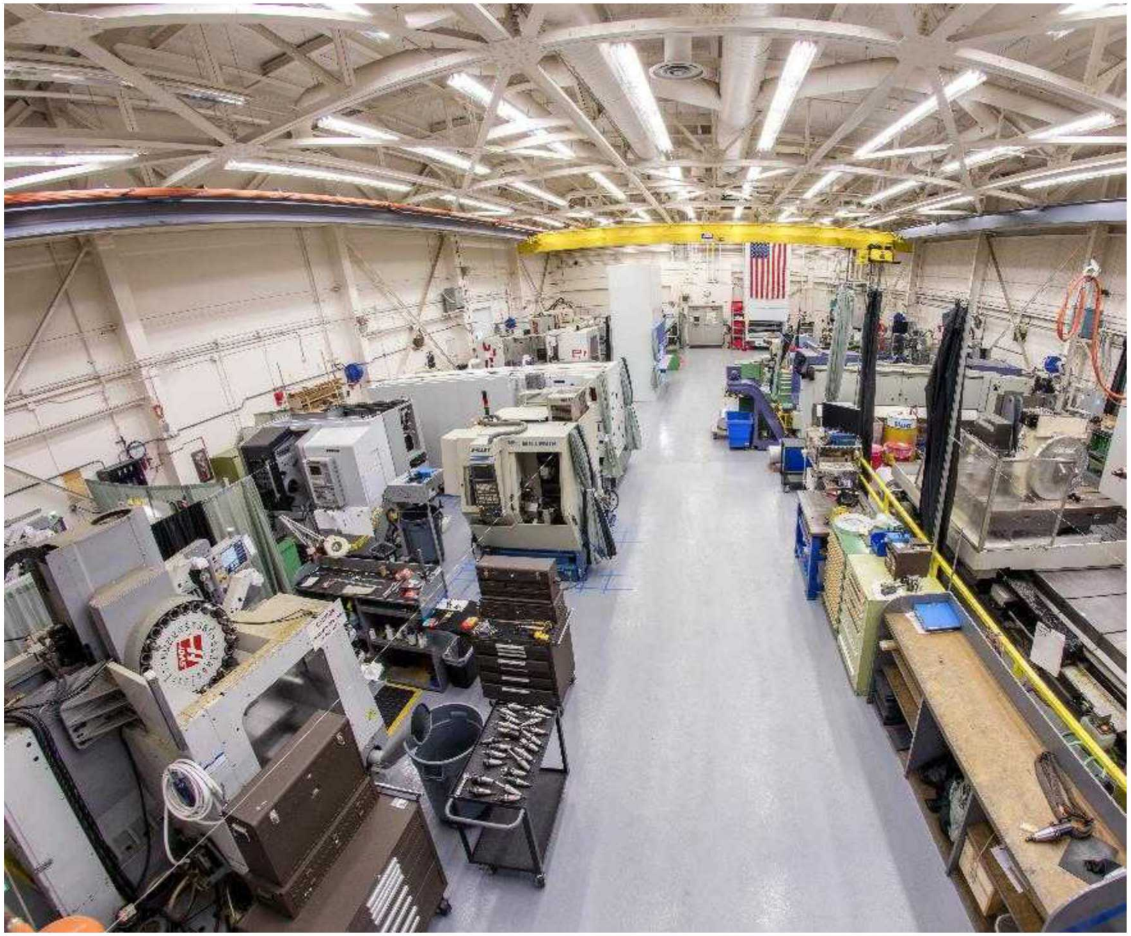
Milling machine with 3 axis controller



Small manually operated lathe

Milling machine with part mounted in vise for machining. Above is an end mill cutter that will machine the aluminum.

Main Machine shop for our site



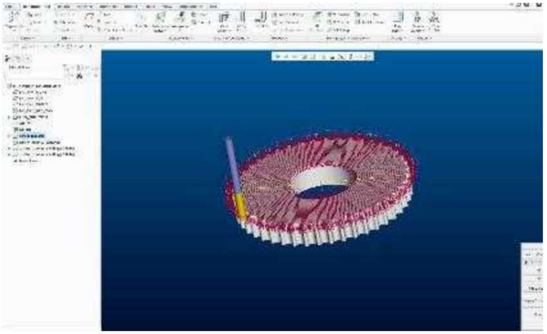
Our site has a large modern machine shop where many projects are supported. The shop is staffed with journeyman machinists, Machine programmers, inspectors and support staff. It is managed by a team leader and division manager. The shop is well equipped to machine almost any type of part that is required.

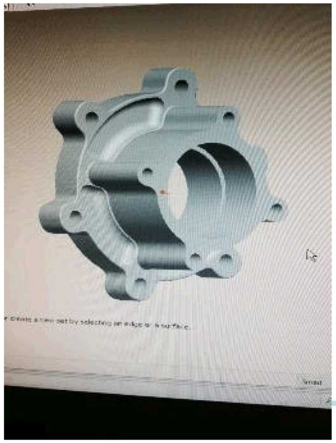
Mechanical inspection for finish machined parts

Another area within our fully equipped shops is an inspection department. Here precise instruments and talented inspectors are required to understand and interpret both drawings and solid models to determine if the part that was made in the machine shop was built to specifications. Much of the equipment is computer controlled .

Machine shop – CAD to CAM

A cad model from a designer is used to generate a tool path which will be post processed into a code that the machine tool controller will understand and create the desired toolpath. Below are some examples of parts created from this process.





where to obtain training

Junior college programs

most junior colleges in the area have a machine tool technology, Engineering technologies, CAD design (Drafting programs)are a few examples.

On the job training

Many machine shops or technology companies will hire a junior college student for a support type position. After the person demonstrates their ability and desire to learn they will progress to an apprentice or trainee to become a Journeyman machinist or a senior technologist. This could be a 3- 5 year gradual process.

Its up to you

Industry has many levels of machinists and technologists. Machine operator, machine set-up, CNC programmer, Journeyman machinist, maintenance machinist, Tool and die maker, Mold maker. Technologist's have a wide range of skill levels and duties depending on the employer or ones experience. To advance you may have to move to a new company, complete training courses or continue your education to learn new skills.This will help you advance to more challenging levels of work and responsibility.

BASIC REQUIREMENTS TO BECOME A JOURNEYMAN MACHINIST OR MECHANICAL TECHNOLOGIST

- MECHANICAL APPTITUDE – A GENERAL UNDERSTANDING OF MECHANICAL ASSEMBLIES. - This would entail having an interest in designing and building (I.E parts for your bike) Repairing things (I.E. car maintenance) or helping your family on home repairs.

- BASIC MATH INCLUDING GEOMETRY AND TRIGONOMETRY. - Basic math is used to calculate speeds and feeds, addition and subtraction when analyzing engineering drawings (I.E. blueprints) , Geometry used to understand the angular dimensions required to mill a hex shape (I.E bolt head shape) . Trigonometry is used for solving the X – Y coordinates of a bolt hole. (I.E. the bolts on the rim of your car) Technologists may need to calculate pressure data for plumbing
- Systems or the required torque on a bolt.

- ABILTY TO COMMUNICATE OR RESEARCH. - Both verbal communication and basic document writing is essential as you will communicate with co –workers as well as project managers and engineers. Some examples are maintaining notes outlining the steps used on certain processes or leaving a note to next person on a shift. Much of the information is in handbooks a technologist or machinist may refer to. There are many applications which may require internet research or reaching out to technical help from companies that supply products.

- POSITIVE ATTITUDE - The ability to get along with others in the workplace is very important. Another point is the strive to learn as much as you are able to while still completing your tasks. This may require a person to do some research on their own time in order to prepare themselves for more challenging work assignments.

SAFETY IS VERY IMPORTANT PART OF THE JOB

Example of a Job description for a Journeyman Machinist at Sandia National labs

Performs a variety of duties in collaboration with mechanical engineers, technologists, and computer numerical control (CNC) programmers in the manufacture and machining of machine shop tools, dies, jigs, fixtures, mechanical engineering fabrications, prototypes, piece parts, production piece parts assemblies, and components. Performs skilled machining and fabrication tasks using a variety of machines and tools, analyzes data, and recommends modifications to meet desired specifications.

Designs and develops industrial machinery and equipment and machine attachments required for production or experimental use, considering such factors as accessibility, economy, mobility, and performance requirements. Performs skilled machining and fabrication tasks using a variety of machines and tools to machine, fabricate, construct, and modify machine shop tools, dies, jigs, fixtures, one-of-a-kind prototypes, and production piece parts. Consults with and advises engineers, CNC programmers, and tool designers on the development and modification of tools, parts, and components. Performs precision work to exacting tolerances and dimensions; recommends revisions in design or substitutions in material based on machinability, manufacturability, or fabrication problems encountered; and solves problems relating to unusual materials, work-holding arrangements, machine settings, fabrication methods, and production processes. Analyzes data and recommends modifications to components or test procedures to meet desired specifications, requirements, and design for manufacturability tenets. Lays out, fabricates, and assembles metalworking dies, molds, and machine tool fixtures by analyzing drawings, sketches, models, specifications, diagrams, and engineering or shop specifications. May use computer-aided design (CAD) and computer-aided manufacturing (CAM) programs to design piece parts and control machine function. Computes dimensions and determines machining and material or parts required. Checks work with a variety of precision instruments. May monitor and verify quality in accordance with statistical process or other control procedures.

Skill and knowledge in mathematics, mechanics, or related technologies, such as machining, computer-aided design and manufacturing software, or metal forming techniques. Knowledge of and experience with installing, testing, repairing, and maintaining tools, machines, or equipment. Ability to read and understand written or verbal instructions, design definition, drawings, layouts, and other related specifications. Ability to understand and create CNC, CAD, and CAM programs. Knowledge of machining characteristics of materials and experience selecting materials.

Example of Job description for a mechanical technologist at Sandia Labs

Sandia National Laboratories

Primary Job Duties

The Engine Combustion Research Department has an opening for an electromechanical technologist who will join a world-class team of scientists, technologists, post-doctoral fellows, and visiting researchers. The successful applicant will serve as a technologist in the department supporting research efforts and must be capable of working with minimal guidance.

Duties will include but are not limited to:

- **Specifying, procuring, assembling, debugging, and maintaining custom-built and commercial mechanical and electrical components and systems (e.g., high-pressure combustion vessels, internal combustion engines, fuel injection systems, high-pressure gas delivery systems, custom electronics and laboratory control devices) necessary for carrying out our research mission. This will involve substantial hands-on activity as well as inspection and quality assurance of vendor supplied components.**
- **Designing specialized mechanical components and developing fully dimensioned production drawings, using commercial computer-aided design packages.**
- **Instrumenting devices, such as high-pressure fuel injectors (3,500 atm), and installing/maintaining basic lab instrumentation and equipment (e.g., commercial gas analyzers, flow instrumentation, and electronic solenoid valves).**
- **Specifying, procuring, assembling, debugging, and maintaining commercial electro-mechanical equipment.**
- **Supporting resident and visiting researchers and coordinating support activities with peers, facilities and maintenance personnel, and external suppliers.**

The successful candidate will work in a very challenging and rewarding environment that provides considerable opportunity for personal, professional, and technical growth.

Required qualifications

This position requires a minimum of a two-year degree in electromechanical engineering, physics, or a related field, or a minimum of five years of work experience in a research laboratory environment and specialized training related to the job description above. Candidates must be self-motivated and detail-oriented, must enjoy taking considerable responsibility and initiative, and must work well in both a team environment and as an individual. Skill requirements include the following: hands-on experience with complex mechanical components and systems; basic machine shop experience including use of lathes, mills, drill presses, etc.; an ability to maintain basic laboratory electrical and instrumentation systems that include devices such as flow valves, solenoids, pressure transducers, thermocouples, and gas analyzers; an ability to develop drawings with standard computer-aided design tools; and the ability to assemble custom electronic control devices and cabling, troubleshoot existing equipment, and maintain simple LANs.

INTRODUCTION

My name is Tim Gilbertson and I am employed at Sandia National Labs in Livermore, Ca. I am currently a mechanical technologist in Sandia's Combustion research center. I began my Career and have approximately 20 years of experience as a Machinist. I will give you a short definition/ description of both of these occupations.

a Journeyman machinist utilizes precision machine tools that remove material from a workpiece to fabricate precision machine parts. The machines are both manual and computer numerical controlled. The references used to make the parts are Blueprints, 3D "cad" models, Sketches, Verbal instructions or from Precisely measuring an existing component, Parts are made from many different materials from Metals to plastics.

a Mechanical Technologist will perform a wide variety of tasks such as mechanical assembly of devices, the design and assembly of high pressure gas and liquid plumbing systems, Installing and troubleshooting electro-mechanical sensors, The design hardware using cad (computer aided drafting)software, manage fabrication at machine shops, machining of parts, setting up test apparatus and operating experiments.

In both of these occupations the individual will perform both hands on work as well as using computers for CAD -computer aided drafting or CAM computer aided manufacturing as well as other software's such as Lab-view which is used to control or monitor electro mechanical assemblies. Many types of tools will be used from mechanics tools such has wrenches and screwdrivers to precision measuring tools such as digital calipers and micrometers. Continual learning through your experiences or training courses to use new software's or equipment is part of the job. The work is many times challenging and sometimes stressful but in the end, a completed machined part that was very difficult or the successful build of a complex project that required gaining new knowledge while still completing the project on time is very satisfying. The feeling of accomplishment is very rewarding. Within both occupations there are many different levels one can aspire to. At my table will be both PowerPoint presentations that further explain the paths to these career choices as well as pictures that serve as examples of typical work. I also have some actual parts that you can look at.