Engine Research Laboratory

Laboratory Coordinator: Dr Avinash Kumar Agarwal

Associated Faculty Members (if any): NA

List of Major Equipment:

- Single Cylinder Optical Research CRDI Engine (SCORE) with AC Dynamometer (AVL, Austria)
- Single Cylinder Optical Research GDI Engine (SCORE) with AC Dynamometer (EngineTech, Korea)
- Two Cylinder Engine for Diesel HCCI Experiment.
- Single Cylinder Engine for Laser Ignition of CNG and Hydrogen.
- Single Cylinder Engine for Combustion Endoscopy.
- Tata Safari Dicor (3 Liters) CRDI Engine with Eddy Current Dynamometer (300 HP; Tata)
- Tata Safari Dicor (2.2 Liters) CRDI Engine with Eddy Current Dynamometer (300 HP; Tata)
- Wagon-R Gasoline PFI Engine with Eddy Current Dynamometer (80 kW; Maruti)
- Two-Wheeler Chassis Dynamometer up to 150 kmph (Dynomerk, India)
- Two-wheeler Transient Engine Dynamometer (Dynomerk, India)
- Transient Dynamometer for Heavy-Duty Engine (75 KW) (Dynomerk, India)
- 4-Cylinder Genset, 140 kW (Cummins)
- 2-Cylinder Genset, 15 kW (Caterpillar)
- High Speed 8 Channel Combustion Data Acquisition System (Hi-Technique, USA)
- High-Speed Combustion Analysis System (Indi-smart, AVL, Austria)
- High-Speed Combustion Analysis System (Ki-Box, Kistler, Switzerland)
- SPC Smart Particle Sampler (SPC 432 AVL, Austria)
- FTIR Emission Analyzer (FTE-6000 Horiba, Japan)
- Exhaust Emission Particle Sizer with Thermo-diluter (EEPS 3090, TSI, USA)
- Nd-YAG Laser and Optics (Litron, UK)
- Time-Resolved 2D, 3D and Tomographic PIV (La-Vision, Germany)
- 2D and 3D Phase Doppler Interferometry (Artium, USA)
- High-Speed Cameras (Photron, USA)
- Laser Beam Profiler (Data-Ray, USA)
- Bomb Calorimeter (Parr 6200, USA)
- Kinematic Viscometer (Setavis, UK)
- Rancimat Instrument (Metrohm, Switzerland)
- Copper Corrosion Bath (Setavis, UK)
- Engine Endoscope (Karl-Storz, Germany)
- Constant Volume Spray Chambers and Constant Volume Combustion Chambers for Various Experiments (6 Types)
- Pressure Transducers with Charge Amplifiers (AVL, Kistler), Precision Shaft Encoders
- 3-D Simulations Software (Convergent Science)
- 1-D Simulations Software (Gamma Technology-Suite; GT-Suite)
- High-Speed Computing System (W0rkstations, 24 Core, and 32 Core)

Brief description of the laboratory:

Engine Research Laboratory was created in the Department of Mechanical Engineering on October 16th, 2005. This laboratory aims to develop state-of-art experiments related to Internal Combustion Engines and Vehicles apart from emission and engine-related tribological investigations. This laboratory aims to develop highly efficient engines using state-of-the-art facilities via conducting experiments for various investigations such as performance, emission, combustion and in-cylinder flow visualization. This is a dedicated laboratory for IC engines, the country's first laboratory to use laser diagnostics and micro-sensors for engines. This dedicated engine research laboratory paves the way for a balanced development of this front-line area of research. The laboratory has several fully instrumented single and multi-cylinder test benches for different engines/ dynamometers. Presently ERL is working on several advanced research topics such as Particle Image Velocimetry (PIV) for in-cylinder flow visualization, Phase Doppler Interferometry (PDI) for spray characterization, combustion visualization and optical diagnostics, Gasoline Direct Injection (GDI), Gasoline Compression Injection (GCI), HCCI/ PCCI of gasoline and diesel-like fuels, engine noise and vibration, laser ignition of CNG and hydrogen. Presently, ERL is working on developing methanol fuelled engines and DME fuelled engines for the Indian automotive sector under the guidance of the National Institution for Transforming India (NITI AYOG).

Laboratory research keywords:

Engines, laser ignition, advanced combustion technologies, alternative fuels, spray and combustion dynamics, optical engines, methanol-fueled engines, DME-fueled engines

Major Research and Development Contribution of the Laboratory

Year	Major research and development activity
2020-2021	▪ **R&D 1: ECU Calibration for Methanol Adaptation in Motorcycles** The ECU calibration is required for methanol adaptation in the existing SI engines equipped with an electronic fuel injection (EFI) system. An ECU was calibrated by tuning fuel injection quantity, AFR, volumetric efficiency, and ignition timing to optimize engine performance, combustion, and emissions in M85-fueled (85%v/v methanol + 15% v/v gasoline) single-cylinder port-fuel-injected SI engine. M85 produced better results compared to baseline gasoline. The BTE was increased by up to 23% at lower loads and up to 8% at higher loads with M85 than gasoline. CO and HC emissions were reduced considerably. NO emissions were higher at lower speeds and comparable/lower at higher speeds compared to gasoline. ▪ **R&D 2: Combustion Control in Gasoline Compression Ignition Engine** A detailed study was done to understand the role of combustion chamber design on vertical plane air-flow structures. A realistic bowl geometry was modelled and simulated using CONVERGE under non-firing conditions to study the flow dynamics, fluid vortex location, the importance of the interfacial region, variation of r-θ velocity components, turbulent kinetic energy production regions, etc. These results were validated with the flow-field

	results of a light-duty optical engine obtained through Time-Resolved Particle Image Velocimetry (TR-PIV). Secondly, GCI combustion engine simulations for varying swirl ratios (SR) were performed in CONVERGE CFD software to understand the effect of in-cylinder air motion on the mixture stratification and combustion. A 1/7th sector geometry for a conventional re-entry piston bowl was modelled and simulated. Two different mechanisms were used for model validation. The results indicated that the large-scale flow structures control the fuel dispersion in the combustion chamber. The charge convection because of increased swirl substantially influences the combustion. A distinguished ignition kernel was observed for all test cases. Lastly, the results of both the studies were combined, and a shallow piston (bathtub) geometry was investigated for the GCI engine. The bathtub geometry showed satisfactory results because of the absence of interfacial regions in the counter-rotating vortices. Overall, bathtub geometry showed good potential in lowering the HC and CO emissions from the GCI. ▪ **R&D 3: Development of Fuel Injection System for Di-Methyl Ether Applications in Compression Ignition Engines** This study's objective was to investigate the technical feasibility of operating a commercial single-cylinder diesel engine equipped with a mechanical fuel injection system with dimethyl ether (DME) without any significant engine-level modifications. A dedicated fuel supply line was designed to add the lubricating additives and supply the liquefied DME to the diesel engine. The existing high-pressure (HP) pump was inadequate to pump the required DME; hence a pneumatic pre-supply pump was connected in series in the low-pressure line. Using a heat exchanger, the injector return line was modified to handle and cool the liquefied DME. >75% rated load could be achieved with these arrangements by reducing the injector nozzle opening pressure. In-cylinder combustion was dominated by diffusion combustion for the DME engine. Engine emissions such as HC, CO, NOx, and soot were reduced significantly for the DME engine. The DME engine noise was lower due to superior spray atomization and DME evaporation.
2019-2020	▪ **R&D 4: Development and Experimental Evaluation of Diethyl Ether (DEE)-Diesel Blend Fueled Tractor Engine Prototype** This study investigates the combustion, performance and emission characteristics of a three-cylinder naturally aspirated water-cooled tractor engine fueled with different blends of DEE with mineral diesel ranging from 15% v/v to 45% v/v. test engine prototype was developed and operated at different loads at a constant speed without significant structural modifications for DEE blend adaptation. Engine combustion and performance for test fuel blends were comparable to that of mineral diesel; however, due to the lower calorific value of the test fuel, the engine could not be operated on complete load conditions. A significant reduction in NOx and particulate emissions were observed, with slight increase in HC emissions. With the addition of DEE fraction beyond 45% v/v in the test fuel, stable engine operation could not be achieved due to higher volatility and lower lubricity of DEE compared to diesel ▪ **R&D 5: Development of Port Fuel Injected Methanol (M85) Fueled**

	Two–Wheeler Prototype A functional two–wheeler prototype used M85 (85% v/v methanol + 15% v/v gasoline) in an ECU-controlled port fuel-injected engine. Various strategies of methanol utilization in this two–wheeler engine were evaluated. Finally, a retro fitment kit for the existing PFI two-wheeler with minimal structural changes was developed for successful M85 adaptation. This thesis describes the entire process of ECU recalibration for methanol utilization. In addition, a comparative study was performed for simulated on-road two-wheeler performance on a chassis dynamometer using a gasoline-fueled motorcycle with stock ECU vis-à-vis M85 fueled motorcycle using recalibrated ECU, followed by a comparison of emissions.
2018-2019	▪ **R&D 6: Laser Plasma Ignited Hydrogen Enriched Compressed Natural Gas Engine Development and Experimental Evaluation** This experimental study aims to assess the challenges and benefits of using hydrogen-enriched compressed natural gas (HCNG) blends as fuel and laser as the source of ignition in a prototype IC engine. Experiments in this study were conducted in two phases. In the first phase of experiments, a constant volume combustion chamber (CVCC) was used to study the fundamental aspects of LI. In the second phase, an experimental engine setup was developed to compare LI vs SI systems for HCNG blends for their combustion, performance and emissions characteristics. Fuel was introduced using a port fuel injection system in the prototype HCNG fueled engine. This study investigated HCNG mixtures for different lambdas (λ) ranging from rich to lean fuel-air mixtures using a Q-switched Nd: YAG laser (200 mJ; 30 Hz; 6-9 ns) in the CVCC. Experiments were conducted at different ambient pressures of 5 bar and 10 bar. These pressures simulated the in-cylinder pressures at the time of spark ignition in an engine cycle. Flame kernel evolution in HCNG blends of varying compositions (10%, 20%, 30%, and 40% v/v hydrogen) was compared with baseline CNG for a specified λ. A high-speed camera was used to trigger the laser and the data acquisition system. Flame kernel evolution was recorded using the shadowgraphy technique. Images were captured at 54000 fps and further analyzed to obtain the temporal propagation of flames in different orthogonal directions. It was noted that for any typical initial chamber pressure, P_{max} during combustion reduced with increasing λ. Peak pressure and flame speed were higher at λ = 1.1 for HCNG mixtures. ▪ **R&D 7: Spray, combustion, emissions and particulate investigations of gasohol fueled gasoline direct injection engine** A macroscopic spray investigation was performed to determine spray penetration length and cone angle. A section of this thesis focuses on microscopic spray investigations using the phase Doppler interferometry (PDI) technique for the measurement of various spray characteristics such as arithmetic mean diameter (AMD) and Sauter mean diameter (SMD), spray droplet size distributions and spray droplet velocity distributions etc. After performing spray experiments, the same test fuels were experimentally investigated in the engine. The engine could be operated either with a thermal cylinder head or with an optical cylinder head. In optical engine investigations,

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<tr><td></td><td>phase Doppler interferometry (PDI) was implemented in the engine cylinder to evaluate real-time spray droplet velocity and droplet diameter distribution under various engine operating conditions. Many questions were answered by these comprehensive experiments, which otherwise remained unanswered in a constant volume spray chamber experiment. The results obtained from these experiments helped optimize parameters for engine experiments with thermal heads. Effects in variation in spark timings (ST), fuel injection pressures (FIP), engine load and engine speed (rpm) on combustion, performance and emission characteristics were investigated experimentally. In engine experiments with a thermal head, detailed investigations were conducted to evaluate engine performance, combustion and emission characteristics for the test fuels. Engine exhaust particle sizer (EEPS) was used to obtain particle number-size distribution and mass-size distribution. Primary alcohol investigation can be implemented on a large scale with the lowest environmental impact.</td></tr>
<tr><td>2017-2018</td><td>
R & D 8: Feasibility of Using Methanol-Diesel Blends in an Unmodified Compression Ignition Genset Engine with Mechanical Fuel Injection Equipment
Miscibility of methanol in mineral diesel and stability of methanol–diesel blends are the main obstacles faced in using methanol in compression ignition engines. In this experimental study, combustion, performance, emissions, and particulate characteristics of a single-cylinder engine fueled with MD10 (10% v/v methanol blended with 90% v/v mineral diesel) and MD15 (15% v/v methanol blended with 85% v/v mineral diesel) are compared with baseline mineral diesel using a fuel additive (1-dodecanol). The results indicated that methanol blending with mineral diesel resulted in superior combustion, performance, and emission characteristics compared with baseline mineral diesel. MD15 emitted a lesser number of particulates and NOx emissions compared with MD10 and mineral diesel. This investigation demonstrated that methanol–diesel blends stabilized using suitable additives can resolve several issues of diesel engines, improve their thermal efficiency, and reduce NOx and particulate emissions simultaneously.
R & D 9: Enhancement of Tribological Properties of Epoxy Composite Coatings for Engine Applications
This research focuses on achieving improved mechanical properties with a low coefficient of friction ≤0.1 and a minimal wear rate ≤10 -7 mm 3 / Nm for such coatings. The applications of epoxy composite coatings can be in extreme contact conditions such as engine piston rings and bearings. The present work is divided into five parts. The first part involves tribological and mechanical investigations of epoxy and its composites, adding graphene and graphite by ten wt. %, coating on steel substrate under dry and lubricated conditions at different loads and speeds. It was observed that epoxy/graphene composites exhibit a lower coefficient of friction (~0.18) and a wear rate of 5.5 x 10 -6 mm 3 /N-m at 3 N load and 0.63 m/s sliding speed under dry contact conditions when it was compared to epoxy. The second part of the thesis includes investigations of the tribological and mechanical properties of epoxy composite filled with nano-particles and liquid lubricants coated on D2 steel.</td></tr>
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	Friction reduction by liquid lubricant (SN150 and PFPE by 10 wt. %) filled epoxy composites and associated lubrication mechanism have been studied. It was observed that the in-situ lubricant at the interface assisted in making the partial fluid film. The wear life improved by more than 200 times, and the coefficient of friction became half that of the composite without the lubricant.
2016-2017	▪ **R & D 10: Acoustics, Vibrations, Performance, Combustion and Emissions Characterization of Diesohol Fuelled Single Cylinder Compression Ignition Engine** This research work's comprehensiveness and focus on alcohol-diesel blends' noise and vibration characteristics are markedly different from earlier investigations. Towards this goal, 18 different diesel-alcohol blends were evaluated as potential candidates for partially replacing diesel using a single cylinder four stroke CI genset engine. Three different alcohols were used to prepare these blends: methanol, ethanol, and n-butanol. For specific formulations, co-solvents like dodecanol, and butanol, were used to eliminate the phase separation problem of the blends. The engine was run at a constant speed of 1500 rpm. However, investigations were conducted at six different loads. An elaborate experimental setup was developed to record data needed for calculating engine performance, combustion, noise, vibration, and emission characteristics from the engine fuelled by these 18 different diesel-alcohol blends. Before running tests on the engine, each test blend was characterized for its phase stability, density, calorific value, viscosity, oxidation stability, and corrosiveness. Results showed strong correlations between trends related to noise, combustion, emissions, and engine performance parameters. Experimental data were also analyzed to understand the effect of the inherent fuel oxygen content of alcohols on these parameters. Overall, it was found that most of the test fuels could partially replace diesel for Genset applications if they are also found to be economically viable. ▪ **R & D 11: Mode Switching Prototype Engine Development for Low-Temperature Combustion** Low-temperature combustion (LTC) concept has evolved over the last two decades in response to the demand for lowering NOx and soot emissions from direct injection (DI) diesel engines. In LTC, auto-ignition can be controlled by modifying fuel properties to make it more chemically reactive or inhibitive by adding an ignition promoter or inhibitor, as per the requirement. The fuel properties directly control the vital properties of the fuel-air mixture. Based on fuel properties, three distinct fuel-air mixture preparation techniques, namely, port fuel injection, early direct injection, and late direct injection, can be applied to LTC engines. Different derivatives of LTC, such as PCCI, PHCCI, etc., have been thoroughly investigated, and the suitability of each derivative was determined for a particular operating range. To explore the applicability of each LTC derivative for developing a production-grade LTC engine, this study was divided into three sections, namely (i) partially homogeneous charge compression ignition (PHCCI) combustion, (ii) premixed charge compression ignition (PCCI) combustion and (iii) mode switching between conventional CI combustion and LTC. Depending on the operating condition,

	mode switching involves dual combustion modes, which is an effective solution for commercializing LTC technology. In PHCCI combustion investigations, five test fuels were investigated at different loads, EGR rates and intake charge temperatures. These experiments validated the feasibility of LTC using low volatility fuels such as mineral diesel. PCCI experiments were carried out to explore the possibility of using a fuel injection strategy for different combustion modes. After successfully achieving control over PCCI combustion, an optimized fuel injection strategy was implemented on a production-grade engine to achieve mode switching between conventional CI combustion and LTC. This experimental study involved a journey starting with the fundamental combustion investigations of PCCI and culminating in developing a commercially viable mode switching LTC engine prototype, which will be energy efficient and environmentally friendly.
2015-2016	▪ **R & D 12: Spray, Engine Combustion, Performance, Emissions, Vibrations and Acoustics Studies of Biodiesel and SVO Blends** Initial investigations were carried out to measure important fuel properties, including density, viscosity, and calorific value for all test fuels. This was followed up by detailed investigations of spray characteristics for different test fuels. Finally, and most importantly, an exhaustive suite of experiments was conducted to understand performance, emissions, noise, and vibration characteristics for the test engine run on 12 different biofuel-diesel blends. Four of the fuels studied were 20% blends of different vegetable oils (Karanja (K20), Jatropha, Rapeseed, and Soybean) and diesel. These blends are named K20, J20, R20, and S20, respectively. Then there were 20% blends of four different biodiesels derived from Karanja, Jatropha, Rapeseed, and Soybean. These blends are named KB20, JB20, RB20, and SB20. Finally, we also tested pure biodiesels for Karanja, Jatropha, Rapeseed, and Soybean. These are named KB100, JB100, RB100, and SB100. Characteristics of these test fuels were compared against that of mineral diesel. Biodiesel properties such as viscosity and density significantly affect spray characteristics, resulting in relatively inferior spray atomization compared to mineral diesel. Biodiesel showed a slight improvement in noise and vibration characteristics due to a reduction in HRR max because of higher SMD of spray droplets compared to mineral diesel. Biodiesel engines emitted lower HC and NO x emissions, while CO emission and smoke opacity were relatively higher than mineral diesel, with a slight reduction in BTE. Finally, it is recommended to use a 20% biodiesel blend in a single-cylinder Genset engine because it improves most engine characteristics.

Figure #1 Single cylinder optical research engine (SCRE)

This flexible internal combustion system provides varying fuel injection strategies, injection timings, supercharging boost pressure, compression ratio (slightly) etc. It is equipped with fuel conditioning, lubricating oil conditioning and coolant condition systems for conducting investigations under standard controlled conditions. This facility provides measurement and control of fuel injection pressure and injection pattern (two pilots, one primary and one post-injection). It has an AC dynamometer, a state-of-the-art intake air measurement system, and a gravimetric fuel flow meter. For particulate characterization, Smart Particulate Sampler (SPC) is installed in this system. This facility has installed a water-cooled piezo-electric pressure transducer, fuel-line pressure sensor and crank angle encoders for in-situ combustion analysis. For Combustion visualization, it has a transparent quartz liner and quartz window in the piston crown. The engine also has provisions for the installation of an endoscope for combustion visualization, which is particularly very useful at higher engine load conditions

Figure #2 Experimental Setup of GDI Engine with the thermal head

It employs a 6-hole GDI injector (Bosch, GDI HDEV5). A fully programmable MOTEC open ECU (M400) controls the fuel injection quantity, timing, and spark timing. A peak and hold injector driver module (ZB-5100G, Zenobalti) connected to the engine via open ECU is used to operate the injector upon the encoder signal. For combustion analysis, a spark plugs pressure transducer (ZI31_Y5S, AVL) is connected to a data acquisition (DAQ) system (Indi micro, AVL). This DAQ system has an in-built charge amplifier, which converts the charge into voltage and provides the in-cylinder pressure signal. The crank angle position is measured by an optical crank angle encoder (365C, AVL) which gives 720 pulses per revolution. Sensors for lubricating oil pressure and temperature, barometric pressure, coolant in and coolant out temperatures, exhaust gas temperature and engine speed (rpm) are installed on the engine. Connections of the ECU include sensors for reference trigger, synchronization trigger, throttle position, manifold pressure, engine temperature, intake air temperature and narrow-band lambda sensor.

Figure #3 Two-Wheeler Chassis Dynamometer

The vehicle testing facility at ERL can do development emission testing for 2-wheelers (Max. Speed up to 150 Kmph). Testing facility capabilities include vehicle performance and tailpipe emissions testing per Indian standards.

<u>Capabilities</u>

1. Max. Speed test, Power Test, Acceleration Test
    - Road Load Simulation (RLS) and Wide-Open Throttle (WOT) mode
2. Fuel Consumption Test
    - Road Load Simulation (RLS) mode
3. Emission Test
    - Constant speed tailpipe emission using Road Load Simulation (RLS) and Wide-Open Throttle (WOT) mode
4. Driving cycle evaluation
    - World Motorcycle Test Cycle (WMTC), Indian driving cycle (IDC) etc. using driver's aid mode on portable emission analyzer (AVL-MDS 450)
5. Calibration of Fuel Supply Device (ECU/ Carburetor) and Catalytic Converters
    - Road Load Simulation (RLS) and Wide-Open Throttle (WOT) mode

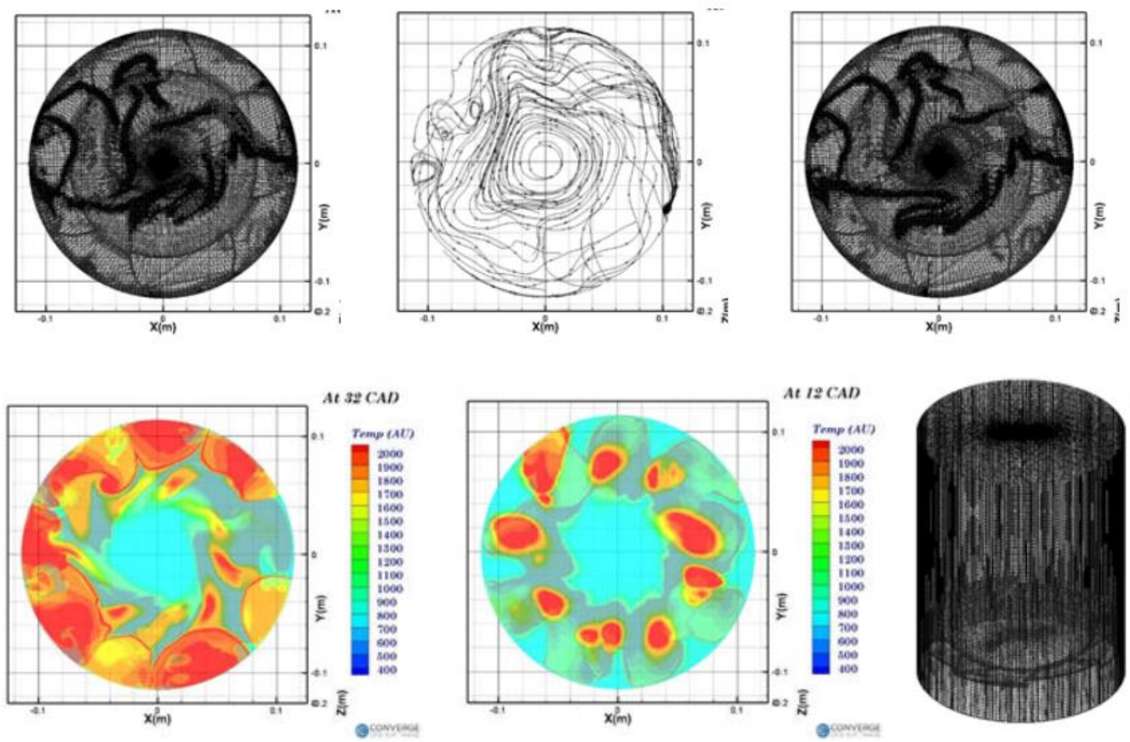

Figure #4: Simulation capabilities

Engine Research Lab's simulation facility can comprehensively study the combustion, performance and emission parameters of engines. This facility is an excellent tool for adaptations of preliminary investigations of newer alternative fuels in existing engines and developing new engines for alternative fuels. ERL has a dedicated workstation equipped with 1-D and 3-D software, GT Suite and Converge, for carrying out simulations. GT-Power is designed for steady state and transient simulations suitable for engine/powertrain control. The software uses 1-D gas dynamics to represent the flow and heat transfer in the components of the engine model. Converge CFD is a 3D modelling software that lets us view the element's graphical interface that cannot be easily modelled and visualized with 1-D software such as GT-Power.