Scope for improving the efficiency and environmental impact of internal combustion engines using engine downsizing approach: A comprehensive case study

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Abstract. Downsizing, decrease of engine size, shows up as a significant method of enhancing fuel utilization of engines while keeping up bit of leeway of low emissions these days in market. The downsizing methodology with turbocharged applications is presently to an ever-increasing extent situated towards fuel economy, because of specific arrangements. The utilization of gasoline direct injection combined with turbochargers gives a few methods of improving aversion to knock particularly at heavy load and lower engine speeds where current PFI motors with forced induction are as yet restricted. In this study we are discussing about the performance, test conditions and emissions with respect to standard naturally aspirated engines. We have also compared various methodologies used for downsizing rather than turbocharging and how they help in overcoming the issues with turbocharging like low boost and turbo lag. Reducing the weight of moving parts like piston and crankshaft, thus reducing the overall weight of engine which increases its efficiency, by 3D printing methods is also studied. Shortcomings and conclusions drawn from the use of various Alternate Fuels and comparisons of various methodologies like Exhaust Gas Recirculation, Water Injection, coupling of a small compressor etc. are recorded and discussed.

1. Introduction

With the various stringent emission norms and fuel save strategies applied to the current IC engines, the world is moving towards least Carbon, NOx and HC emissions standards to lower ozone layer depletion, and other similar issues related to it. Now to tackle this there are many strategies that can be implemented, some of them are like switching to electric but switching to electric is impossible in a shorter duration of time. So, the most significant strategy to bring about the emission restriction is engine downsizing, and we will be emphasizing more on the topic of downsizing an engine based on the research conducted by different researchers around the world on different fields. Downsizing is a concept of reducing the displacement of engines to make them efficient and emit fewer emission while retaining its power. So, in these various studies were considered which make significant impact on engine downsizing in the field of fuel, Forced Induction, Exhaust treatments, high pressure injection systems, optimization of engine parts. Thus, we have reviewed and conducted a case study on more than 25 papers and recorded under various sections like operating conditions, engine and fuel used, parameters used to achieve downsizing, advantages on performance and its effects on emissions. So,
after considering the challenges they faced and results they drawn there are a few techniques and conclusions that this research has focused on which make maximum impact on the point of downsizing.

2. Downsizing methods

2.1. Alternate Fuels
Fuels which can decrease knocking factor can be used to enhance engine compression ratio and can increase the ignition advance angle with respective to the crank angle can increase the power output and bio-fuels and alcohols can reduce the emissions released into the atmosphere.

2.2. Forced Induction
Turbochargers and superchargers are used in this technique to compress more air into the combustion chamber to burn more fuel and increase the power output. Hybrid turbochargers are also used to increase efficiency of the engines by using the energy from exhaust gases.

2.3. Engine design & Construction
Decreasing the weight of engine piston up to 15% by using selective laser sintering (SLS) which is a 3D printing method in order to reduce difference between Indicated power and break power which results increase in output, this increase in output can be used to decrease in engine size. Decreasing the weight which acts on bearing of crankshaft can also increase output.

2.4. Direct Injection systems & Exhaust treatments
Customary answers for forestall pinging like fuel improvement or low compression ratio increment fuel use. One of the huge challenges with downsized motors is the rise in pinging tendency, predominantly under high burden low speed conditions because of expanded chamber pressures and temperatures. This outcome in end-gas to auto-touch off before the fire shows up at the charge, achieving high-pressure waves - pinging. The expression “knock” portrays the sound coming about because of the unconstrained ignition of the unburned air-fuel blend in front of the progressing turbulent flame front. The unburned blend is compacted by the extension of the consumed gases created in the turbulent flame spreading from the spark plug outwards. Research on ignition pinging have shown that pinging can be abstained from by hindering the spark timing. There are various issues alongside like high knocking, richer fuel mixtures, less engine efficiency, turbo lag and less boost at low speeds etc. which can be solved by various implementations and improvements on downsized engines like water injection with fuel injection, exhaust gas recirculation, coupling of a supercharger less flow rate compressor etc.

3. Case Study on Downsizing Engines
3.1. Alternate Fuels
One of the ideas was to test different fuels in one engine configuration and so, this study [1] consists of experimental investigation on SI engine with 87 AKI E0 gasoline as fuel in precise structure and in intermediary alcohol fuel mixture with “24%iso-butanol-fuel (IB24) and 30%ethanol-gas (E30)”. A solitary chamber motor has been used with two compression ratios, 9.2:1 - 11.85:1 respectively. The engine was combined with using pressurized water operated valves, research facility air consumption, and was capable of EGR remotely. All fuels were worked to full-stack conditions in stoichiometric proportion or $\lambda=1$, utilizing both 0% and 15% outer cooled EGR. "Higher octane number bio-fuels better utilize higher pressure proportions with high stoichiometric force capacity and ethanol (E30) empowered multiplying of stochiometric force ability with the 11.85:1 pressure proportion, when contrasted with 87 AKI, up to 20 bar IMEP at stoichiometric proportion or $\lambda=1$ with 15% EGR, and 18.5 bar with 0% EGR
which was utilized to furnish thermodynamic points of interest with all energizes.” The outcomes portray that E30 may additionally diminish the cutting back and down-speeding of motors by accomplishing all the lower speed force, even with high pressure proportions, likewise mid-level alcohol gas mixes to motor and vehicle streamlining can lessen vehicle fuel utilization and exhaust CO2 emanations. Secondly, replacing fossil fuels with bio-fuels like RON-95, RON-102, E85 and E22 has the potential to significantly reduce the exhaust CO2 emissions [2]. Gasoline is a combination of hydrocarbons and supplanting a huge level of it with a solitary bio-segment can along these lines sway certain actual properties of the fuel, similar to, changes to the calorific worth, refining bend and possibly the octane rating impacts ignition conduct. Table 1 illustrates the case study of approaching engine downsizing using alternate fuels.

3.2. Forced Induction

One of the thoughts for turbo-charging is exploring the possibility of engine downsizing and parametric studies related with this procedure [10]. Experimental information and Extrapolations of information utilized for making a bend to fit and to rough motor, transmission and vehicle exhibitions. A turbocharger configuration is advanced to consider both blower range and turbocharger productivity under low speed and high force conditions. This reduces turbocharger inertia directly reducing turbo lag. The engine was rated with 200kW rated engine power, and 230g/kW-hr. BSFC with a vehicle of gross weight 1650kg. Normally suctioned engines have a normal estimation of power density around 50 kW/l which gives a motor uprooting of 4.0 liters. Also, different other displacements were also used for the comparison test like, 3.2 l, 2.4 l and 1.6 l, which gives a downsizing percentage of, 0%, 20%, 40% and 60% respectively, bringing down the number of cylinders from 8 to 4. For the test, base heap of 500 W was utilized for each speed. As pattern focus for 1650 kg, vehicle fuel usage over the cycle is found to be 12.6 l/100 km. Likewise, the estimation of vehicle fuel use was duplicated for all the leftover engines and turbocharged separately to reestablish appraised power and the full heap of the first objective base qualities. New turbocharging innovation comprising consecutive equal stream blower design called “Successive Turbocharging” can be recommended which can possibly convey the necessary low speed torque and high-speed performance also higher fuel efficiency than naturally aspirated engines. Hence, due to reduction in throttle losses, 40% downsizing yields to a deduction of 23% in fuel utilization while 8-10% reduction by fuel cut off in idling and 38% reduction for 60% downsized engines.

Secondly, reviewing the actual use of a smaller engine in place of a higher displacement stock Naturally Aspirated engine [11]. The engine was coupled in an average size vehicle as a cutting back idea, expecting to upgrade the fuel execution while maintaining stock engine performance characteristics. The stock engine used was a 3.3 l V6 engine while the intended engine is a 2.0l to be turbocharged and the engine was altered to go with the 4–12MPa direct injection framework with the multi-opening injectors and intake and exhaust with variable valve timing camshafts (VVT). The turbocharger was kept regarding engine with the goal that the particular power was accomplished over 85kW/l while the most extreme torque should reach by 2000 rpm. The intended fuel used for this purpose was pump gas or gasoline. The fuel efficiency of the vehicle with 2.0 L turbocharged engine, was enhanced due to the deduced friction and pumping wastes w.r.t to, V6 3.3L engine. Likewise, the effect of the transmission gear proportion on the maneuverability and mileage in the cutting back idea was researched. These showed promising and better fuel efficiency than the base stock engine. Table 3 illustrates the case study of approaching engine downsizing using forced induction.
### Table 1. Comprehensive summary on engine downsizing using alternate fuels

| Ref | Operating Condition | Engine & Fuel Used | Method used to achieve downsizing | Performance Advantages | Effect on Emission | Conclusion | Change required |
|-----|---------------------|-------------------|-----------------------------------|-----------------------|-------------------|------------|----------------|
| [3] | The working stage is the 7000rpm Wide Open Throttle full peak power. A single-opening port water injector with a measurement of 0.15 mm. | V8 DI Spark Ignition turbocharged engine. Displacement ≈3800 cc. Oversquare engine peak Power > 500 kW @ 7000rpm | Mathematical examination on the possibilities of water injected to increment ping resistance and decrease fuel utilization in downsized GDI motors. | Burning effectiveness increment and related decrease in BSFC. Water included the inlet port in steady charge cooling in the burning cylinder. | Decrease of fuel utilization due to lower substance reactivity of the weakened end gases. | Increment of IP of about 2% and a decrease of the injected fuel around 17%, along these lines prompting a general decrease of BSFC of almost 20% | Addition of water injector in the intake port. |
| [4] | Spark timing = 25 After Top Dead Center Flat shaped piston. Speed= 1200rpm Initial temp= 390 Kelvin Initial P= 1 bar AFR = 14.7 | Bore = 85mm Stroke = 90mm CON Rod length 138mm CR = 9.5 2-inlet valves & 2-outlet valves. Fuel (M8, M5, M10, M15) + gasoline. | "Knock combustion was mimicked in a downsized SI engine with various methanol-isooctane blends." | Methanol in iso-octane builds its opposition against knock because of its lower power, lower Heat discharge rate and in-chamber temperature decrease the collaboration between pressure wave and the fire front as well as put off the beginning of knock. | Fuel Consumption on Rate continuously increment also, show up soon with the methanol-vo| "Methanol in isooctane builds its opposition of knock because of its lower force of substance responses, lower HRR and in-chamber temperature lessen the collaboration between pressure wave and the fire front just as put off the beginning of knock." | VVT, DI and cooled EGR. |
| [5] | Mathematical investigations have been done at incomplete burden activity and at two diverse motor rates (3000 and 4000 rpm) | Displacement=136 8 cc Cylinder = 4 Bore = 7.2 cm Stroke = 8.4 cm CR=9.8 Max power 147.5hp-5500rpm | Mathematical examination of a downsized SI motor energized by Butanol/gas mixes at part-load activity. | "Bio-fuels will decrease the general CO2 emarnation. at the point when the motor is powered by perfect n-butanol, torque and efficiency arrive at values about 2% higher than those acquired with slick fuel." | "CO2 outflows increase due to enormous measure of C6H10OH consumed in the chamber." | Because of alcohol more modest warming qualities, the SFC increments with alcohol substance. SFC for slick butanol filling is 30% more noteworthy more that of gas filling, the exhaust gas temperature diminishes while CO2 emissions increment. | ECU controlled Fuel Injection |
| [6] | Fuelled with 30 and 35% vol Butanol/gas mixes and contrasted with the unadulterated gas. Motor speed range (1000-8500) | 4 Strokes, Single chamber Cooling model Air cooling. Displacement= 121.9 cc Bore = 5.6cm Stroke = 4.95cm CR 9.2; Peak power= 74kW@8000 | Heat discharge examination of Bio-Butanol/fuel mixes on a rapid SI motor | Butanol gives higher pinging opposition by permitting increment the start timing in SI motors, prompting more effective ignition. | | Butanol mix proportion expanding, one can accomplish a more effective ignition measure with utilizing the ideal working boundaries. | ECU controlled Fuel injection |
| [7] | Air intake pressure = 0.85-0.9 bar temperature = 290-305 K | Motor sort SI motor Model CT 150 (2011) Bore = 6.51 cm Stroke = 4.44 cm Cleared volume= 0.147 L. | Exploratory investigation on outflows and execution of an inside ignition motor energized with fuel and gas/n-butanol mixes | Results demonstrated that BSFC expanded by 3.4% for B10 contrasted and gas, while the CO and UHC outflows didn't show a huge contrast among gas and the fuel mix. | CO2 - 43% CO - 32% Unburned HC - 26% | Motor test shows that utilizing n-butanol-gas mixed fills marginally decline the yield torque, power, volumetric effectiveness, fumes gas temperature | No modificati ons required on a gasoline engine |
One of the ideas is that, in some cases Fixed Geometry Turbocharger may not ready to give any lift pressure in any event, during uniform state conditions, and pinnacle torque generally [19]. Streamlining of the boosting framework and use of most recent air consumption way needed to incorporate the electric supercharger, and utilizing Water Charge Air Cooler framework. For the engine a 1.0 L 3-chamber turbo GDI engine was considered. A 3.3 kW electric supercharger was utilized to reason turbocharge slack, likewise it won’t have any effect on electricity [20]. On the off chance that in the event that the pointed boosting pressure is more noteworthy than the encompassing “pressure and the current boosting pressure in the vehicle on quickening, at that point the turbocharger performs in manoeuvring mode to aid in boosting. Table 4 illustrates the case study of approaching engine downsizing using injection and exhaust treatment.

### 3.4 Engine Component Redesigning Optimization

One of the ideas is to optimize the engine piston [25] by changing the piston bowl shape, introducing piston surface cooling channels and ring groove cooling channels. Due to these modifications break power is increased by decreased friction between cylinder wall and piston rings also by decreasing heat transfer to ring grooves by introducing groove cooling channels. Mixture formation is improved by increase in free spray penetration length is increased by 25%. Decreased weight of piston with introducing truss and stiffening members and eliminating material. High material density can be achieved by approximately 99.5% compared with traditional designing and manufacturing processes. Secondly, other similar but significantly effective way is to re-designing the piston and decrease weight [26]. These can be achieved by topology optimization and introducing holes into grooves. Holes were
provided on piston grooves, both, to avoid pressure drop and to create a controlled turbulence, which by-passes air backwards which in turn reduces leak in pressure. By decreasing the weight using topology, disruptive mass and inertia decrease are achieved. Table 2 illustrates the case study of approaching engine downsizing using design optimization of engine component.

### Table 2. Comprehensive summary on downsizing engines using design optimizations of engine components

| Reference | Method | Achieved through | Results |
|-----------|--------|------------------|---------|
| [24]      | Redesigning the combustion engine piston | • By changing the combustion engine piston bowl shape | • Increased break power by decreased friction between cylinder wall and piston rings, by decreasing heat transfer to ring grooves by introducing groove cooling channels |
|           |        | • Introducing Piston surface cooling channels | • Decreased weight of piston with introducing truss and eliminating material with increase in strength |
|           |        | • Ring groove cooling channels | • Achieved a high material density (approximately 99.5%) compared with traditional manufacturing. |
| [25]      | Redesigning piston and decrease weight | • The topology optimization | • Holes that are given on piston grooves not exclusively to dodge pressure drop yet in addition to make a controlled turbulence, which sends air backwards which reduces leak in pressure. |
|           |        | • Introducing holes into grooves | |
| [26]      | Redesigning crankcase | • Topology optimization | • Decreased weight of the crankcase by redesigning crankcase structure |
|           |        | | • Increased thermal efficiency |
|           |        | | • Decreased oil temperature by providing required thickness at require location thickness |

### Table 3. Comprehensive summary on downsizing engines using forced induction

| Ref  | Operating Condition | Engine & Fuel Used | Method used to achieve downsizing | Performance Advantages | Effect on Emission | Conclusion | Changes required |
|------|---------------------|--------------------|----------------------------------|------------------------|--------------------|------------|------------------|
| [12] | Injection type: Direct injection Ignition type: Spark ignition No. of cylinders: 4 Bore*Stroke(mm): 80.56*86mm Engine Disp: 1.783 litres Compression ratio: 10.3:1 Max torque: 284 Nm from 1500 up to 4500 rpm. | The compression ratio is fixed over 10 to 1.A 3.0-liters motor, while keeping same quickening execution. At full load, the particular fuel utilization is under 300 g/kWh over the entire motor speed range. 1.8l IDE idea changed by IFP for a turbocharged application were utilized. The relative air/fuel proportion is fixed to 1.0 while upstream turbine temperatures in each parchments are beneath 950°C. | Renault IDE motor permits to exploit its high knocking cutoff to supplant a 3.0 liter normally suctioned motor and consequently to have a fuel utilization advantage of over 15% with at any rate a similar acceleration. Huge change in HC emissions by utilizing a camshaft with a decreased valve open term. | Fuel utilization advancement of 20% using the downsized motor with a fuel utilization reaching 8.3Litres/100km while standard engine has a fuel consumptio of 10.5L/100k m. | Downsizing is by all accounts a decent method to lessen CO2 discharges to meet following stage guidelines and to fit with ACEA responsibility. This is conceivable just if the motor permit same speeding up execution and comparable drivability. | Coupling of twin scroll turbocharg er rather than a conventio nal turbocharg er. |
| [13] | Injection type: PFI (Low pressure injection system with water injection system installed) | Ignition type: Spark ignition No. of cylinders: 2 Bore*Stroke (mm): 80.5*80.6 Engine Disp: 875.4 cm3 Compression ratio: 10:1 Max torque: | Tests were done at all the way open throttle conditions picking a H2O to gasoline mass proportion of 0.2, because of a past examination did to upgrade the water sum as far as motor | Engine is ran at standard ratio conditions, made possible by WI, keeping the pre-set weight, with likely good conditions on the fuel usage in light of the better-consuming arranging constrained by the CO discharged with WI is essentially lower CO2 transmitted with WI is higher than the looking at gas case for every motor rate. | The impacts of water infusion on motor execution, fuel utilization, fumes gas outflows and ignition clamor were assessed on a PFI turbocharged twin chamber SI motor. Tests were completed at Wide | Water injection by mixing gasoline and water with H2O/gas mass of 0.2. This can be achieved |
| Description                                                                 | Specification                                                                 |
|-----------------------------------------------------------------------------|------------------------------------------------------------------------------|
| 146.7 Nm at 2000 rpm                                                      | execution. At the distinctive motor rates and at full gasoline tasks, the relative air-fuel proportion was that set by the ECU map comparing to the ping restricted IG increment. |
| advancement of IG timing. These inclinations are asserted by the delayed consequences of the showed unequivocal fuel usage. Diminishes from about 8% to 12% appeared differently in relation to the reference cases, highlighted by ISFC profiles. |
| Hydrocarbons, created with the WI is lower than the relating full gas at standard ECU movement. |
| Open Throttle situations in the motor speed limit 3000-4500rpm with a stage of 500rpm, setting the H2O/gas mass at 0.2. The possible advantages of WI were researched at increased motor load investigating a spark clear from sans ping up to ping-restricted activity. |
| by installing a water injection system with the injection system. |
| Injection type: Direct injection Ignition type: TSI spark ignition          | No. of cylinders: 4 Bore*Stroke (mm): 76.5*75.6 Engine Disp: 1390 cm³ Compression ratio: 10:1 Max torque: 240 Nm at 1750 to 4500 rpm |
| To explore the pinging process, the test example is worked “at a speed of 1750 rpm at full burden with proportionality proportion 1.0, and the charge pressure” is expanded by methods for the remotely determined blower until pinging happens. |
| Engine estimations and response engine reproduction results have given impacting boundaries ready to diminish pre-ignition inclinations. |
| The fire engenderin during pre-ignition happens out of nowhere and prompts fast pressure increments and significant pressure variances in the burning chamber. |
| Supercharged gasoline engines see, adjacent to the notable impact of knocking, additionally, pinging marvels as restricting condition. Pinging wonders result from the auto-ignition range set by response energy for a given fuel/air combination in the burning cylinder. |
| The pre-ignition propensity of a combinati on can be affected by improving admission valve timings. |
| Twin turbocharged motor, with intake and exhaust VVT.                     | No. Of Cylinders: 8 Compression Ratio: 9:1 Displacement: 3010 |
| Engine altered diminishing by 10% the chamber, and supplanting the first gas-dynamic framework with the triple-turbocharger. |
| Higher boost pressure at low engine speed. Lower pumping misfortunes at fast, full burden, better transient reaction. |
| Because of low pumping wastes there is an expansion in eco-friendliness and decline in discharges. |
| Twin-Turbochargers gives higher lift pressure at lower engine speeds and limits pumping misfortunes at high speeds. |
| The 20% cutting back of a current acquired by diminishing bore and embracing a triple turbocharg er spread out. |
| Injection type: Direct injection (Centrally mounted Denso 6-hole injector 17.5 cm³ Compression ratio: 10.8:1 Exhaust valve open: -236.5 to -206.5 CAD) | The engine utilized for tests was a solitary chamber Volvo engine. No. of cylinders: 1 Bore*Stroke (mm): 93.2*82 Displaced volume: 492 cm³ |
| This chamber head utilized stream isolating dividers in the admission ports which in blend with limitation plates permitted the stream in the admission ports to be modified, in such manner that the tumbling air movement of the in-chamber stream could be affected. |
| Direct gasoline infusion joined with super charging and cutting back is a practical idea to meet future prerequisites for discharge decrease just as expanded proficiency for traveller vehicles. |
| A negative outcome on pumping misfortunes In any case, the patterns for the shown fuel utilization for 360 and 720 CAD both show the comparativ e conduct. |
| PIV estimations demonstrated that the beginning stage preceding any tumble expanded demonstrated a rotational speed of the tumble in the request for the engine speed. |
| Plenum to change the intake produced stream field in a direct infused super charged idea to build tumble. |
| Supercharger consisted of a BLDC motor Turbocharged engine with marked torque | For small engine (about 1.0L) downsizing, the While small turbochargers are required by small Unburned HC are declined as The Turbo-Claw compressor is a new form of radial Coupling of electricall |
driving. This was designed for the engine speed range between idle and 2800 rpm. performance improvements, and equivalent performance to the 1.4L engine, at higher engine speeds. At lower engine speeds, however, the 1.0 L engine short of boost with persistent turbo-lag.

most appropriate technology is to use is a relatively large turbocharger to recoup exhaust energy to improve peak power.

downsized engines, due to the high-speed problems, large turbochargers are coupled with them. This results in turbo lag and minimum boost.

the compressor reduces turbo lag and provides boost which reduces unburning of fuels at lower speeds.

turbo compressor. The innovation is uniquely placed as it is amenable to being electrically driven at speeds substantially lower than conventional turbo compressors. It driven

(18) Injection type: Direct injection Sweep volume: 0.5L CR: 10:1 IVOT: 128 before TDC IVCT: 364 before TDC EVOT: 364 after TDC EVCT: 154 before TDC Engine type: 4 stroke No. of cylinders: 1 Bore*Stroke (cm): 8.0*10.0 4 valve engines

In this test the effect of disturbance power on pinging ascribews was thought of. Different levels of beginning spin extent inside chamber were first thing performed to analyse the effect of choppiness power on start measure. Pinging occasion can be evaded if fire speed is adequately quick or choppiness power is enormous which will give no an ideal opportunity for pinging as no closure gas autoignition. The connections between ping power and unburned mass partition show that ping power generally depends upon unburned mass division. In this work, the impact of various disturbance powers on pinging attributes was contemplated utilizing CONVERGE recreation combined with a nitty gritty science solver in an exceptionally cut back spark-ignition motor.

Table 4. Comprehensive summary on downsizing engines using Injection and Exhaust Treatments

| Ref | Operating Condition | Engine & Fuel Used | Method used to achieve downsizing | Performance Advantages | Effect on Emission | Conclusion | Changes required |
|-----|---------------------|--------------------|-----------------------------------|------------------------|---------------------|------------|------------------|
| [21] | Injection type: Direct injection “No. of cylinders: 4 Bore*Stroke (mm): 83*92 Engine disp: 2 litres 16V motor Compression ratio: 9:1 | The motor produced by the “Ultra boost project (the UB100)4 is designed to be 60% downsized to achieve a 35% reduction in fuel consumption and CO2 emissions. | “The point of this work was to research the impact of key engine working boundaries on PN discharges under exceptionally supported conditions. | Better fuel economy and boost with downsized engines compared to standard naturally aspirated engines. | As burden builds, the measure of fuel present in the chamber likewise expands prompting an expansion in PN discharges. An expansion in cooled/outside EGR will expand PN discharges. CO2 outflows increases. | “A broad test lattice of 96 test focuses has been embraced on an incredibly profoundly helped engine, over the engine map at working purposes of up to 32 bar BMEP. The particulate outflows have been estimated from this engine unexpectedly, utilizing a DMS500. | Coupling a turbocharger or supercharger with a gasoline direct injection engine. |
Intake Boosting System:
Two Stage Turbochargers

| Engine Type | Displacement | Compression Ratio | Expansion Ratio |
|-------------|--------------|-------------------|-----------------|
| In-Line 4 Cylinders | 0.734L | 9.5 | 30.0 |

The external two chambers work in the traditional four stroke cycle, and the plan boundaries are nearly not changed aside from the mathematical pressure proportion decreased from 9.0 to 7.0, contrasted with the first four-chamber four stroke engine.

The mathematical development proportion of the inward chamber is 30.0, bringing about a general viable extension proportion of 13.8 of the working gases in the engine.

Deficient burning misfortunes are lower with the 9.2 piston than with the higher-pressure proportion 11.85 piston paying little mind to fuel type for most conditions.

At low loads, the cycle engine is better over the five strokes cycle engine regarding fuel change effectiveness. Contrasted with the first engine, the fuel utilizing under the most-regularly worked conditions are improved by 9–26%.

A two-stage turbocharging framework was utilized to support the engine WOT force tantamount to the first engine.

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High pressure fuel system, “side mounted DI, split injection during cold start”

Transmission: 6-speed automatic

| Displacement | Engine Bore: 75.5 dia |
|--------------|-----------------------|
| 2359 cm³ | 8.8 x 9.7 cm |
| C R: 11:3:1 and turbocharge d | 11.85 piston |

“The high-pressure pump of the T-LPDi engine has a fuel return line on top of it to re-course the disintegrated LPG fuel, which brings about a flame lock marvel. A controller is prepared between the LPG fuel tank also, HPP, which has a fuel flexibly entry with a cut-off valve and fuel return section to pressurize the disintegrated fuel as ΔP of 5 bars,“

“The GDI engine showed relatively higher engine torque and power from 4000 rpm than the T-LPDi engine due to larger engine displacement volume effect during naturally aspirated operation. Engine performance of the T-LPDi under the 4000-rpm region was superb, delivering a higher power than the GDI, which indicates a potential to simultaneously improve fuel economy and CO₂ emissions.”

“The CO₂ emissions and Fuel Economy of the T-LPDi vehicle were improved by 22.89% and 0.45% relative to the GDI vehicle.”.

This investigation utilized LPG fuel to expand the value of CO₂ emanations what’s more, improve the extreme molecule discharge issue related with GDI engines.

DI system

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Bore: 75mm
Stroke: 84.8mm
Compression Ratio: 9.5
Engine Displacement: 1.5L

A traditional turbocharger is being reformed into an hybrid turbocharger

Utilization of mixture turbocharger helps with boosting pressure during quickening to maintain a strategic distance from super slack, and it neither produces power nor devours power, while it is inactive.

Recovery of exhaust gases when hybrid turbocharger used is higher by 8% under high speed or load conditions.

Energy sparing capability of hybrid turbocharger in different driving cycles was evaluated, The crucial clarification behind fuel saving is the reduction of siphoning disaster and alternator impact

Hybrid replacing traditional turbocharger
4. Conclusion
From the above research carried upon the topic of downsizing engines, we learned about the different strategies and methodologies that can be implemented to make this happen, as such as,

1. Higher octane bio-fuels like Ethanol (E30) better use higher pressure proportions with less fatty stoichiometric torque capacity even up to doubling it, also improving low end torque while still having lower exhaust emissions.

2. Adding water in the intake port on steady charge cooling in the burning chamber, builds the ignition effectiveness and decrease in brake explicit fuel utilization.

3. Methanol in iso-octane increases anti-knock property because of its lower force of compound responses, the communication between pressure wave and the fire front was reduced by lower heat discharge rate and in-chamber temperature.

4. Engines fuelled by neat n-butanol experience higher torque and proficiency than those got with pure fuel because of alcohol having more modest warming qualities, thus diminishing brake specific fuel utilization, so Bio-fuels will lessen the general CO2 discharge.

5. Butanol provides higher anti-knock property which allows higher advance of the ignition timing in SI engines, prompting more productive ignition. In the part of fuel oxidation rate, the fuel/air ratio is the overwhelming component as opposed to fuel type sometimes.

6. Brake Specific Fuel Consumption (BSFC) increases for B10 as compared with gasoline, CO, CO2 and UHC outflows decline significantly for mixed fills when contrasted with slick gasoline due to improved ignition, since n-butanol has additional oxygen, permitting partial decrease of the CO and UHC through arrangement of CO2.

7. Comparing two engines, a small capacity turbo-charged engine and a larger naturally aspirated engine, testing the smaller engine at 1500 rpm and 4000 rpm and up to 6000 rpm for the larger, the resultant BSFC show that, Down-sizing gives a decline, Single camshaft with concentric axes (SOHC) for admission and fumes flaps (VVT) gives an abatement, Optimized burning chamber configuration gives a lessening, Homogeneous DI gives a diminishing. A slenderer stoichiometric proportion in Stratified Direct Injection blend arrangement gives a lessening and the temperature controlled cooled EGR framework gives a further decrease. These all adds up to the total gain as a whole to the total reduction in BSFC.

8. With the help of Water Port injection advancing spark timing accelerates the rate of combustion (50 % burn point) and shortens its durations (0-10 % and 0-90 % burn points) which leads to higher peak in-cylinder pressure without the possibility occurrence of knock by this engine thermal efficiency can be increased and fuel consumption can be reduced. [9] Increased levels of downsizing might be difficult to achieve due to the higher in-cylinder pressures requirement. Decreasing the number of cylinders might offset increased levels of friction. The likely reduced torque response of the engine would need to be addressed by an enhanced charging system and perhaps increased levels of hybridization. Significant CO2 emission reduction can be achieved by RON-95 and E-85 respectively. So, from the above we can conclude that by the mixed combination of these ideas we can achieve downsizing of the engine so as to meet our common goal of reducing carbon emissions and extracting the same or more performance for the same or lower amount of fuel used in it.

9. The exhaust gas reuses produce a decrease in performance and an expansion in specific fuel utilization regarding the unadulterated air–fuel taking care of keeping unvaried the engine control boundaries. Simultaneously, the charge dilution prompts a solid decrease of both the consumed gas temperature and the intensity of knock. Utilizing EGR, a similar torque level gave by the undiluted charge, can be gotten by closing the gap in volumetric efficiency by methods for higher turbocharging proportions.
10. Lightweight pistons and crankshafts using 3D printing and their topology optimization can reduce the weight of moving components thus reducing the overall weight of engine closing the difference between indicated power and brake power thus increasing output while downsizing engines. Providing coolant vents in piston using 3D printing can reduce the transfer of temperature to piston rings thus engine temperature can be controlled while downsizing.

Finally, the future scope of the topic downsizing of the engine is quite high as there are combined systems like different types of hybrid systems which help in further helping to this and overall, we can conclude that the future of IC engine is far from over as each year new sophisticated solutions are invented to further support to this cause and that full electrification of automobiles are not the most accurate and valid solution to the transportation industry problems.

5. References
[1] Splitter, Derek, and James Szybist. "Intermediate alcohol-gasoline blends, fuels for enabling increased engine efficiency and powertrain possibilities." *SAE International Journal of Fuels and Lubricants*, 7, no. 1 (2014): 29-47.
[2] OudeNijeweme, D., P. Stansfield, A. Bisordi, M. Bassett, J. Williams, M. Gold, R. Ali, and J. Rogerson. "Significant CO2 reductions by utilising the synergies between a downsized SI engine and biofuels." In *Institution of Mechanical Engineers Internal Combustion Engines: Improving Performance, Fuel Economy and Emissions Conference*, pp. 203-216. 2011.
[3] Berni, Fabio, Sebastiano Breda, Mattia Lugli, and Giuseppe Cantore. "A numerical investigation on the potentials of water injection to increase knock resistance and reduce fuel consumption in highly downsized GDI engines." *Energy Procedia* 81 (2015): 826-835.
[4] Feng, Hongqing, Jianan Wei, and Jing Zhang. "Numerical analysis of knock combustion with methanol-isooctane blends in downsized SI engine." *Fuel* 236 (2019): 394-403.
[5] Scala, F., E. Galloni, and G. Fontana. "Numerical analysis of a downsized spark-ignition engine fueled by butanol/gasoline blends at part-load operation." *Applied Thermal Engineering* 102 (2016): 383-390.
[6] Deng, Banglin, Jianqin Fu, Daming Zhang, Jing Yang, Renhua Feng, Jingping Liu, Ke Li, and Xiaojing Liu. "The heat release analysis of bio-butanol/gasoline blends on a high-speed SI (spark ignition) engine." *Energy* 60 (2013): 230-241. Elfasakhany, Ashraf. "Experimental study on emissions and performance of an internal combustion engine fueled with gasoline and gasoline/n-butanol blends." *Energy Conversion and Management* 88 (2014): 277-283.
[7] Baêta, José Guilherme Coelho, Michael Pontoppidan, and Thiago RV Silva. "Exploring the limits of a down-sized ethanol direct injection spark ignited engine in different configurations in order to replace high-displacement gasoline engines." *Energy Conversion and Management* 105 (2015): 858-871.
[8] Zhuang, Yuan, Yu Sun, Yuhan Huang, Qin Teng, Bo He, Wei Chen, and Yejian Qian. "Investigation of water injection benefits on downsized boosted direct injection spark ignition engine." *Fuel* 264 (2020): 116765.
[9] Shahed, S. M., and Karl-Heinz Bauer. "Parametric studies of the impact of turbocharging on gasoline engine downsizing." *SAE International Journal of Engines*, 2, no. 1 (2009): 1347-1358.
[10] Han, Donghee, Seung-Kook Han, Bong-Hoon Han, and Woo-Tae Kim. *Development of 2.0 L Turbocharged DISI engine for downsizing application*. No. 2007-01-0259. SAE Technical paper, 2007.
[11] Lecointe, Bertrand, and Gaëtan Monnier. *Downsizing a gasoline engine using turbocharging with direct injection*. No. 2003-01-0542. SAE Technical Paper, 2003.
[12] Tornatore, Cinzia, Daniela Siano, Luca Marchitto, Arturo Iacobacci, Gerardo Valentino, and Fabio Bozza. "Water injection: A technology to improve performance and emissions of downsized
turbocharged spark ignited engines. "SAE International Journal of Engines 10, no. 5 (2017): 2319-2329.

[13] Willand, Jürgen, Marc Daniel, Emanuela Montefrancesco, Bernhard Geringer, Peter Hofmann, and Markus Kieberger. "Limits on downsizing in spark ignition engines due to pre-ignition." MTZ worldwide 70, no. 5 (2009): 56-61.

[14] Rinaldini, Carlo Alberto, Sebastiano Breda, Stefano Fontanesi, and Tommaso Savioli. "Two-Stage turbocharging for the downsizing of SI V-Engines." Energy Procedia 81 (2015): 715-722.

[15] Berntsson, Andreas W., Göran Josefsson, Roy Ek Dahl, Roy Ogink, and Börje Grandin. "The effect of tumble flow on efficiency for a direct injected turbocharged downsized gasoline engine." SAE International Journal of Engines 4, no. 2 (2011): 2298-2311.

[16] Pullen, K., S. Etemad, W. Thornton, and J. Villegas. "The TurboClaw compressor for engine downsizing by twin-charging." In 7th international conference on compressors and their systems, pp. 93-99. 2011

[17] Chen, Lin, Haiqiao Wei, Ceyuan Chen, Dengquan Feng, Lei Zhou, and Jiaying Pan. "Numerical investigations on the effects of turbulence intensity on knocking combustion in a downsized gasoline engine." Energy 166 (2019): 318-325.

[18] King, Jason, Matthew Heaney, James Saward, Andrew Fraser, Mark Criddle, Thierry Cheng, Guy Morris, and Paul Broore. "Hyboost: An intelligently electrified optimised downsized gasoline engine concept." In Proceedings of the FISITA 2012 World Automotive Congress, pp. 483-496. Springer, Berlin, Heidelberg, 2013.

[19] Dong, Hao, Zhichao Zhao, Jianqin Fu, Jingping Liu, Jian Li, Ke Liang, and Qianlu Zhou. "Experiment and simulation investigation on energy management of a gasoline vehicle and hybrid turbocharger optimization based on equivalent consumption minimization strategy." Energy Conversion and Management 226 (2020): 113518.

[20] Leach, Felix, Richard Stone, Dave Richardson, Andrew Lewis, Sam Akehurst, James Turner, Sarah Remmert, Steven Campbell, and Roger F. Cracknell. "Particulate emissions from a highly boosted gasoline direct injection engine." International Journal of Engine Research 19, no. 3 (2018): 347-35

[21] Li, Tie, Bin Wang, and Bin Zheng. "A comparison between Miller and five-stroke cycles for enabling deeply downsized, highly boosted, spark-ignition engines with ultra-expansion." Energy Conversion and Management 123 (2016): 140-152.

[22] Galloni, E., G. Fontana, and R. Palmaccio. "Effects of exhaust gas recycle in a downsized gasoline engine." Applied Energy 105 (2013): 99-107

[23] Cho, Jaeho, Kangjin Kim, Sung Ha Baek, Cha-Lee Myung, and Simsoo Park. "Abatement potential analysis on CO2 and size-resolved particle emissions from a downsized LPG direct injection engine for passenger car." Atmospheric Pollution Research 10, no. 6 (2019): 1711-1722.

[24] Dolan, Robert, Roger Budde, Christian Schramm, and Ing Reza Rezaei. "3D printed piston for heavy-duty diesel engines." In Proc. of the 2018 Ground Vehicle Systems Engineering and Technology Symposium. 2018.

[25] Orquéra, Myriam, Sébastien Campocasso, and Dominique Millet. "Design for additive manufacturing method for a mechanical system downsizing." Procedia CIRP 60, no. 1 (2017): 223-228.

[26] Pandiyan, A., G. Arun Kumar, B. Baskar, A. Shajin, A. Sathis Kumar, and Mohammed Saleem. "Thermal Effect on Topology Optimized Crank Case Cover for Additive Manufacturing." ARPN Journal of Engineering and Applied Sciences 11, no. 18 (2006): 11098-11103.