

Design Optimization of Complete Air Intake Filtration System for Truck Application

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Abstract— Today's air filters are designed to give superior filtration performance for enhanced engine life. Airborne dust particles are very abrasive in nature and lead to engine undue wear, which increases oil consumption and loss of power (frictional power). Required filtration efficiency can be achieved with many technologies available with media materials and their configuration. Optimization to reduce overall pressure drop across air intake system plays a vital role in improving engine performance in terms of power, fuel economy and emission. If too high pressure drop exists in the system, then the combustion will not be complete due to in-sufficient volume of clean air available for combustion leading to reduced power, higher fuel consumption and also increased emissions. This paper discusses the function, design guidelines of Air Intake Filtration system for reduction in pressure drop. A selection matrix approach is discussed for the optimum selection of filter and with due consideration emphasized on performance parameters of air intake filtration system like pressure drop, particle separation, filtration efficiency, dust holding capacity, etc. Advantage of these guidelines is reduction in design-cycle time and hence the cost.

Index Terms— direct flow air filter, study of air intake filtration system, design guidelines, CFD analysis to reduce pressure drop & to increase the efficiency.

1 INTRODUCTION

Modern diesel engine requires 15000 units of air per unit of fuel consumed. Hence the clean atmospheric air is very much essential to burn the fuel inside the combustion chamber to produce useful power and undesired emissions. Pressure drop also plays an important role to improve engine performance characteristics. Effective air filtration is essential to protect the engine from particulate contaminants such as dust which can significantly impact engine wear and performance.

Dust particles are enemies of the heart of the vehicle i.e. Engine. If dust particles enter into combustion chamber of the engine leads to ENGINE WEAR and it is quit complex and mainly depends on Particle size, Particle concentration, Type of contamination [1].

Quartz (Silica) is a major component of dust. Silica is harder than steel, and quickly wears steel components inside engines, compressors, and blowers. Abnormal wear is associated with contamination levels found inside the engine, which increases oil consumption, engine overheating, loss of power, exhaust emission failure etc. Contamination levels are controlled by the type of AIS used.

The air filter should be designed to adequately protect the engine for the severe conditions which are going to encounter during its service life.

Airborne dust particles are very abrasive in nature and will cause maximum piston ring to cylinder wall wear. Harmful particle sizes are in the range of 1 to 20 μm . Particles' size less than 1 μm don't cause any significant wear, but their presence weakens the oil film.

The air filter should be designed to adequately protect the engine for the severe conditions which are going to encounter during its service life. Wear rates may increase exponentially with the presence of abrasive particles even in small amounts. Wear rates are also proportional to

- The amount of ingested dust concentration

- Particle number concentration
- Particle size
- Particle shape
- Particle type

2. PROBLEM STATEMENT AND STUDY OF AIR INTAKE FILTRATION SYSTEM

2.1 Problem Statement:

Optimization of existing design to reduce overall pressure drop across air intake system plays a vital role in improving engine performance in terms of power, fuel economy and emission. Engine performance characteristics such as power, fuel economy and emission can be improved by reducing pressure drop in the system.

Objectives of the Project: To reduce pressure drop by 10% (its requirement from customer) for an existing air intake filtration system.

Approach: ALD (Analysis Lead Design) approach will be used to optimize the design to reduce the pressure drop across the system. **Competitor's** Air Intake System will be benchmarked to understand the different technologies available in the market.

The existing design will be studied and many regions are identified to optimize the design.

CAD and CAE tools required: Parts' modeling will be done in Pro-E and the CFD simulation will be done using FLUENT.

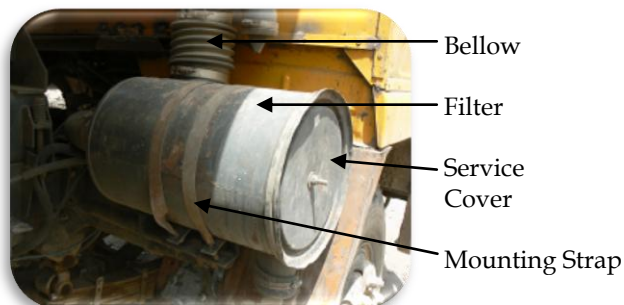
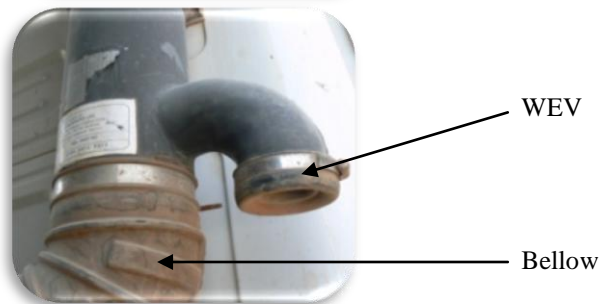
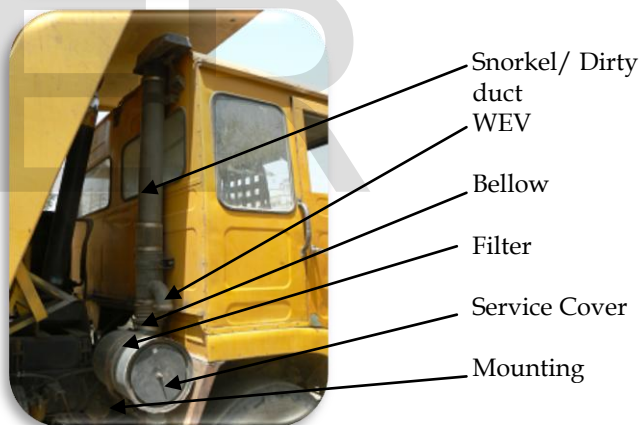
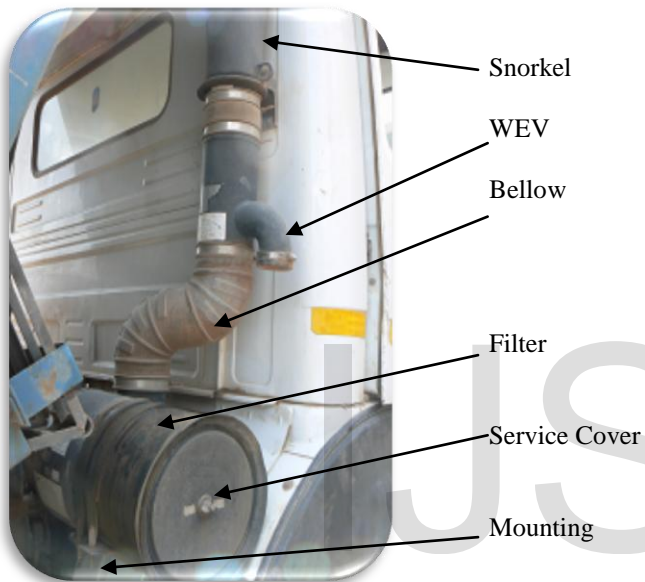
2.2 Study of existing Technologies:

A study was done on the complete air intake system of different trucks found on Indian Roads, especially in Pune.

TATA 2518

for most of the Indian make Trucks.

ASHOK LEYLAND - TAURUS HD2516



Specifications:

Make: Cummins B 5.9 BS-III,
 No. of Cylinders: 6 Inline,
 Capacity: 5.9 L,
 Aspiration: Turbo with Intercooler,
 Rated RPM: 2500
 Rated Power: 135KW
 Max. Torque: 680 N-m.
 Intake Air Flow Rate: 481 CFM

Figure 1 : TATA 2518

This air intake system consists of air filter assembly made by FLEET GUARD; T-Type intake opening, which is being used



Figure 2: ASHOK LEYLAND - TAURUS HD2516

This air intake system consists of air filter assembly made by FLEET GUARD; T-Type intake opening, which is being used for most of the Indian make Trucks. Pre-cleaner is a part of Filter. Mesh (Cigarette Screen) at the Intake entrance is made up of metal. It has MAF sensors.

Typical air intake system consists of following parts:

2.2.1 Snorkel: It is the plastic part which transports the air from pre-cleaner to main filter without any leakage of air. It should separate the water. It should accommodate cigarette screen or/ and pre-cleaner (if required). It should have proper mounting arrangement so that it can be mounted on the cab (optional). Its location should be such that it should not draw warm air.

2.2.2 Bellows: It is the rubber part which absorbs the vibrations caused by cabin (if snorkel is attached to cab). It prevents the relative movement between the section of the system attached to the cab and the section attached to the frame. Under no operating conditions bellows may be detached from the air filter or the unfiltered-air pipe and allow ingress of water, dirt and warm intake air. The interface between the bellows and the unfiltered-air pipe or intake duct shall be designed in such a way as to prevent the ingress of water and dirt completely. It must be designed to be as simple and easy to assemble. Its material shall be moulded components made from rubber. The maximum permissible deformation of the bellows is 10%. It needs to be tested for vibration.

2.2.3 Service Cover: Service cover is made of plastic which protects filter element from outside environment. It enables to replace the filter element at the time of servicing. It is the connection between bellow and air filter assembly. It may accommodate dust/water ejection valve.

2.2.4 Dust/Water ejection valve: It is the rubber part which is used to drain water or dust from air filter.

2.2.5 Air Filter Assembly: It consists of primary element, secondary element and filter housing.

Primary Element: It is the replaceable filter element on which the contaminant accumulates first. It must have higher efficiency, higher dust loading capacity, lower restrictions, longer durability and robustness, recyclable. The filter element must

be of adequate dimensions, so that the specified service intervals can be adhered to even when there is a high concentration of dust in the ambient air. The tests required for this filter element are vibration test, pressure drop test, collapse test, dust holding, efficiency test.

Secondary Element: It is the replaceable filter element that usually fits inside the primary filter element. The purpose is to prevent contaminant from entering the clean air ducting while servicing the primary. Typically, the safety element is changed once for every 3-5 times primary change. It should not create a high pressure drop.

Filter Housing: It is the outer cover made of plastic which accommodate filter element, pre-cleaner (if required) and secondary filter element (if required). It holds dust particles up to the required quantity specified by the customer. It accommodates the dust ejection valve.

2.2.6 Filter Mounting Bracket: It may be located on engine, or frame. It should hold the air filter assembly at any specified working environment. At any time it should not fail to hold the air filter assembly. It should be easily accessible so that changing of filter should be easy. Test required for validation is vibration test.

2.2.7 Clean Air Duct: It is the duct which transports specified amount of clean (filtered) air with specified velocity to the intake manifold or turbo charger intake, whichever is applicable. It should have a provision of accommodating many sensors like vacuum sensor, MAF, Humidity sensor and by pass line for air compressor (optional). It should not be detached at any operating condition.

3. SELECTION OF RIGHT FILTER AND DESIGN GUIDELINES

3.1 Selection of right filter:

Selection of right filter to suit for the required application with the given specifications plays a very important role in designing a filter system.

Preparation of selection Matrix:

Basically Air Filter can be defined using Four Variables, viz.

- Filtration Efficiency
- Initial Pressure Drop
- Flow Rate
- Dust Holding Capacity.

For example if we have the initial pressure drop along with the flow rate data available with us then we can plot the graph and select the appropriate filter.

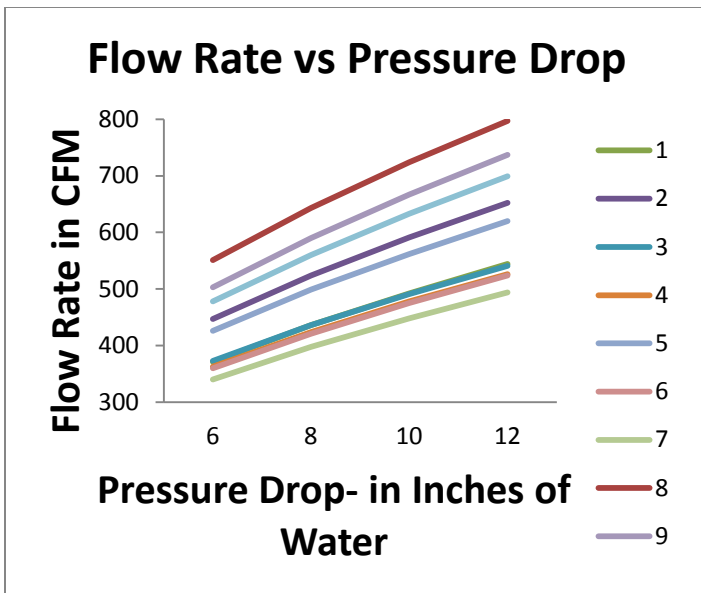


Figure 2: Flow rate versus Pressure drop

The Air Induction System inducts, transports, and filters a sufficient quantity of ambient air to satisfy the engine's need of sufficient clean air while minimizing the intake, noise and minimal pressure drop across the system

3.2 Design Guidelines:

The Air Induction system will provide the following functions:

- Induct and transport air in sufficient quantities to satisfy the engine air demands.
- Filter the air, Reduce & control the ingested dust concentration levels within acceptable limits.
- Reduce overall engine wear.
- Smooth engine performance.
- Serviceable air filter element.
- Minimize water, snow, and particulate ingestion.
- Attenuate engine and air flow noise that is transmitted through the air induction system.
- The AIS will monitor differential pressure (DP) across the air filter, identify when the filter needs servicing, and provide an appropriate indication to the driver / owner.
- Provide stable and repeatable air flow for the Mass Air Flow (MAF) sensor operation.
- Minimize air leakage between the Filter and the Turbocharger.
- Provide attachment of the following:
 - Sensors like MAF, Humidity, etc.
 - Bypass air line for compressor.

Key Requirements of air induction system:

- Filtration efficiencies (initial and overall).
- Dust/contaminant removal capacity.
- Water and snow ingestion
- Overall sound attenuation;
 - In passenger cabin (drivers right ear).
 - Drive by noise requirements.

- Flow management (power loss).
- Overall Emissions.
- Service requirements.
- Packaging requirement, styling and appearance.

Design Considerations:

- Higher filtration performance: To improve engine performance characteristics and to protect the engine from wear.
- Packaging requirements: To meet the customer requirements & to save the space.
- Lower system restrictions: To reduce the pressure drop, hence to increase the performance of filter.
- Serviceability: To easily service the filter at the time of servicing.
- Induction noise: Some of air filters reduces the intake noise which protects human ears which are seating inside the cabin.
- High dust holding capacity: It increases efficiency of air filter thus service life also increases.
- Higher efficiency: It increases service life of filter and reduces maintenance cost.
- Longer durability: It increases filter life and reduces maintenance cost.
- Robustness: It reduces damaging chances to air filter, hence reduces maintenance cost
- Superior sealing: It protects filter, engine as well as occupants inside cabin from dust.
- Manufacturability: It reduces production cost of air filters thus reduces its final cost.
- MAFS performance: Mass air flow sensors are required to measure the amount of air flows through filter.
- Generic designs: Generic designs save lot of time of designers while designing the filters and hence reduces design cost.

3.2.1 Design guidelines for the each component of the air intake filtration system:

1. Cigarette Screen

❖ Design Considerations:

- Material: metal or plastic, preferably polyamide
- Tests: Pressure drop.
- Analysis required: CFD for pressure drop.



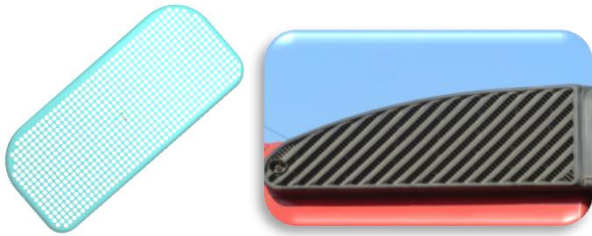


Figure 3: Typical Cigarette Screen

- ❖ **Calculations:** To calculate the Open Surface Area Required.

$$A = \frac{Q}{V_{\max}}$$

Where,

A. = Open Surface Area of Cigarette Screen, m²

Q. = Volume Flow Rate of Air, in m³/min

V_{max}. = Maximum Velocity of Air at intake of the Screen, in m/min.

2. Pre-Cleaner

This is situated before the main filter.



Figure 4: types of Pre-cleaner

❖ **Function:**

To increase main filter service life, by removing the larger dust particles up to 80% dust separation.

It can be achieved with many techniques. To name a few, Spin on type, Vortex tubes etc. or even if the air entering into the filter housing tangentially, then it also serves as the pre cleaner.

❖ **Design considerations (if it is not a part of Filter)**

- To get a minimum degree of separation for dust of 80%, design of vortex tubes to be considered, so that higher swirl is generated in the incoming air, so that most of the dust is separated out.
- The minimum no. of vortex tubes can be arrived by knowing the capacity of each vortex tube, which will come from experimental validation.
- Material: Operating Temperature must be kept in mind and plastic may be used. Ex: Poly Propylene or Poly amide
- Tests: Pressure drop and dust and water separation.
- Analysis required: CFD for pressure drop.

3. Snorkel:

❖ **Functions:**

- To transport the unfiltered air from inlet to air-filter.
- To separate water.
- To reduce the turbulence of flow of air.

❖ **Design considerations:**

Fluid flow in pipes is affected by many different factors:

- The viscosity, density, and velocity of the fluid.
- Changes in the fluid temperature will change the viscosity & density of the fluid.
- The length, inner diameter, and in the case of turbulent flow, the internal roughness of the pipe.
- The number & types of bends in the pipe layout.
- Entrance & exit conditions of the pipe.
- Fluid flow in pipes is affected by many different factors:

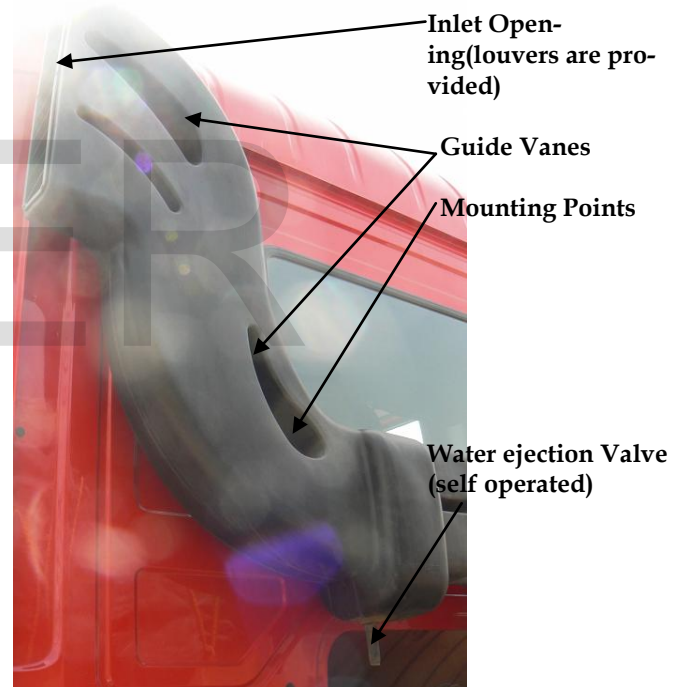


Figure 5 Typical Snorkel

Basically Snorkels can lead to drop in pressure for 3 reasons:

Head Loss due to lesser open cross section area, Skin Friction Drag & Form Drag Friction.

Head Loss due to lesser open cross section area:

Ideally inlet opening of the snorkel can be calculated using the following formula.

Inlet Opening cross sectional area,

$$A = \frac{CMM}{V_{\max}}$$

Where,

CMM. = the air flow rate in m³/min

Vmax. = the Unfiltered Air Intake Maximum flow Velocity in m/min

The empirical relation between pressure drop and area of cross section can be given as below:

$$\Delta P \propto \frac{1}{A^2}$$

Reynolds Number: A useful factor in determining which type of flow is involved is the Reynolds number. This is the ratio of the dynamic forces of mass flow to the shear resistance due to fluid viscosity and is given by the following formula.

$$Re = \frac{\rho * v * d}{1000 * \mu}$$

Where:

ρ = Density (kg/m³)

v = Mean velocity in the pipe (m/s)

d = Internal pipe diameter (mm)

μ = Dynamic viscosity (Pa s)

In general for a fluid like water when the Reynolds number is less than 2300 the flow is laminar. The flow is turbulent for Reynolds numbers above 4000.

Calculating the total pressure drop:

The total fluid head resistance may be used to calculate the pressure required to overcome the resistance to fluid flow.

$$Pd = h * \rho * g$$

Where,

Pd.= pressure drop (bar)

h. = head loss (m)

ρ . = fluid density (kg/m³)

g. = acceleration due to gravity (m/s²)

4. Air Filter:

Filter housing should be made from plastic. The point of intake must be of a design suitable for largely preventing the ingress of particles and water into the system. It must also ensure that the filter element remains sealed on the filtered-air side under all operating conditions.

Primary Media

- Media can be selected based on the requirement like paper media wetted with an agent, which increases the initial filtration efficiency as well as dust holding capacity.

Filter Housing

❖ **Design Considerations:**

- It depends on the size and dimensions of the primary and secondary filter elements.
- Material used: Poly amide

Air filter- Secondary:

❖ **Design Considerations:**

- Material to be selected on the basis of operating temperature conditions, the level of vibration absorption etc. preferably EPDM

4. STUDY OF EXISTING DESIGN

The optimization carried out using a strategy of Analysis Lead Design (ALD), in which the existing design will be studied for pressure drop and critical regions would be identified and optimized the parameters of the design at those regions to come up with optimization of pressure drop.

The layout of current design is as follows:

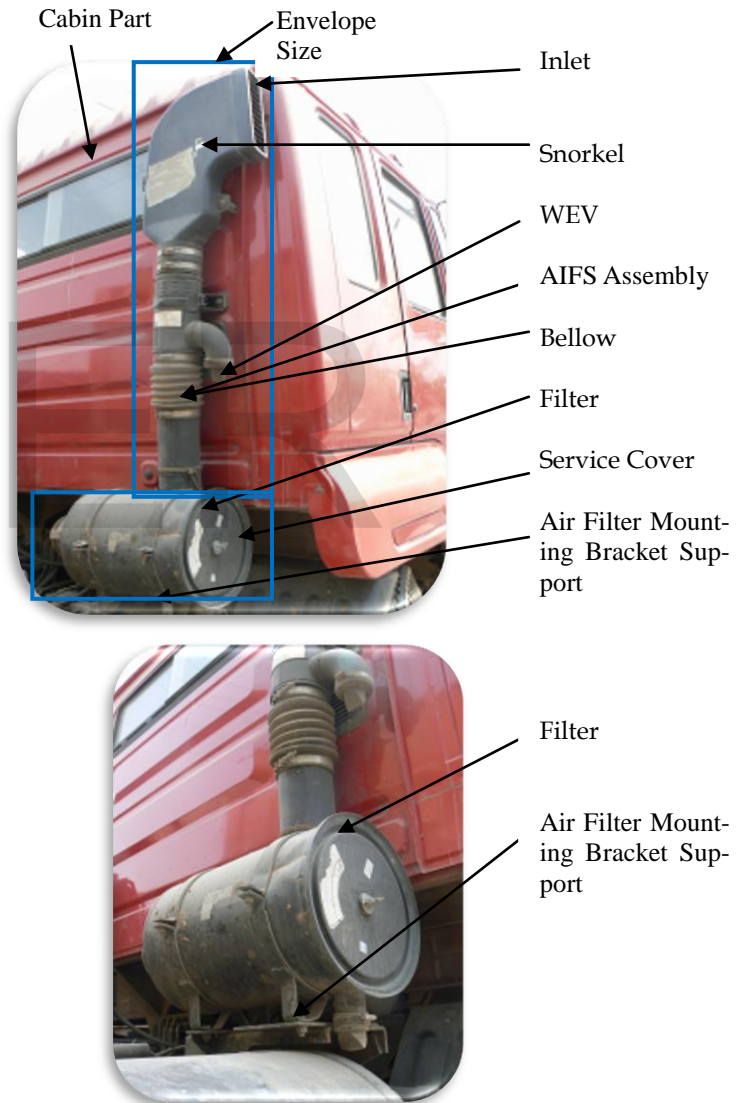


Figure 5: Existing Design of AIS

The total pressure drop of 17.02 inches of water is observed in this existing design in following areas:

- Inlet-Screen Outlet
- Across Pre-Cleaner Region
- Across Snorkel
- Inlet Bellows Out-Filter Body in
- Filter Body In to Primary Media Inlet
- Across Primary Media
- Between Primary & Secondary Media
- Across Secondary Media
- Secondary Media Outlet-to-Filter Body Outlet
- Across MAF & Turbo Piping
- Exit Outlet

By changing the design parameters we are trying to optimize the design to reduce the overall pressure drop in the system. Then we will run CFD analysis to evaluate pressure drop in the system. These CFD results will be verified with mathematical solution by using CFD equations.

5. CONCLUSION

Optimization of existing design to reduce overall pressure drop across air intake system plays a vital role in improving engine performance in terms of power, fuel economy and emission. Engine performance characteristics such as power, fuel economy and emission can be improved by reducing pressure drop in the system.

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Nomenclature:

AIFS- Air Intake Filtration System
CFM- Cubic Feet per Minute
CFD- Computational Fluid Dynamics
AIS- Air Intake System
AIF- Air Intake Filtration
SPL-Sound Pressure Level (decibel)
WEV- Water Ejection Valve

MAF.-Mass Air Flow

EPDM- Ethylene Propylene Diene Monomer

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