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AUTOMOTIVE INTAKE MANIFOLD

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ABSTRACT

The intake manifold of a spark-ignition engine carries the air that passes the throttle body to the individual cylinders. Its geometry decides how much air each cylinder receives, how much pressure is lost on the way, and how evenly the charge is shared between cylinders. A manifold that feeds one cylinder better than another causes unequal air-fuel ratios, uneven combustion and a loss of power, while a high pressure drop reduces the volumetric efficiency of the engine. This project studies the design of an intake manifold for a four-cylinder, 1.2 litre, naturally aspirated petrol engine using computer-aided design and computational fluid dynamics.

The manifold was modelled in SolidWorks as a parametric assembly of a throttle inlet, a plenum and four runners, so that the plenum volume, runner diameter, runner taper and entry shape could be changed from a small set of dimensions. Three design variants were prepared from this model. The baseline variant has a 1.2 litre plenum with straight runners of 32 mm diameter. The second variant keeps the same plenum but uses runners that taper from 36 mm at the plenum to 30 mm at the port. The third variant combines the tapered runners with a larger 1.8 litre plenum and bellmouth entries at the runner inlets.

The internal air volume of each variant was extracted and analysed in ANSYS Fluent as a steady, incompressible-corrected turbulent flow using the k-omega SST model. A mass-flow inlet of 0.058 kg/s, corresponding to the engine at about 5500 rpm, was applied at the throttle face, and the four runner exits were set as pressure outlets. A mesh independence study fixed the mesh at about 1.86 million poly-hexcore cells with inflation layers on the walls. Velocity contours, pressure contours, streamlines, the mass flow through each runner, the total pressure drop and a volumetric efficiency index were compared for the three variants.

The baseline manifold showed a maximum runner flow deviation of 7.6 percent from the mean, with runner 1 nearest the throttle receiving the most air, and a pressure drop of 3.42 kPa. Tapered runners reduced the deviation to 3.4 percent and the pressure drop to 2.86 kPa. The third variant gave the most uniform distribution, with a maximum deviation of 1.4 percent, a pressure drop of 2.41 kPa and a volumetric efficiency index of 0.903 against 0.874 for the baseline, a relative gain of 3.3 percent. A static structural check of the selected design in glass-filled nylon under a 0.3 MPa backfire pressure at 120 degrees Celsius gave a factor of safety of 4.2.

I. INTRODUCTION

In a reciprocating petrol engine the power that can be produced depends largely on the mass of air that enters each cylinder during the intake stroke. The intake manifold is

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the passage that connects the throttle body to the intake ports of the cylinder head, and it is therefore one of the components that most directly influences breathing. A typical manifold for an inline engine consists of a plenum chamber that receives air from the throttle and a set of runners that branch from the plenum to each port. The shape of these passages decides the resistance that the air meets and the share of air that each cylinder receives.

Two problems are common in manifolds designed without detailed flow study. The first is maldistribution, in which the cylinders nearest the throttle or aligned with the incoming jet receive more air than those at the far end of the plenum. Since the fuel injectors in a port-injected engine deliver nearly equal quantities to each cylinder, unequal air means unequal mixture strength, which raises emissions, reduces power and can cause knock in the lean cylinder. The second is excessive pressure loss caused by sharp bends, sudden area changes and flow separation at runner entries, which lowers the density of the charge reaching the cylinders and therefore the volumetric efficiency.

Computer-aided design and computational fluid dynamics provide a practical way to address both problems early in the design process. A parametric CAD model allows the designer to vary plenum volume, runner diameter, taper and entry radius quickly, and a CFD solver such as ANSYS Fluent can predict the velocity field, pressure field and mass flow split for each version without making a physical prototype. The results show where separation, recirculation and high velocity occur, and these locations can be corrected in the next design iteration.

This project applies such a workflow to the intake manifold of a four-cylinder, 1.2 litre engine. A baseline manifold and two improved variants are modelled in SolidWorks, analysed in ANSYS Fluent under the same boundary conditions, and compared on runner flow uniformity, pressure drop, peak velocity and a volumetric efficiency index. The selected variant is then checked for strength under backfire pressure at operating temperature. The aim is to identify a manifold geometry that shares air evenly between cylinders with the least pressure loss while remaining suitable for manufacture.

II. LITERATURE SURVEY

Studies on intake system design have long recognised that the manifold affects both the quantity and the distribution of air delivered to an engine. Early experimental work used steady flow benches, on which air is drawn through the manifold by a blower and the flow through each runner is measured with orifice plates or hot-wire probes. These tests showed that the cylinders at the ends of the plenum and those facing the throttle jet often differ in flow by several percent, and that the difference grows with engine speed. Researchers also observed that sharp-edged runner entries create a vena contracta that reduces the effective flow area, and that rounding the entry into a bellmouth recovers a large part of this loss. Flow bench methods remain useful for validation, but they require a physical part for every geometry tested, which makes them slow and costly during early design work.

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Wave dynamics in the intake system form a second major area of study. When an intake valve closes, the moving air column is brought to rest and a pressure wave travels back along the runner, reflects at the plenum and returns towards the valve. Investigations of this effect showed that a runner of suitable length can time the returning wave so that it arrives at the next valve opening and raises the pressure in the port, a process known as ram or tuning effect. Work on variable-length intake systems has used this principle to improve torque at different speeds. The literature points out that runner length mainly governs the speed at which tuning occurs, whereas runner diameter and taper govern pressure loss and mean velocity, so both must be considered together when a manifold is designed for a given engine.

Computational fluid dynamics has become the most common tool for manifold analysis in recent studies. Researchers have modelled the internal air volume of manifolds in commercial solvers and solved the Reynolds-averaged Navier-Stokes equations with two-equation turbulence models such as standard k-epsilon, realizable k-epsilon and k-omega SST. Comparisons with flow bench measurements have generally shown agreement in runner mass flow within a few percent, with the k-omega SST model giving better prediction of separation near bends and entries. Mesh independence studies and the use of inflation layers near walls are repeatedly described as necessary for reliable pressure drop predictions. Most published analyses treat the flow as steady with all runners open, which does not capture valve events but gives a consistent basis for comparing alternative geometries under the same conditions.

Several design studies have used CFD to compare manifold variants and recommend geometric changes. Reported modifications include increasing plenum volume to reduce the influence of the throttle jet, moving the throttle inlet from the end of the plenum to its centre, tapering the runners towards the port to accelerate the flow smoothly, and adding radiused or bellmouth entries. These studies commonly report improvement in flow uniformity, measured as the deviation of individual runner mass flow from the mean, together with reductions in pressure drop. A recurring observation is that a larger plenum improves sharing but increases the volume between throttle and valves, which can slow the throttle response, so the plenum is usually sized as a multiple of the engine swept volume rather than made as large as possible.

Material and structural aspects have been studied alongside flow performance. Traditional manifolds were cast in aluminium alloy, while most current production manifolds are injection moulded in glass-fibre reinforced polyamide, which lowers mass, reduces heat transfer to the incoming air and gives smoother internal surfaces. Work on polymer manifolds has examined their strength under internal pressure from engine backfire, under vacuum during closed throttle operation and at the elevated temperatures found near the cylinder head. Finite element analysis is commonly used to check stresses and deformation for these load cases. The present project follows this combined approach, using parametric CAD, steady CFD comparison of three variants and a structural check of the selected design in a single study workflow.

III. SYSTEM ANALYSIS

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The system under study is the air path of a four-cylinder, 1.2 litre port-injected petrol engine, from the 48 mm throttle body to the four intake ports of the cylinder head. At about 5500 rpm the engine draws close to 0.058 kg/s of air, which must be divided equally among the four runners for each cylinder to receive the same charge. The analysis requires the internal fluid volume of the manifold, the operating air flow and the outlet conditions at the ports. The main quantities of interest are the mass flow through each runner, the deviation of each from the mean, the total pressure drop between throttle face and port exits, the peak velocity and the zones of separation or recirculation. These quantities are obtained from a steady CFD solution using the k-omega SST turbulence model on a verified mesh. The volumetric efficiency index is computed from the mean total pressure at the port exits relative to inlet conditions, and a structural check confirms that the chosen geometry can carry backfire pressure at operating temperature.

Existing System

In conventional practice, intake manifolds for small engines are often developed from an earlier design with modest dimensional changes, and their performance is judged through prototype testing. A pattern or a die is made, the manifold is cast in aluminium or moulded in polymer, and the part is tested on a flow bench or on an engine dynamometer. If uneven cylinder air flow or poor breathing is found, the geometry is altered and a new prototype is made, so every design iteration costs tooling, material and testing time. Flow bench tests give the flow through each runner but do not show where separation or recirculation takes place inside the passages, so the designer has limited guidance on what to change. Hand calculations based on pipe flow formulas estimate pressure loss in straight sections but cannot represent the interaction between the throttle jet, the plenum and the runner entries. As a result, maldistribution is often corrected only partly, by trimming injector pulse widths in the engine calibration rather than by improving the manifold itself.

Disadvantages of Existing System

- Each design change requires a new casting or moulding and a fresh prototype.
- Flow bench testing gives runner flow totals but not the internal flow pattern.
- Separation and recirculation zones inside the plenum and runners remain hidden.
- Hand calculations cannot represent the throttle jet striking the plenum walls.
- Unequal air distribution is often hidden by calibration rather than corrected.
- Comparing several plenum volumes and runner shapes takes weeks of testing.
- Tooling and material costs rise quickly with every iteration.
- Sharp runner entries and abrupt area changes are rarely evaluated in detail.
- Structural strength under backfire pressure is checked only after manufacture.
- Design decisions depend heavily on the experience of individual engineers.

Proposed System

The proposed approach develops the intake manifold through a combined CAD and CFD workflow in which design variants are compared virtually before any part is made. A parametric SolidWorks model defines the throttle inlet, plenum, runners and

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port flanges from a small set of driving dimensions, so plenum volume, runner diameter, taper and entry radius can be changed and regenerated quickly. Three variants are created: a baseline with a 1.2 litre plenum and straight 32 mm runners, a second with runners tapering from 36 mm to 30 mm, and a third that adds a 1.8 litre plenum and bellmouth runner entries. The internal air volume of each variant is extracted and meshed with poly-hexcore cells and wall inflation layers, and ANSYS Fluent solves steady turbulent flow under identical boundary conditions. Runner mass flow, flow deviation, pressure drop, peak velocity, streamlines and a volumetric efficiency index are compared, the best variant is selected, and its strength under backfire pressure at 120 degrees Celsius is checked in ANSYS Mechanical.

Advantages of Proposed System

- Several manifold geometries are compared without making a physical prototype.
- The parametric CAD model regenerates a new variant in a few minutes.
- Velocity and pressure contours show exactly where losses and separation occur.
- Mass flow through every runner is measured under identical conditions.
- Flow deviation from the mean gives a clear measure of cylinder air sharing.
- Pressure drop and a volumetric efficiency index quantify breathing performance.
- Runner taper, plenum volume and entry shape are evaluated one effect at a time.
- The selected design is checked for strength before tooling is ordered.
- Glass-filled nylon lowers mass compared with a cast aluminium manifold.
- The same workflow can be reused for other engines and operating speeds.

IV. METHODOLOGY

The work was carried out in a sequence of defined steps. First, the engine data, including swept volume, bore spacing of 76 mm, port diameter and throttle diameter, were collected and the design air flow of 0.058 kg/s was estimated for 5500 rpm at a volumetric efficiency of about 0.9. Second, the baseline manifold was modelled in SolidWorks with global variables for plenum volume, runner diameter, taper and entry radius, and the two improved variants were generated by changing these variables. Third, the internal fluid volume was extracted, imported into ANSYS Fluent Meshing and meshed with poly-hexcore cells and five inflation layers; meshes of 0.92, 1.86 and 3.10 million cells were compared, and the 1.86 million cell mesh changed pressure drop by less than 1.2 percent from the finest one. Fourth, a mass-flow inlet, pressure outlets, no-slip walls and the k-omega SST model were applied and each case was converged to residuals below 1e-5. Finally, results were post-processed, the best variant selected and a static structural check performed.

SYSTEM ARCHITECTURE

The study workflow is organised as a pipeline with a design feedback loop. The Input Stage holds the engine specification, the operating air flow and the geometric constraints of throttle position, port spacing and packaging envelope. The CAD

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Modelling Stage in SolidWorks contains the parametric manifold model and the three design variants, and exports each as a STEP file. The Pre-processing Stage extracts the internal fluid volume, names the inlet, outlet and wall boundaries and generates the poly-hexcore mesh with inflation layers after the mesh independence check. The CFD Solver Stage in ANSYS Fluent applies the 0.058 kg/s mass-flow inlet, pressure outlets and k-omega SST turbulence model and iterates to convergence. The Post-processing Stage produces velocity and pressure contours, streamlines, runner mass flow reports, pressure drop and the volumetric efficiency index. The Variant Comparison Stage ranks the designs and feeds geometric changes back to the CAD stage, and the Structural Check Stage in ANSYS Mechanical verifies the selected manifold under backfire pressure and temperature.

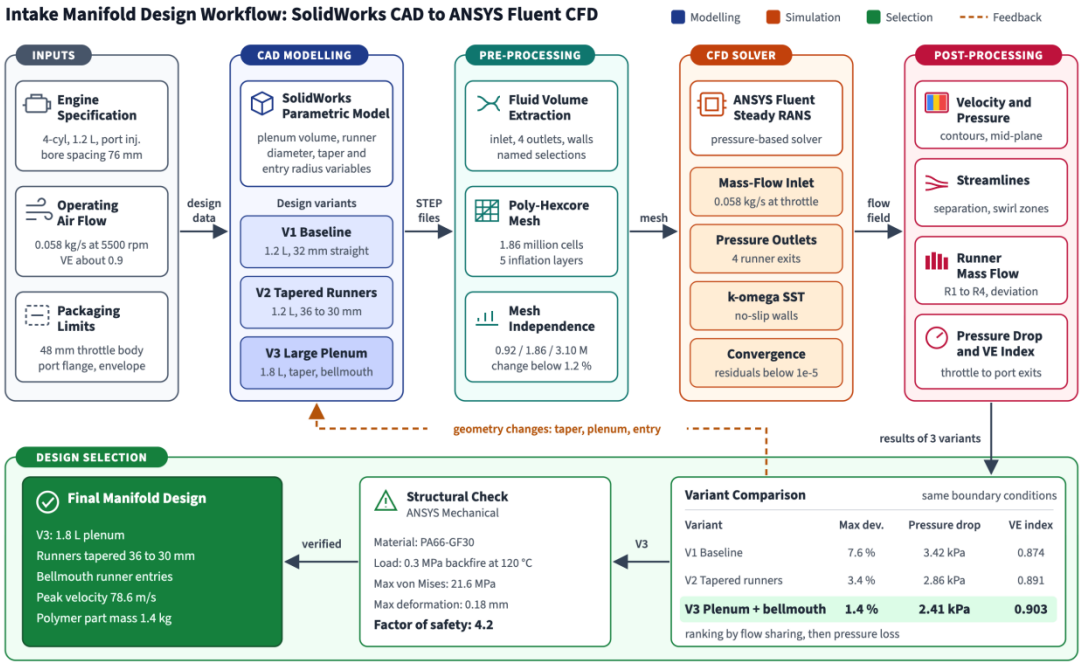


Fig. 1 System Architecture

V. RESULT AND OUTPUT

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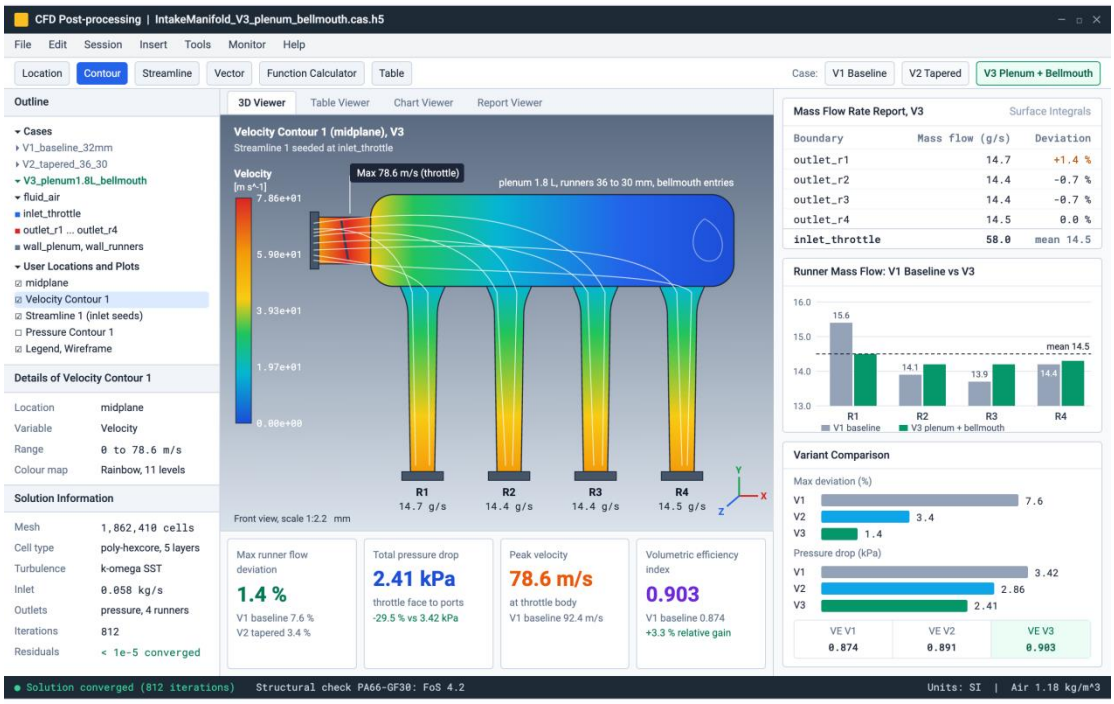


Fig. 2 Result and Output Screen

VI. CONCLUSION

This project developed the intake manifold of a four-cylinder, 1.2 litre petrol engine using a combined CAD and CFD workflow. A parametric SolidWorks model made it possible to produce three design variants from a few driving dimensions, and ANSYS Fluent was used to analyse all three under the same air flow of 0.058 kg/s and the same outlet conditions. Because every variant was solved on a verified mesh with the same turbulence model, the differences in results can be attributed to the geometry alone.

The baseline manifold, with a 1.2 litre plenum and straight 32 mm runners, delivered 15.6 g/s to runner 1 and 13.9 g/s to runner 3, a maximum deviation of 7.6 percent from the mean, and had a pressure drop of 3.42 kPa. The velocity contours showed the throttle jet striking the plenum wall opposite runner 1 and separation at the sharp runner entries. Tapering the runners reduced the deviation to 3.4 percent and the pressure drop to 2.86 kPa. The third variant, with a 1.8 litre plenum, tapered runners and bellmouth entries, reduced the deviation to 1.4 percent, the pressure drop to 2.41 kPa and the peak velocity from 92.4 m/s to 78.6 m/s.

The volumetric efficiency index rose from 0.874 for the baseline to 0.903 for the third variant, a relative gain of 3.3 percent, which indicates that each cylinder receives a denser and more evenly shared charge. The structural check of this variant in PA66-GF30 under a 0.3 MPa backfire pressure at 120 degrees Celsius gave a maximum von Mises stress of 21.6 MPa, a maximum deformation of 0.18 mm and a factor of safety of 4.2, and the polymer part has a mass of about 1.4 kg against 3.1 kg for an aluminium casting of the same shape.

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The results are based on steady simulation with all runners open, so they compare geometries rather than predict exact engine output. Future work can include transient simulation with valve opening sequences, coupling with a one-dimensional engine cycle model to study runner length tuning across the speed range, a check of the throttle response delay caused by the larger plenum, and flow bench tests of a 3D-printed prototype to validate the simulated runner flows and pressure drop.

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