

Computational Fluid Dynamic Analysis of Compressible Flow across a Complex Geometry Carburettor Venturi

Arvind.T, Swaminathan M. R

Department of Mechanical Engineering, College of Engineering, Anna University, Guindy, Chennai,
Tamil Nadu, India

Abstract—

A commercial computational fluid dynamics package could be used to develop a three dimensional, fully turbulent model of the compressible flow across a complex geometry venturi, such as those found in small engine carburetors. The results of the CFD simulation can be used to understand the effect of the different obstacles in the flow on the mass flow rate and the static pressure at the tip of the fuel tube. This would be helpful to analyze the pressure loss in the throat area. Analysis would be performed to study airflow across carburettor venturi by locating fuel tube at the diverging nozzle of the venturi and for various positions of throttle valve in the present paper, fuel tube and throttle plate would be modelled and analyze in order to have better understanding of the flow in complex venturi. The results of this study necessitate for modification throttle valve design. The carburettor body is remodelled with two throttle bodies replacing conventional throttle. Analysis has been performed to study flow field with modified design and results have been discussed.

Keywords— CFD, Carburettor, Venturi, Throttle plate

I. INTRODUCTION

Large volumes of small engines (two wheelers) are being sold in India every year. Its emissions comprise a significant percentage of total pollutants in India. As demonstrated by the automotive industry, significant reductions in emissions are technologically possible, particularly with the use of electronic fuel injection. However, due primarily to cost constraints, small engine manufacturers rely on small, inexpensive carburetors to generate the fuel mixture for their engines. Thus, a better understanding of carburettor performance and modelling could lead to better fuel mixture control and lower emissions from small engines.

A real carburettor venturi has details in its geometry that create disturbances in the flow and may cause pressure losses that cause deviations from an ideal isentropic flow. Examples of these carburettor parts are the choke plate, throttle plate, fuel tube, side passages to secondary systems, and, sometimes, an additional concentric fuel tube in the venturi throat. Some details of typical carburetors used in small engines are shown in figure. The pressure losses created by these elements reduce the mass flow rate that could be driven through the venturi for a given pressure difference between the inlet of the venturi and the intake manifold. In the present study, the inlet obstacles, fuel tube, and throttle plate were modelled with in order to gain a better understanding of the flow in complex venturis. The results of this study can be used to aid in the design of devices employing venturis, such as jet pumps, ejectors, venturi scrubbers, and industrial mixers. Several studies have addressed the modelling of fuel flow in carburetors: Asano et al. [1], Ehara et al. [2], Furuyama [3], Furuyama [4], Harrington and Bolt [6], Isobe and Asano [5], Jagdish et al. [7], Sendyka and Filipczyk [8], Sendyka and Heydel [9], and J. Szczecinsky and Rychter [10]. All of these studies are based on the representation of carburettor circuits as a flow network under steady state conditions. The configurations of all of these studies are slightly different from each other, but they proved the feasibility of the representation of the carburettor circuits as flow networks.

II. PHYSICAL MODEL OF THE PROBLEM

The detail of carburettor parts inside the venturi is shown in Fig. 1. The simplest model of airflow in a carburettor venturi is based on the equations for compressible flow of an ideal gas through a converging isentropic nozzle. The air mass flow rate m_a is given by:

$$m_a = C_d A_t \sqrt{2 \rho_{a0} (P_{v,0} - P_{v,t}) \phi}$$
$$\phi = \left[\frac{\gamma}{\gamma-1} \right] \left[\left(\frac{P_{v,0}}{P_{v,t}} \right)^{2/\gamma} - \left(\frac{P_{v,0}}{P_{v,t}} \right)^{\gamma+1/\gamma} \right]^{0.5} / (1 - P_{v,0}/P_{v,t})^{0.5}$$

where C_d is the discharge coefficient based on the throat area A_t , ρ_{a0} is the air density at total inlet conditions, $P_{v,0}$ is the isentropic stagnation pressure at the inlet of the venturi, and $P_{v,t}$ is the static pressure at the venturi throat accounts for the compressibility effects, where γ is the ratio of specific heats. These expressions can be used for real gases by using the compressibility factor Z in the denominator of the above equation. The above equations may be regarded as a steady-state one dimensional model of compressible flow across a variable area duct. For a given flow rate, they can be used to predict the static pressure as a function of the local duct area, assuming that all the properties of the flow are uniform across the cross-sectional area.

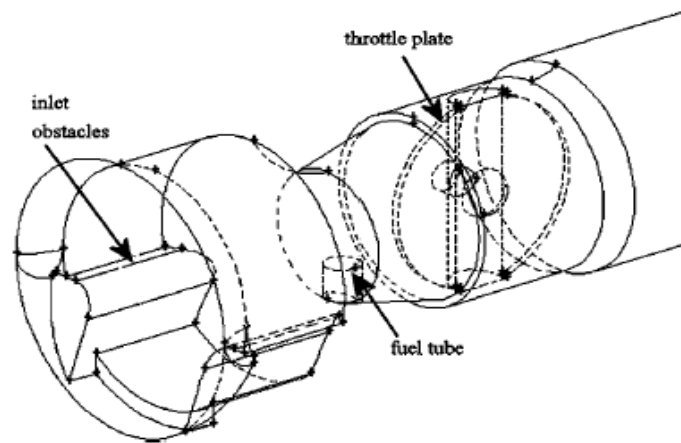


Fig. 1 Carburettor Model

III. THREE DIMENSIONAL CFD STUDY

A. General Characteristics of the Numerical Model.

A three-dimensional model of a carburettor venturi was generated in CFD tool CFX to study the effect of different venturi parts on the flow field and is shown in Fig. 2. The geometry was discretised with tetrahedral mesh, with a refined mesh near the venturi throat. The RNG k- ϵ turbulence model was used, with standard wall functions for near-wall treatment. The discretisation scheme used was second order in space. The convergence criteria were set to a maximum residual equal to 1×10^{-6} for the energy equation and to 1×10^{-4} for the other equations.

The inlet boundary condition was defined with the isentropic stagnation pressure and temperature, and the outlet boundary condition was defined with the outlet static pressure. An ideal gas model was used in order to take into account the compressibility of the airflow.

B. Boundary conditions

The carburettor venturi had an inlet diameter of 25 mm, a throat diameter of 12 mm and exit diameter of 20 mm. This venturi had inlet obstacles, a fuel tube, and a throttle plate. The inlet boundary conditions in CFX were set to the laboratory conditions ($T_0=293$ K and $P_0=1$ atm) and the outlet boundary condition to the outlet pressure in the low-pressure plenum in the flow bench $P_{out}=94.5$ KPa. Four throttle plate angles were simulated: 90 deg (wide open throttle), 75 deg, 60 deg, and 45 deg. The CFD results were used for assessing the details of the flow, the values of the discharge coefficients, and localized values of the flow variables; specifically, the static pressure at the tip of the fuel tube. The following sections present a systematic study of the effect of different carburettor parts. First, carburettor venturi was modelled without obstacles. Second, the inlet obstacles were added, and then the fuel tube was added to the geometry. Finally, the effect of throttle plate angle was studied.

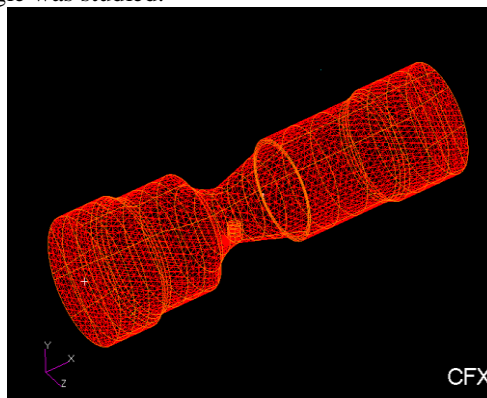


Fig. 2 Meshed model

C. Venturi without obstacles

The Fig. 3 shows the static pressure, velocity, turbulent kinetic energy, Total pressure and velocity vector for a compressible air flow across the venturi without obstacles i.e. fuel tube and throttle plate. In the Fig. 3 (a), the Static Pressure is almost uniform in the radial direction except at the throat where it changes next to the wall. After venturi the pressure variation is almost constant (no pressure fluctuation). In the Fig. 3 (b), the velocity increases at the converging nozzle and then separates from the wall at the diffuser in the region of adverse pressure gradient. The velocity is almost constant behind the venturi. In the Fig. 3(c), the total pressure (stagnation pressure) is uniform throughout the flow except at the wall of the throat. Generally the reduction in stagnation pressure creates wake region (turbulence region). In the Fig. 3 (d), the turbulence kinetic energy field shows that the intensity of turbulence created. The highest turbulence region created at near wall throat.

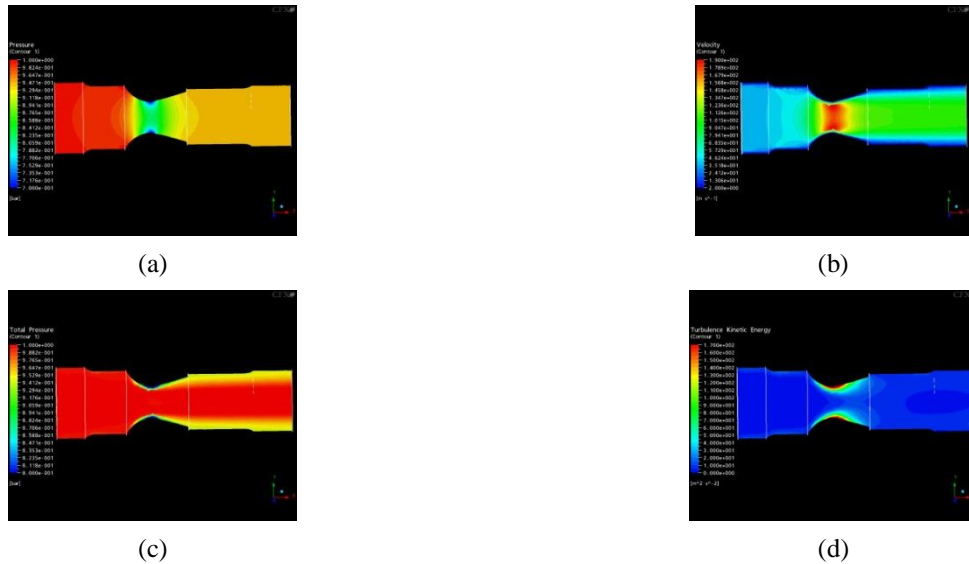


Fig. 3 Steady air flow across carburettor Venturi without obstacle:

(a) Static Pressure (bar) (b) Velocity (m/s) (c) Total Pressure (bar) (d) Turbulent Kinetic Energy (m^2/s^2)

D. Effect of fuel tube

The Fig. 4 shows the static pressure, velocity, turbulent kinetic energy, total pressure and velocity vector for a compressible air flow across the venturi with fuel tube of 3 mm diameter with projection of 3 mm at throat section i.e. $1/4^{\text{th}}$ of throat diameter.

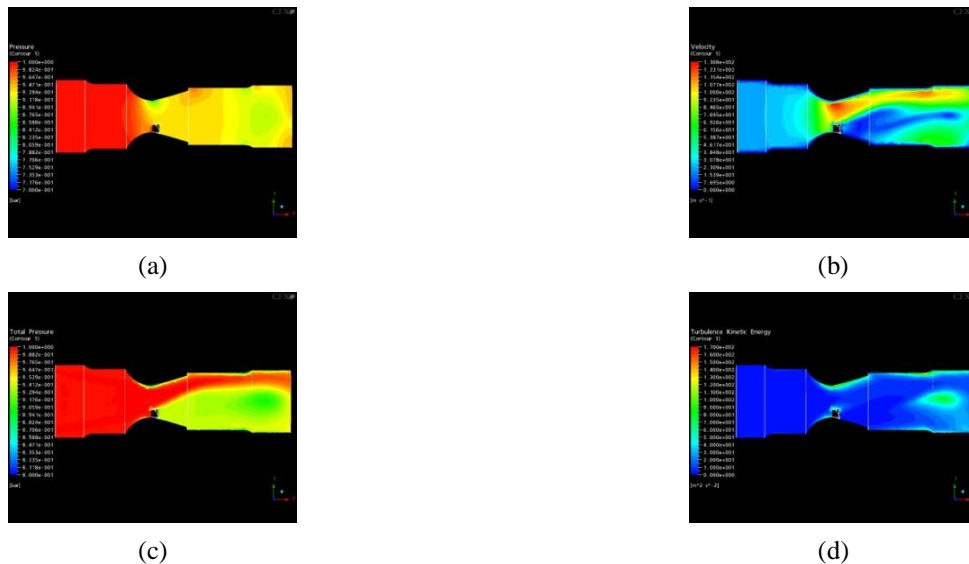


Fig. 4 Steady air flow across carburettor Venturi with fuel tube of 3 mm diameter with projection of 3 mm at throat section:

(a) Static Pressure (bar) (b) Velocity (m/s) (c) Total Pressure (bar) (d) Turbulent Kinetic Energy (m^2/s^2)

In the Fig. 4 (a), the presence of fuel tube strongly affects flow field and static pressure drop in the venturi. It reduces the cross sectional area and also comparatively lower pressure drop at throat in the radial direction. In addition, a sharp leading edge of the fuel tube creates a separation region, which results in a lower pressure at the tip of the fuel tube. Downstream of fuel tube, it is almost uniform in radial and axial directions. In the Fig. 4 (b) and (c), the presence of fuel tube effectively reduces the velocity and creates the wake region (fluctuating velocity field) behind the venturi. This wake zone may be responsible for fuel puddling after the carburettor; once the fuel droplet is captured in this region, there is no momentum to drive it to the manifold. The stagnation pressure shows that there is a considerable reduction behind the venturi with the presence of fuel tube and ultimately creates turbulence region. In the Fig. 4 (d), the kinetic energy field shows that the wake is created in the downstream of fuel tube. The intensity of turbulence is high at the downstream and is moderate at the near wall throat.

E. Effect of throttle plate at wide open angle

Besides the fuel tube the throttle plate is another largest restriction for the air flow in the intake manifold. The throttle plate was modelled as close as possible with axis rod, plate and screw. The carburettor venturi has been simulated for various positions of throttle plate with fuel tube 3 mm height. The Fig. 5 shows the Static Pressure, Velocity, Turbulent Kinetic Energy, Total pressure and Velocity vector for a compressible air flow across the Venturi with fuel

tube (3 mm) and Throttle plate at 90 degrees position. The Fig. 5 (a) shows that at wide open throttle plate position (i.e. aligned with the flow), there is no significant variation of static pressure at downstream. Additional stagnation points are created by the leading edge of the throttle plate, shaft and screw. In the Fig. 5 (b), the velocity field shows that fuel tube and throttle make large obstruction in the flow. The velocity of the flow is immediately reduced behind the fuel tube and throttle plate and again there is a rise in velocity at downstream. This will create wake region. These wake region create improper fuel mixing with air. In the Fig. 5 (c), the stagnation pressure field shows that the throttle plate position strongly affects the variation. There is a drop in stagnation pressure observed surrounding the throttle plate in top view position. In the Fig. 5 (d), the turbulence kinetic energy indicates that there is increased turbulence near the downstream and also at the walls.

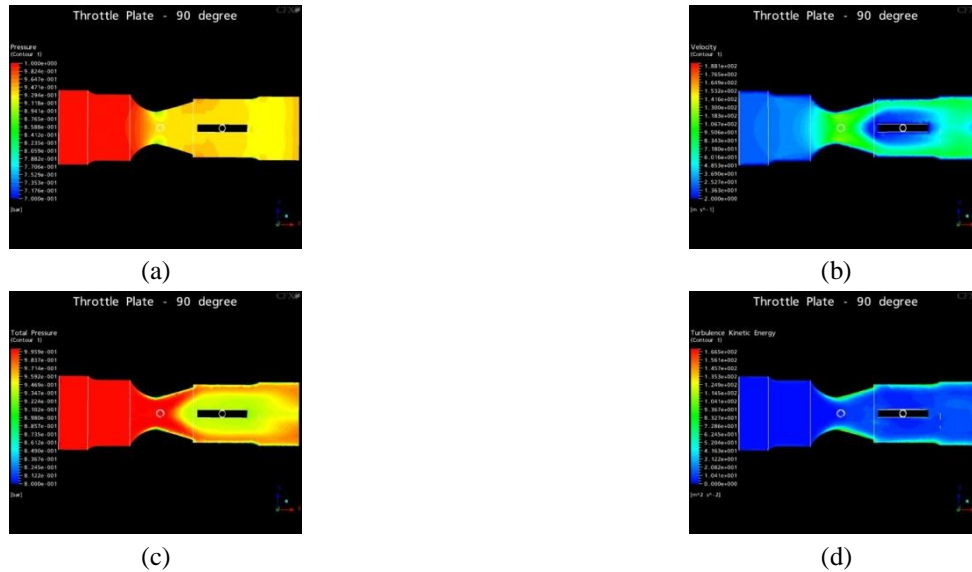


Fig. 5 Steady air flow across carburettor Venturi with fuel tube of 3 mm diameter with fuel tube (3 mm) and throttle plate at 90 degrees position:
 (a) Static Pressure (bar) (b) Velocity (m/s) (c) Total Pressure (bar) (d) Turbulent Kinetic Energy (m^2/s^2)

F. Effect of throttle plate at 75 degree angle

The Fig. 6 shows the Static Pressure, Velocity, Turbulent Kinetic Energy, Total pressure and Velocity vector for a compressible air flow across the Venturi with fuel tube (3 mm) and Throttle plate at 75 degrees position. In the Fig. 6 (a), the pressure field varies at the downstream as well as varies with a small magnitude before throttle position. In the Fig. 6 (b), the velocity field shows that drop in velocity near the walls of throttle plate and it continuous along the stream line till downstream. Near the walls of carburettor the flow observed as uniform. In the Fig. 6 (c) the stagnation pressure field indicates that loss in stagnation pressure surrounding the throttle plate and at downstream is comparatively higher than throttle plate 90 degrees position and also indicates the increased asymmetry in the flow. In the Fig.6 (d) the turbulent KE shows that increased turbulence near the throttle plate walls and at downstream.

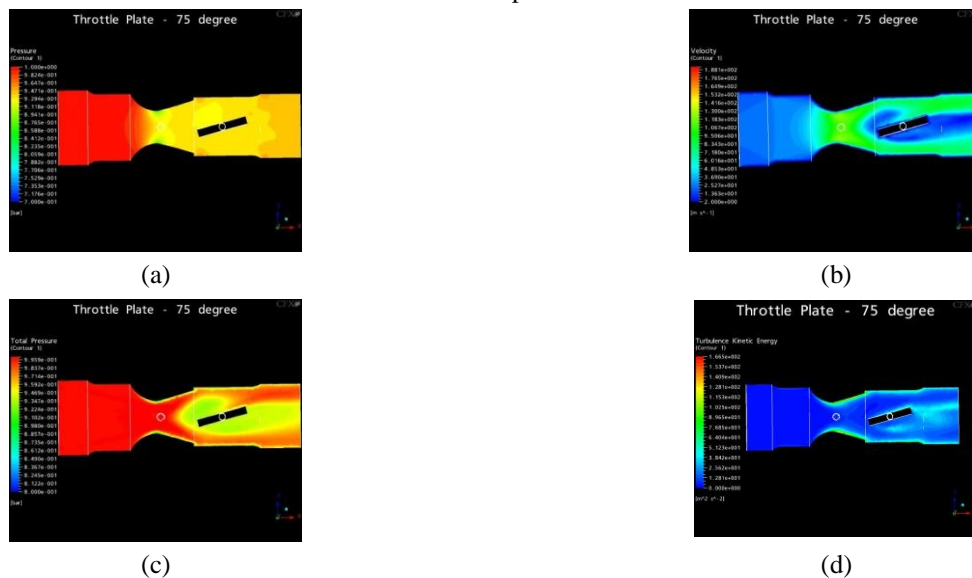


Fig. 6 Steady air flow across carburettor Venturi with fuel tube of 3 mm diameter with fuel tube (3 mm) and throttle plate at 75 degrees position:
 (a) Static Pressure (bar) (b) Velocity (m/s) (c) Total Pressure (bar) (d) Turbulent Kinetic Energy (m^2/s^2)

G. Effect of throttle plate at 60 degree angle

The Fig. 7 shows the Static Pressure, Velocity, Turbulent Kinetic Energy, Total pressure and for a compressible air flow across the Venturi with fuel tube (3 mm) and Throttle plate at 60 degrees position. In the Fig. 7 (a), the pressure field is comparatively increased near the walls of throttle and at the downstream. In the Fig. 7 (b), the velocity field is comparatively high and a drop in velocity than 75 degrees position in the downstream. In the Fig. 7 (c), the stagnation pressure field is increased and a drop in pressure near the throttle plate wall and comparatively high pressure drop at downstream than 90 and 75 degrees position. In the Fig. 7 (d), the turbulence kinetic energy intensity is high at downstream than throttle positions of 90 and 75 degrees.

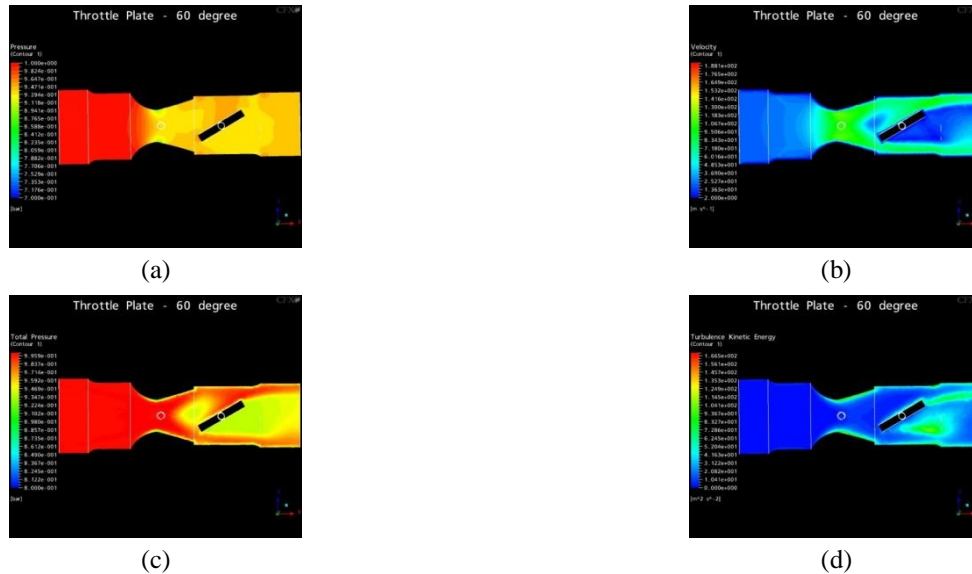


Fig. 7 Steady air flow across carburettor Venturi with fuel tube of 3 mm diameter with fuel tube (3 mm) and throttle plate at 60 degrees position:

(a) Static Pressure (bar) (b) Velocity (m/s) (c) Total Pressure (bar) (d) Turbulent Kinetic Energy (m^2/s^2)

H. Effect of throttle plate at 40 degree angle

The Fig. 8 shows the Static Pressure, Velocity, Turbulent Kinetic Energy, Total pressure and Velocity vector for a compressible air flow across the Venturi with fuel tube (3 mm) and Throttle plate at 40 degrees position. In the Fig. 8 (a), the pressure field is high when the flow nears the throttle. In the Fig. 8 (b), the velocity field is low at downstream. In Fig. 8 (c), the stagnation pressure field shows that a sudden drop in pressure just before the throttle plate (in top view) and a comparatively increased drop in pressure at downstream than 90 and 75 degrees positions. In the Fig. 8 (d) the turbulence kinetic energy clearly shows that the intensity of turbulence is lower at downstream than other throttle positions. The velocity vector shows that there is recirculation in the flow just before and after the throttle plate. The recirculation causes pressure loss in the flow.

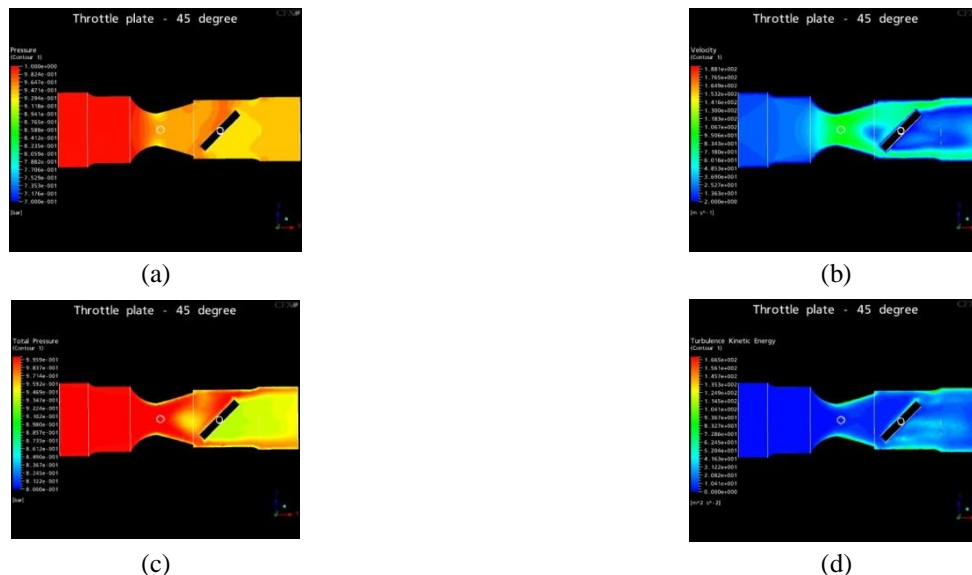


Fig. 8 Steady air flow across carburettor Venturi with fuel tube of 3 mm diameter with fuel tube (3 mm) and throttle plate at 40 degrees position:

(a) Static Pressure (bar) (b) Velocity (m/s) (c) Total Pressure (bar) (d) Turbulent Kinetic Energy (m^2/s^2)

The results of conventional throttle positions clearly indicate that flow recirculation at downstream which causes pressure fluctuations and increased stagnation pressure loss which is undesirable. More over the velocity vectors for various throttle plate positions also show that the recirculation in the flow just before throttle plate (front views). The modified design of throttle has been aimed to get uniform flow (reduced flow recirculation) at the downstream and discharge coefficient.

IV. MODIFIED DESIGN OF THROTTLE PLATE

A throttle plate was modelled with its body divided in two identical half-plates with individual screws for them as shown in Fig. 9. They were located at the same downstream location from the venturi throat as the original throttle plate. The carburettor model modified with throttle plate position of 60 and 75 degrees as shown. The volume mesh of the model has been generated with tetrahedron element of 1.5mm of size.

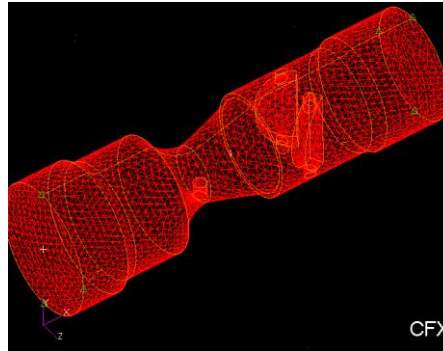


Fig. 9 Modified design of throttle plate

A. Effect of modified throttle plate

The models were analysed for the same boundary conditions. The analyses of results for 75 degrees as shown in the Fig 10, show that reduced stagnation pressure loss at downstream. The kinetic energy field shows that it is almost constant throughout the flow. The velocity vectors clearly shows that reduced flow recirculation at downstream.

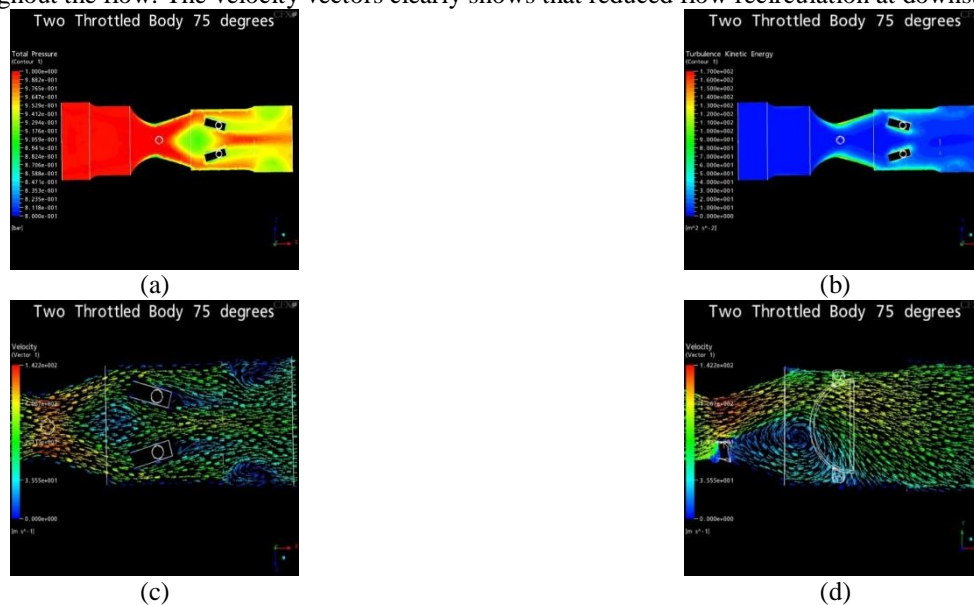


Fig. 10 Steady air flow across carburetor Venturi with fuel tube(3 mm) and double throttle at 75 deg
 (a) Gauge Total Pressure (bar) (b) Turbulent Kinetic Energy (m^2/s^2) (c) Velocity Vector (m/s)(d)-----

V. CALCULATION OF DISCHARGE COEFFICIENT

In addition to getting the information about the overall discharge coefficient to correct the mass flow rate across the carburettor venturi given a pressure drop, it is possible to calculate a local discharge coefficient that may be used to get the static pressure at a particular location in the carburettor venturi. For example, it is of great interest to use the information from the CFD simulations to set the appropriate boundary condition at the tip of the fuel tube in a fuel flow network. This result indicates that the assumption of isentropic flow is valid for the converging side of the carburettor venturi.

VI. CONCLUSION

CFD analysis was done using commercial CFD solver CFX to analyse the flow behaviour of the existing carburettor body used in small engines. The result of conventional throttle positions indicates that flow recirculation at downstream which causes pressure fluctuations and increased stagnation pressure loss which is undesirable. More over the velocity

vectors for various throttle plate positions also show that the recirculation in the flow just before throttle plate (front views). Further increased discharge coefficient has been observed for the modified model.

The analyses of the modified model showed that the design achieves more symmetric and organized flow at the downstream of carburettor. This simple design change has the potential for improving mixture distribution downstream of the carburettor without major changes in the carburettor design.

TABLE I TITLE

S.No.	Description	Static Pressure at throat in bar (P_t)	Stagnation Pressure at inlet venturi in bar (P_0)	Mass flow rate in kg/sec (m)	Coefficient of Discharge (C_d)
1	Plain venturi	0.75563	0.999292	0.00291	0.473
2	Fuel tube without throttle	0.98055	0.99969	0.00118	0.324
3	Throttle plate 45 deg	0.98668	0.999892	0.00106	0.312
4	Throttle plate 60 deg	0.98226	0.999694	0.00137	0.362
5	Throttle plate 75 deg	0.97944	0.99964	0.00161	0.372
6	Throttle plate 90 deg	0.98061	0.999543	0.00169	0.381
7	Two Body throttle- 60 deg	0.98668	0.999892	0.00187	0.394
8	Two Body throttle- 75 deg	0.97829	0.999656	0.00212	0.4012

REFERENCES

- [1] Y. Asano, T. Chuma, H. Haga, and T. Mochida. Effects of air-bleed systems on carburettor performance. Bulletin of JSME, 11(46):691–698, 1968.
- [2] M. Ehara, Y. Kinabara, K. Shinoda, T. Meguro, and T. Ishihara. A study of carburettor design. SAE technical report, (805142), 1980.
- [3] M. Furuyama. Fuel supply characteristics of idle-system of carburetor under steady state conditions. Bulletin of JSME, 21(154):722–729, 1978.
- [4] M. Furuyama. Fuel supply characteristics in the transition region of fixed-venturi type carburettor. Bulletin of JSME, 24(191):842–848, 1981
- [5] I. Isobe and Y. Asano. Discharge beginning points of fuel and bleed-air of carburettor, University of Chiba Report, 4:173–178, 1968.
- [6] D. L. Harrington and J. A. Bolt. Analysis and digital simulation of carburetor metering. SAE technical report, (700082), 1970.
- [7] D. K. Jagdish, S. Govindarajan, V. Balasubramaniam, and V. Ganesan. Theoretical and experimental investigation of metering characteristics of a variable venturi mechanically controlled carburettor. SAE technical report, (2001-28-0015), 2001.
- [8] B. Sendyka and J. Filipczyk. Simulation of the characteristic of a carburettor of an internal combustion engine. SAE technical report, (950987), 1995.
- [9] B. Sendyka and W. Heydel. The analysis of a constant depression carburettor with a fuel feeder. SAE technical report, (940212), 1994.
- [10] J. Szczecinsky and T.J Rychter. Theoretical analysis of mixture stoichiometry in engine carburettor. SAE technical report, (910078), 1991.