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VW-Aero Engine Cylinder Head Cooling Efficiency Investigation †

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Abstract: Light sport aircraft builders widely construct experimental aircraft for their personal enjoyment for both building and flying purposes. A variety of engines are used as powerplants for their aircraft. The Volkswagen (VW) automotive engine is one of the most reliable engine conversions for amateur-built aircraft. The aim of this paper is to investigate the cylinder head temperature of the VW-Aero conversion engine during flight conditions by using CFD. The models of the front and rear cylinder barrels include a cylinder head which is constructed with the addition of a baffle plate and air inlet design shape based on internal air flow patterns. The simulations were performed at a velocity of between 50–100 kt (58–115 mph) at a flying altitude of 6,000 feet as per typical flight conditions. The results showed that the rear cylinder lacked cooling air because it was obstructed by a front cylinder. The rear cylinder encountered heat soak conditions which resulted in higher temperature when compared with what the front cylinder experienced. At a velocity of below 80 kt (92 mph), the incoming air velocity through the engine air duct was inadequate to maintain the engine cylinder's head temperature so that it rises above a normal operating temperature range. At a velocity of above 80 kt (92 mph), the internal baffle plate was capable of feeding air through the controlled path between baffle plate and cylinder fin, which consequently resulted in a controllable engine cylinder barrel and head temperature to be within the normal operating temperature range. The aircraft flying at a velocity of less than 80 kt (92 mph) and equipped with a VW engine would be likely to experience an overheated engine problem due to insufficient cooling air.

Keywords: Experimental Aircraft; Engine; Volkswagen; CFD; Baffle plate

1. Introduction

The using of automotive conversion engine in an experimental aircraft has been widely used as an alternative engine of standard aircraft engine. Among experimental aircraft builders, Volkswagen (VW) automotive conversion engine was the famous choice for amateurs to build their own aircraft. Being an opposed cylinder configuration, VW engine is among automotive engine to be converted as it is closest to standard aircraft engine. VW engine was the fifth choices next to Lycoming (1st, 2nd and 3rd) and Continental (4th) engine for homebuilders' choice from Federal Aviation Administration (FAA) engine data report (2000). Bingelis admitted that VW engine was the top contender to be the most popular automotive engine for amateur-built aircraft. He also stated that it was continuing of the increasing numbers of homebuilt aircraft using VW engine [1].

The major advantage for VW engine is the primary cooling system which is an air cooled. The cooling efficiency of the engine is relied on the compressed air from belt-driven fan passing through shroud and baffle plate then the cylinder head and barrels [2,3]. By removing fan to suit aircraft application, new baffle plates are needed for the engine to provide air cooling path for engine cooling system [4]. Kern revealed that more than hundred different experimental designs were using VW-base engine for their flying machine including motorgliders, powered parachutes, gyroplanes and plans-built aircraft [5]. He also pointed out that suitable VW power for aircraft was between 60–85 hp power rating.

Parker designed Teenie Two aircraft since 1969 which firstly utilized 1200 cc (42 hp) VW engine. The cruising speed achieved 110 mph. Monnett designed Sonerai I aircraft in 1970 particularly to enter Formula-V air racing event which was only for aircraft using VW air-cooled engine upto 100 cu.in (1600 cc). Sonerai II was then designed to be a 2-seater version of Sonerai I. Hummel introduced an affordable Hummel H-5 aircraft in 2002 and Ultracruiser Plus aircraft in 2010 predominantly using VW-engine [6]. In 2010, Thatcher also designed and built his own aircraft, Thatcher CX-4 which was practically inexpensive to build by using basic tools at home garage [7]. The CX-4 was followed by CX-5 design which accommodated 2 people onboard with 85 hp VW-engine [8,9]. AeroVee 2.1 engine produced 80 hp for Sonex, Waiex, Xenos and Onex aircraft which were also designed by Monett [10,11].

Spangler reported on Clagg's CH701 aircraft which used VW-engine with reduction belted drive for his engine [12]. Clagg had flown his aircraft and encountered overheat problem especially during climbing. The CH701 aircraft was designed for short take-off and landing (STOL) purpose which had cruising speed of 70 kt (80 mph). His engine was removed for repairing due to heated problem twice then replaced with other choice of engine recommended from the designer.

Pietrykowski and Tulwin [13] had analyzed the effectiveness of air cooling system of 18 cylinder double row radial aircraft engine by using CFD simulation. They found that the cooling capability depended on surrounding geometries which were cylinder head fin size, area and channel between fin. It is advisable to maximize the local air flow velocity between fins to improve cooling efficiency.

The aim of this paper is to investigate cooling efficiency of Volkswagen automotive conversion engine in experimental aircraft by using CFD simulation of cylinder head and barrel model including internal baffle plates with boundary condition of airspeed between 50–100 kt (58–115 mph).

2. VW-Aero Conversion Engine

The conversion needs some modifications of engine mounting and crankshaft end for propeller installation which requires basic tools and ordinary manufacturing process [14,15]. At the present, there are numbers of VW-Aero engine conversion specialists which are supplying parts and complete engine ready for installation as shown in the Table 1 below.

Table 1. List of Volkswagen conversion engine models and suppliers [16].

Manufacturer	Engine Model [1]	Engine Horsepower (hp)
AeroConversions (AeroVee)	2100 cc	80
Great Plains Aircraft Supply	1835 cc	65
	1915 cc	69
	2180 cc	76
	2276 cc	80
Hummel Engines	1600 cc	50
	1835 cc	60
	1915 cc	65
	2180 cc	76
	2400 cc	85
Motorav Aircraft Engines	2400 cc	100
Revmaster Aviation	2300 cc	85

[1] Normal aspirated engine, carbureted induction system, direct drive.

Being quite relatively limited power output, therefore only specific aircraft models successfully adopted VW engine as the main choice of the engine for their aircraft designs. Table 2 is showing light sport aircraft that have been originally designed with VW-Aero engine as a powerplant. These all aircraft were under experimental category aircraft which the structure were constructed from aluminum alloy except only Sonerai I and II aircraft which fuselage was tube and frame construction.

Table 2. List of light sport aircraft using Volkswagen conversion engine [17].

Aircraft	VW-Engine (hp) [1]	Number of Seat	Speed [1] (mph)		
			Maximum	Cruising	Stall
Teenie Two	42-60	1	120	110	48
Sonerai I	60-80	1	200	150	55
Sonerai II	60-80	2	200	140	55
Hummel H5	60-85	1	135	120	41
Ultracruiser Plus	60-85	1	135	125	36
Thatcher CX4	55-80	1	135	125	36
Thatcher CX5	85	2	120	110	48
Sonex-B	80	2	150	130	40
Waiex-B	80	2	150	130	40
Xenos-B	80	2	120	100	44
Onex	80	1	155	135	45

[1] At mean sea level.

3. 3D Simulation

Cylinder head and barrel of VW-Aero engine model were constructed with external shroud and internal baffle plate by using SolidWorks software. The cylinder head and barrel geometries were taken from VW-Aero 2180 cc engine. The simulations were performed with an external flow analysis at 6000 ft conditions as shown in Table 3.

Table 3. Boundary conditions and values for 3D simulation.

Boundary	Value	Unit
Air density [1] (ρ)	1.0269	kg/m^3
Air pressure [1] (p)	8.1494×10^4	N/m^2
Air viscosity [1] (μ)	1.7324×10^{-5}	kg/m·s
Air temperature [1] (T)	276.46	K

[1] At 6000 ft.

3.1. CFD Modelling

3.1.1. Engine Cylinder Barrel and Head Model

The full scale cylinder head and barrel had been modeled and assembled together covered with shroud and internal baffle plate. Only 2 cylinder assemblies from one side of the engine were simulated. Figure 1 is showing model assemblies in the simulation. The airspeed in simulation was between 50–100 kt. The normal operating temperature range of VW-Aero engine was 180–190 °C. The maximum temperature was 240 °C [4]. At the beginning of the simulation, a constant temperature of cylinder head and barrel were set to 180 °C for normal operation and 240 °C for overheat condition. Cylinder head and barrel were assigned with cast aluminum and cast steel properties respectively. Table 4 is showing engine working condition at 75% of full power which was typical cruising condition at 2950 RPM with normal stoichiometric air-fuel ratio. Figure 2 are showing model assembly for simulation.

Table 4. Engine working condition at 75% power.

Rotational Speed (RPM)	Heat Generation Rate (kW)	Air Fuel Ratio
2950	44	14.7:1

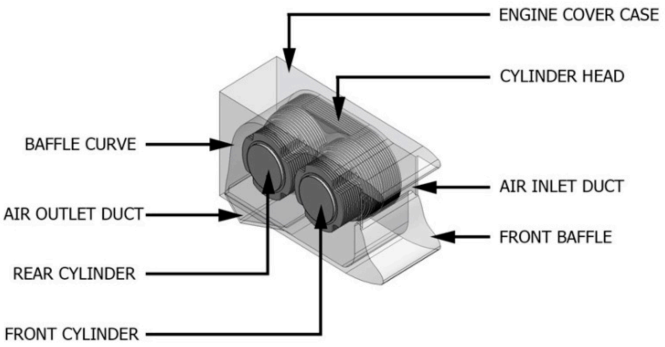
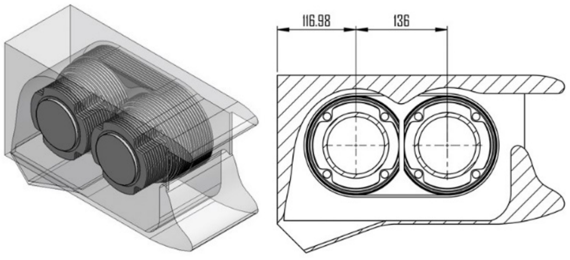


Figure 1. Model assembly descriptions.

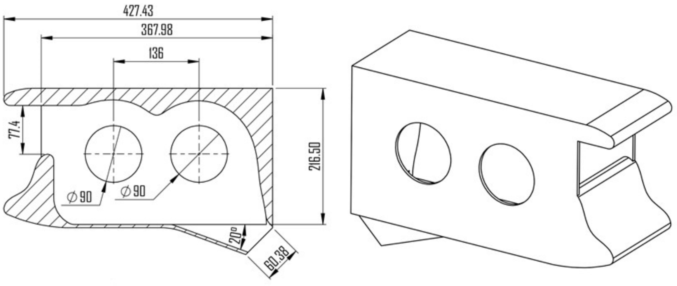


(**a**) (**b**)

Figure 2. Model assembly: (**a**) Isometric view; (**b**) Side view.

3.1.2. Shroud and Baffle Plate Model

Shroud model had made from aluminum sheet as a box model with an inlet at the front for an incoming air to enter. The air outlet was an opening channel underneath which had 20 downward for better scavenging of the air. An internal baffle was modeled from cylinder barrel shape to keep closer distance to engine's finned area for utilizing incoming cold air as possible. Figure 3 are showing the dimension of shroud in mm and internal baffle plate shape (a) and isometric view (b).



(**a**) (**b**)

Figure 3. Shroud and baffle plate: (**a**) Dimensions; (**b**) Isometric view.

4. Results and Discussion

4.1. Result from Initial Temperature Condition of 180 °C

The simulation showed that during cruising speed between 50 to 100 kt, assumed that the initial state temperature was 180 °C which was considered to be normal operating temperature, there was a constantly decreasing of temperature with an increasing of airspeed. The result values were taken from the maximum temperature area at the front cylinder barrel, rear cylinder barrel and cylinder head. It was found that front cylinder barrel continually had lower temperature than rear cylinder barrel and cylinder head respectively along the simulated airspeed range. While the airspeed was progressively reducing from 80 kt, the cylinder head temperature was increased continuously until reaching temperature of 240 °C at 60 kt. For safe engine operation, 80 kt was the minimum airspeed to operate. Figure 4 is showing graph relationships between front cylinder barrel, rear cylinder barrel, cylinder head temperature (°C) and airspeed (kt) at initial temperature of 180 °C.

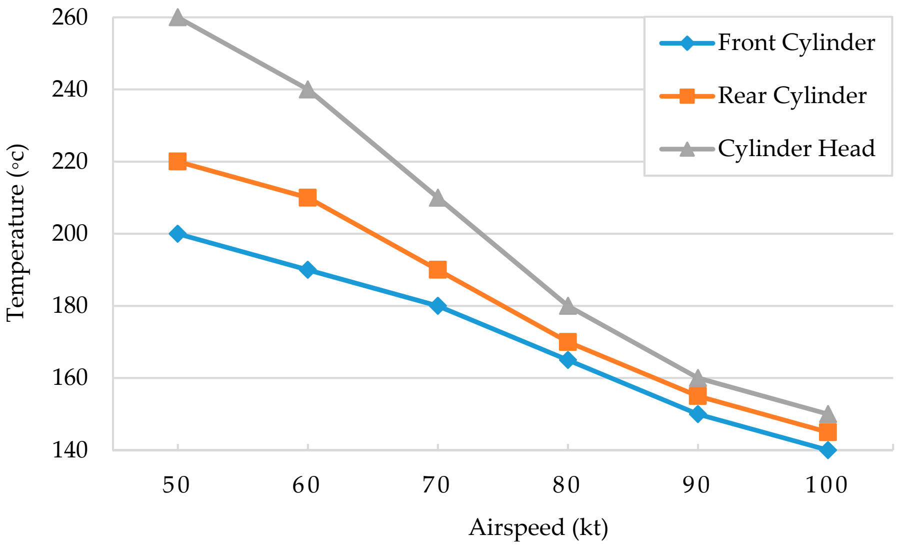
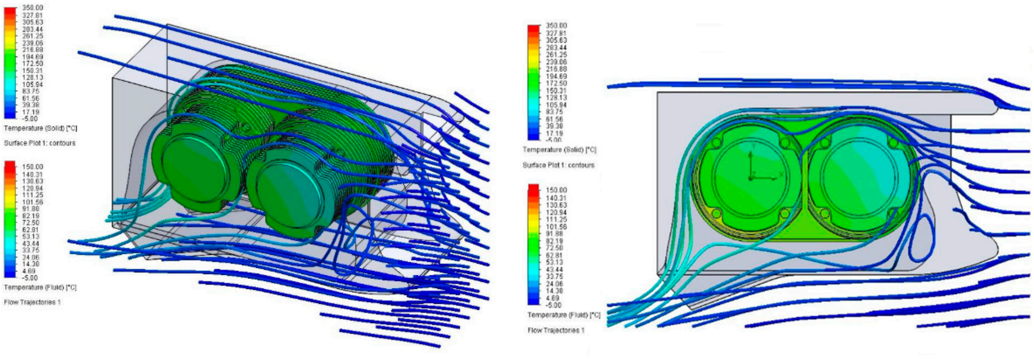


Figure 4. Graph relationships between temperature (°C) and airspeed (kt) at an initial temperature of 180 °C.

Figure 5a is showing temperature contour of an airspeed of 80 kt simulation. The temperature of cylinder head and barrel are within 180 °C. Figure 5b is showing side view of the same result condition. Figure 5a,b are also showing temperature range of the internal airflow inside the baffle plate and external airflow.



(**a**) (**b**)

Figure 5. Simulation result from initial temperature of 180 °C at 80 kt: (**a**) Isometric view (**b**) Side view.

4.2. Result from Initial Temperature Condition of 240 °C

The results from an initial 240 °C simulation showed that all temperatures were also decreased along with an increasing of airspeed as shown in Figure 6. However, these results simulated overheating situation which had not been recovered until reaching an airspeed of 95 kt. If there was a situation of an inevitable flight such as climbing, it would not be able to reduce the temperature if the aircraft was not capable of flying straight level flight higher than 95 kt.

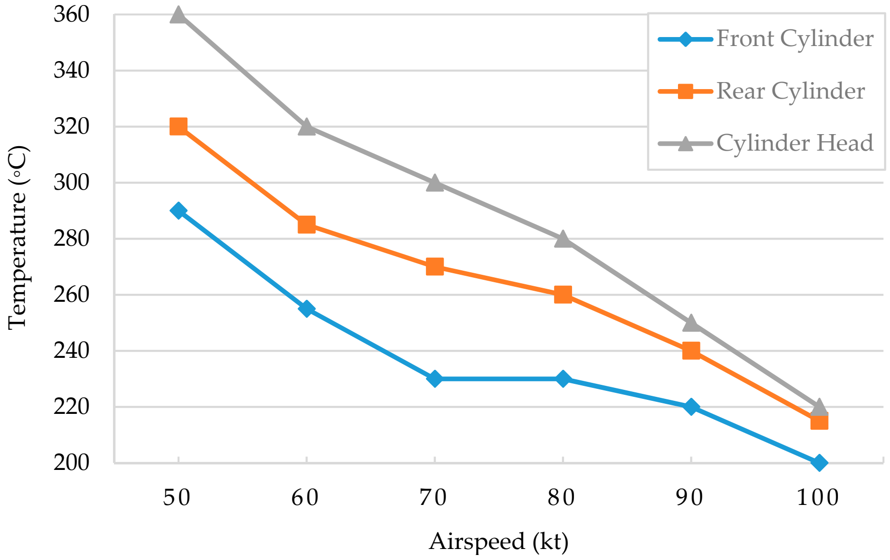
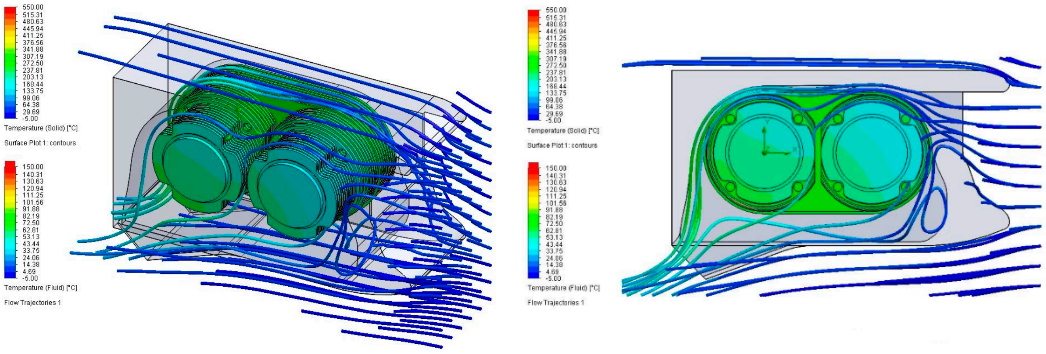


Figure 6. Graph relationships between temperature (°C) and airspeed (kt) at an initial temperature of 240 °C.

Figure 7a is showing temperature contour over cylinder head and barrel of an airspeed of 100 kt simulation. It is also showing temperature range of the internal airflow inside the baffle plate and external airflow. The temperature of cylinder head and barrel are within 220 °C. Figure 7b is showing side view of the same result condition.



(**a**) (**b**)

Figure 7. Simulation result from initial temperature of 240 °C at 100 kt: (**a**) Isometric view (**b**) Side view.

5. Conclusions

The VW-Aero conversion engine model with cylinder barrel, cylinder head and baffle plate were simulated at a velocity between 50–100 kt. The simulations included both initial temperature of normal operation and overheat conditions. There was a continuously decreasing of temperature with an increasing of airspeed. It can be concluded that rear cylinder barrel and rear area of cylinder head tend to experience higher temperature due to lacking of cooling air from the obstruction of the front cylinder which can lead to an engine overheat problem. For normal operating temperature, the minimum safe engine operation was when flying above 80 kt (92 mph) airspeed. Nevertheless, during the situation of an increasing of temperature above normal range, the recovery of heating problem would require above 95 kt (110 mph) of airspeed to ensure the temperature reduction to normal operating temperature.

Supplementary Materials: The following are available online at http://www.mdpi.com/2504-3900/39/1/4/s1.

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