

# **Configuration Selection, Design and Computational Investigation of Cowling System for Microlight Aircraft**

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**ABSTRACT:** The present work involves to configuration selection, design and computational investigation on cowling system of proposed microlight aircraft. The configuration selection of cowling system and its integral subsystems are made by studying various globally certified microlight or small light category aircrafts and British Civil Airworthiness Requirements. Designing process is carried based on configuration selection using CATIA V5 R20 modelling software. After that, the computational investigation of heat transfer rate and temperature distributions inside the cowling system is carried using ANSYS 14.5 simulation software, the maximum temperature spots and minimum heat transfer rate is found for each flight conditions and compared with engine operating limits provided by engine manufacturer.

**KEYWORDS:** Microlight aircraft, Heat transfer, Design, Computational investigation, Cowling, Engine bay, Cooling.

## **I. INTRODUCTION**

The aircraft of present study is an all metal single engine, high wing two seat airplane with a fixed tricycle landing gear [1]. This aircraft is powered with one BRP-ROTAX 912 F3 engine. In this paper, configuration selection, design and computational simulations of fluid flow and heat transfer inside the engine bay for microlight aircraft in the tractor configuration were performed.

The aircraft powerplant system is composed of different elements working at various temperatures and in conjunction with the cowling system creates a space with high intensity of heat transfer to be covered by the ventilation or cooling systems. Therefore a heat transfer simulation, accounting for the complex heat transfer modes, is necessary in order to verify adequate cooling is ensured and that temperatures of the cowling are maintained within the operating limits for all the aircraft's flight conditions. Most of the aircraft engines are air cooled and need proper airflow to prevent from running too hot. ROTAX engines use some form of cooling airflow to keep the cylinders cool. The cowlings use a ram air pressure so that small amount of air is doing all the work by virtue of pressure and airspeed. This way the cowling can be made very streamlined and sleek so that drag is minimized and the aircraft does not suffer in performance. Inside the cowling the cooling can be either up-flow or down-flow.

The design and computational simulation on cowling system, surprisingly only few papers are devoted to this topic. For example, Wienczysslaw et al [2] presented the preliminary design process and numerical simulation for air intake and nacelle for I-23 aircraft. Piotr Lapka et al [3] presented the nacelle design and thermal heat transfer simulation for throughout the aircraft's flight. Additionally, the temperature and air mass flow rate inside the nacelle were determined and high temperature regions inside the nacelle were spotted. A Smali et al [4] presented a two-dimensional

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axisymmetric numerical model for investigating the thermal behaviour of a wind turbine nacelle operating in a cold and in an extremely hot climate, respectively.

Here, the configuration selection is done by studying various types of globally certified small light category aircrafts and with respective BCAR regulations [5]. After that, the design work has carried out using CATIA V5. For the validation, Computational simulation is carried out using ANSYS 14.5 and its results shows potential high temperature spots and reveal influence of thermal radiation on temperature distribution. These results may be helpful in developing new solutions for ventilation and cooling systems, which could reduce the temperature inside the cowling.

## II. DESIGN OF COWLING SYSTEM

To design the cowling system, at first it is necessary to understand the aircraft configuration and its specification, the engine and its specification and the position of various accessories of engine. The configuration selection of cowling system is done by studying various globally certified small light airplanes as well as BCAR. Inside the cowling consists of engine, engine mount, engine accessories, exhaust system and radiators. To get better design of cowl, it is necessary to design all the powerplant systems perfectly and mounted in a right place. All the design work is carried in a CATIA V5 R20 modelling software. The designing of cowling system consists following steps:

- Design of engine mount for ROTAX 912 F3.
- Design of exhaust system.
- Assembling of radiators and its rooting.
- Design of cowling system.

To get better design of cowl, it is necessary to design all the powerplant systems perfectly and mounted in a right place.

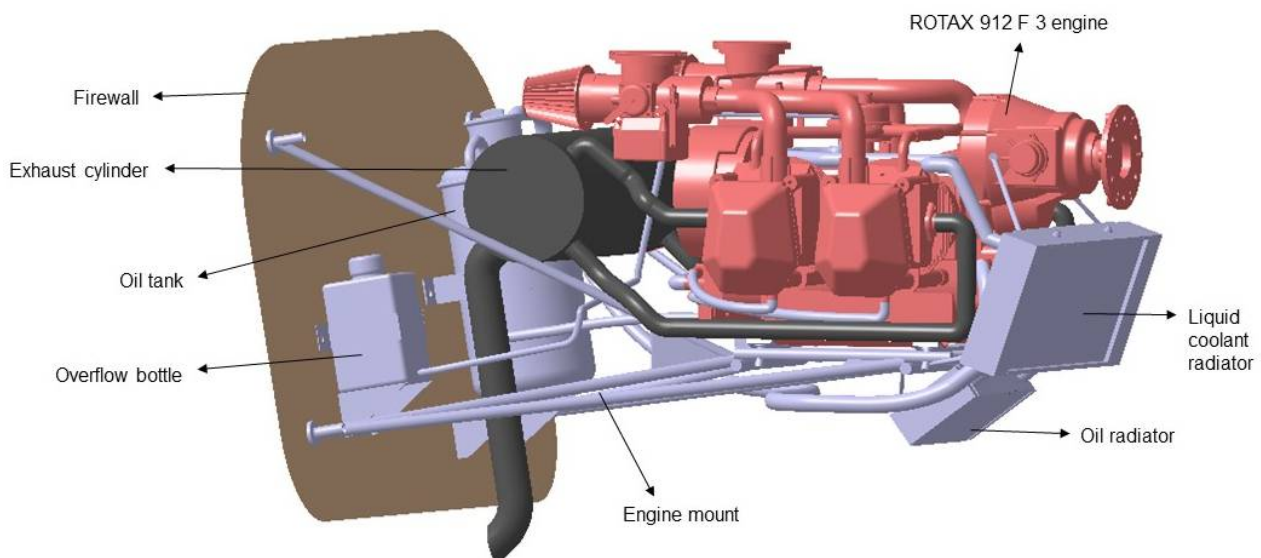


Fig. 1. Final assembly engine bay

The cowling system is designed as per configuration selection and BCAR. The three ducts were created for air intake. One duct is around the spinner mount and two ducts were beside the spinner. For air exit, landing gear bay and gap between cowl and exhaust vane is used. Additionally two ducts are created for liquid coolant radiator and oil radiator as per radiator's surface area.

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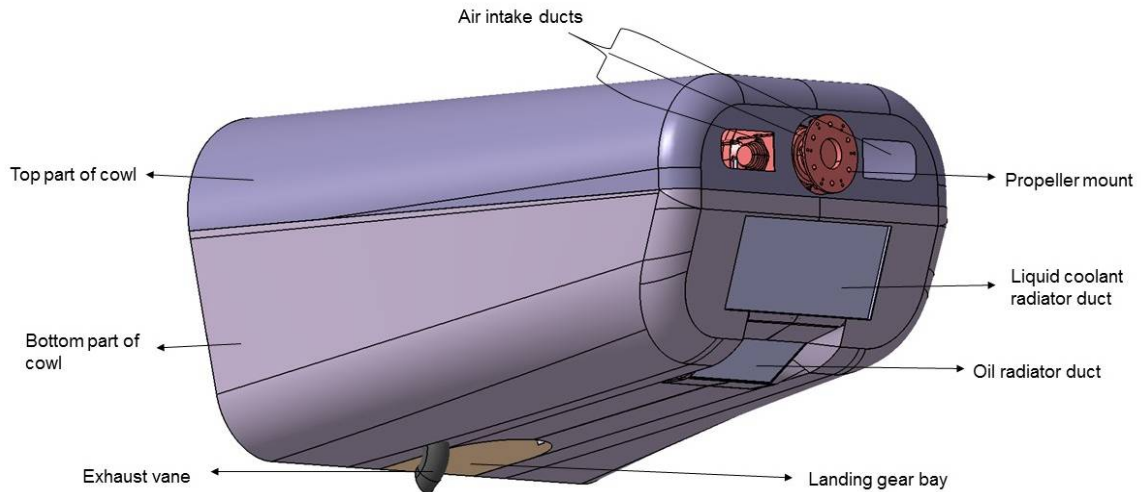


Fig. 2. Designed cowling system

### III. COMPUTATIONAL INVESTIGATION

For computational study of cowling system, ANSYS 14.5 tool is used. The grid is generated using ANSYS ICEM-CFD and post processing is carried in ANSYS FLUENT. The computational study involves the following steps:

- Importing geometrical model to ICEM CFD.
- Generating mesh from ICEM CFD.
- Specifying the boundary conditions to the model.
- Examining and visualizing results in FLUENT post processor.

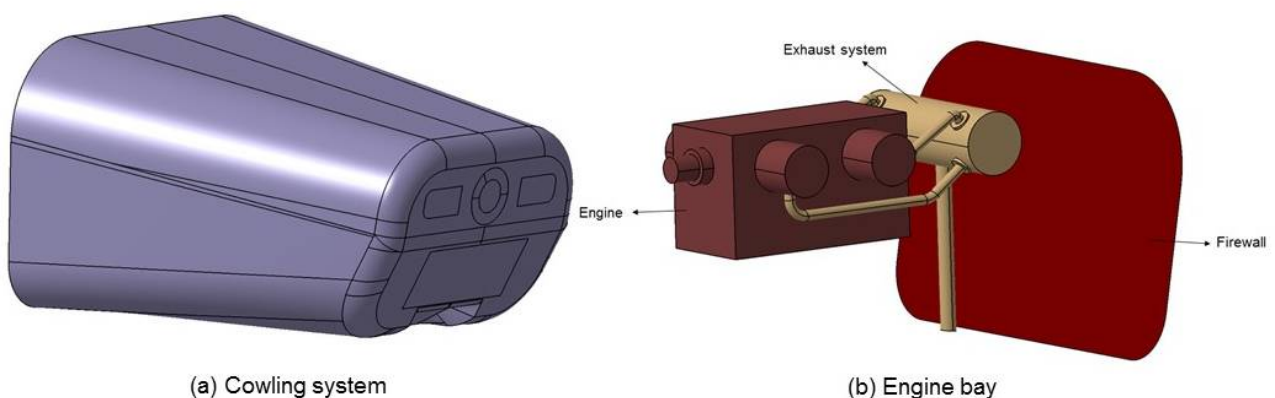


Fig. 3. Geometrical model for simulation

Inside the engine bay, many compartments can be reached very high temperature due to modes of heat transfer. Improper design process can therefore lead to cowling softening and melting, and even aircraft destruction. Therefore, special ventilation and cooling systems of the cowling should be developed to reduce the temperature of the internal side of the cowling and other elements to the desirable level. Here computational investigation is performing to determine the heat transfer rate and temperature distribution over an engine and exhaust system of cowling system in different flight conditions. So, to overcome the complexity of the geometry in grid generation,

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eliminated some of subsystems of powerplant system and modified the engine geometry. In modified engine bay, only engine and exhaust system were placed. And also in cowling, the propeller mount is modified.

### 3.1 Grid generation

Finite control volume approach is used for discretization of geometrical model. Here internal flow analysis is performed. So, the cowl is itself considered as a domine. After importing the geometry, cowl inside fluid body is created and geometry repairing is performed. Based on geometrical model, robust type tetrahedron control volume mesh is generated.

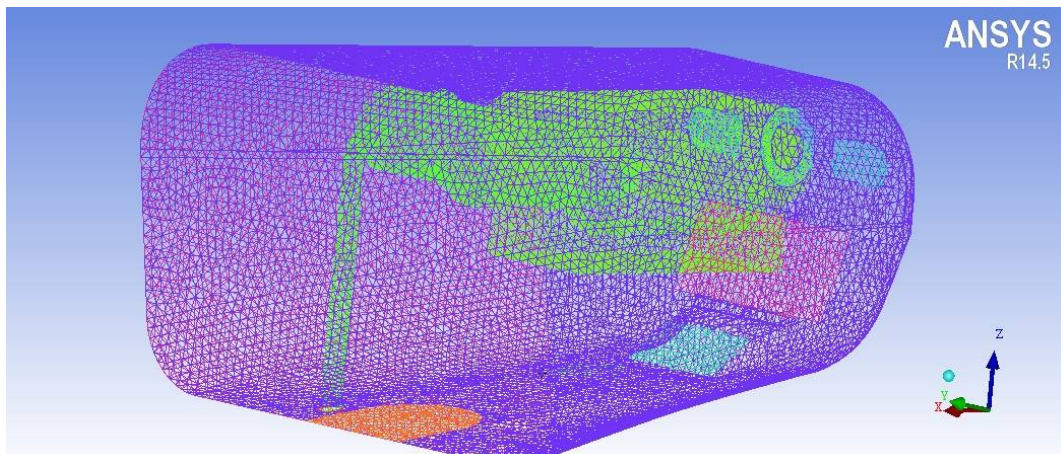


Fig. 4. Isometric view of tetrahedron mesh generated on geometrical model

### 3.2 Grid examination

Table 1. Grid quality check

| Runs | Number of elements | Skewness | Aspect ratio | Orthogonal quality |
|------|--------------------|----------|--------------|--------------------|
| 1    | 217935             | 0.9250   | 0.9566       | 0.8261             |
| 2    | 375911             | 0.9423   | 0.9034       | 0.9347             |
| 3    | 475867             | 0.9201   | 0.8741       | 0.9188             |
| 4    | 659202             | 0.9262   | 0.8791       | 0.9294             |

It is important to check the quality of the structured mesh which affects the accuracy of the CFD simulation. Parameters such as skewness, and the aspect ratio are used to check the quality of unstructured mesh. The value of aspect ratio tends to one is better. Each element has a value of skewness between 0 and 1. The skewness is classified in two ways, equiangle skew and equisize skew. The smaller value of equiangle skew and equisize skew are more acceptable close to zero [6]. For good quality of mesh, the aspect ratio from 0 to 1 and orthogonality from 0.1 to 1 should be maintained [2]. Here in various runs, the best mesh one is with 659202 elements is used for further simulation. It satisfies the skewness, aspect ratio and orthogonality within the limit.

### 3.3 Boundary conditions

Here to solve the governing equations, ANSYS FLUENT 14.5 simulation tool is used. The simulation is performed for five different cases.



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Table 2. Different case studies for simulation

| Case                     | Altitude [m] |
|--------------------------|--------------|
| A - Sea level ISA        | 0            |
| B - Sea level ISA + 30 K | 0            |
| C - Take off             | 100          |
| D - Cruise               | 3000         |
| E - Landing              | 100          |

For the selected control volume mesh, the steady state energy, momentum and radiative heat transfer equations were solved. The standard k-ε model with scalable wall function approximation is used as turbulent model. The semi implicit method for pressure linked equations - corrected algorithm (SIMPLEC) procedure is used to couple the momentum and pressure variables. Additionally, the second order upwind scheme was applied to all balance equations. The finite volume method for convective heat transfer is modelled for thermal radiation. FLUENT is used to perform all the calculations. As per the International Standard Atmosphere, the air properties were assumed. The firewall, cowling and exhaust vane were made of steel. The air and hot exhaust gases were assumed to be totally transparent. Therefore, the thermal radiation was exchanged only between hot and cold surfaces of the engine systems and the cowling.

For each case, the external air velocity and dynamic pressure at all inlets to the computational domain were varying according to the plane operation speed and altitude. In Table 4, the air velocity and dynamic pressure values were estimated by numerical simulations and by applying the ISA model, whereas the total pressure at all outlets from computational domain was equal to the atmospheric one. The five different cases represents the flight conditions. Here the take-off, speed is taken as 31.86 m/s and angle of climb is 16°. And at cruising, speed is taken as 50 m/s. at the time of landing, speed is 31.86 m/s and angle of descend is -16°.

Table 3. CHTCs for various ambient air velocities

| Case | Re      | Pr      | Nu      | CHTC (W/m <sup>2</sup> -K) |
|------|---------|---------|---------|----------------------------|
| A    | 1795000 | 0.71654 | 3373.07 | 99.83                      |
| B    | 1855200 | 0.71126 | 3455.59 | 111.66                     |
| C    | 3647700 | 0.71667 | 5948.57 | 174.82                     |
| D    | 3853600 | 0.7188  | 6221.24 | 172.01                     |
| E    | 3647700 | 0.71667 | 5948.57 | 174.82                     |

Evaluations of thermal boundary conditions on the external surface of the nacelle, which are dependent on the flowing air velocity demand more careful analysis, as they are convective-radiative type. The procedure for finding the convective heat transfer coefficient (CHTC) is based on approximate empirical correlations. As the shape of the aircraft's body is slightly curved, it is not coincident with shapes for which these empirical relations were developed. Therefore, only rough estimates are possible here. The CHTCs were determined using an assumption that the airplane is maintained in ambient air stream of constant velocity. Fully turbulent flow around the external side of the cowling was assumed due to the influence of the rotating propeller on the flow structure.

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Table 4. Air properties according to ISA

| Case | Altitude [m] | Pressure [Pa] | Temperature [K] | Density [kg/m <sup>3</sup> ] | Thermal conductivity [W/m-k] | Specific heat [J/kg-K] | Dynamic viscosity [Pa-s] |
|------|--------------|---------------|-----------------|------------------------------|------------------------------|------------------------|--------------------------|
| A    | 0            | 101330        | 288.15          | 1.225                        | 0.025326                     | 1005                   | 0.000017894              |
| B    | 0            | 101330        | 318.15          | 1.1095                       | 0.02765                      | 1005                   | 0.000019307              |
| C    | 100          | 100130        | 287.5           | 1.2133                       | 0.025275                     | 1005                   | 0.000017862              |
| D    | 3000         | 70121         | 268.6592        | 0.90925                      | 0.023779                     | 1005                   | 0.000016938              |
| E    | 100          | 100130        | 287.5           | 1.2133                       | 0.025275                     | 1005                   | 0.000017862              |

## IV. RESULTS AND DISCUSSIONS

The numerical simulation, five different cases with flight conditions were analysed. It is assumed that for all cases, the air enters the cowling system through intake ducts in the cowling, inlet round the spinner mount and additionally from liquid coolant and oil radiators. For all the cases, the fixed locations of outlets in the gaps between the cowling and exhaust vane as well as in the landing gear bay. Accounting for various air velocities with respect to flight conditions five runs of simulations were performed.

In case A – Sea level ISA, The maximum speed of air in the hot compartment of about 30 m/s at open air inlets and 39.33 m/s at landing gear bay is observed. The high values of convective heat transfer coefficient over an engine and cowling surfaces were also attained, and the temperature of cowling was therefore low on the order of 295 K. In the rare part of the cowling compartment, the air reduces to almost 0 m/s resulting in worse heat transfer conditions than in the front part, hence temperature of the cowling above generator was high and around 319 K. In the region of landing gear bay outlet highest CHTCs were observed. The maximum temperature of 375 K is observed over the exhaust cylinder particularly at on exhaust vane joint due to the low airflow at that region. In this case, the total heat transfer rate of -11.16 KW is observed.

In this case B, the ambient air temperature was increased by 30 K as compared to the air temperature at sea level according to ISA. Here maximum speed of air in the hot compartment up to about 31 m/s and 40 m/s was observed in the region of open air inlets and landing gear bay respectively. The maximum temperature of about 337 K at the cowling surface was observed at the just above and below of the engine due to thermal radiative heating and additionally, low mass flow rate of -0.0177 kg/s in the gaps between the cowling and exhaust vane. The maximum temperature of 385 K is observed over the exhaust cylinder particularly at on exhaust vane joint due to the low airflow at that region. In this case, the total heat transfer rate is -11.36 KW observed.

For case C, the maximum speed of air in the hot compartment up to about 62.44 m/s and 70.89 m/s was observed in the region of open air inlets and landing gear bay respectively. In this case, air is moved almost equally to both top and bottom sections of the cowling system. But at the rear part of the engine, wake formation is more and thus maximum temperature at exhaust cylinder surface. The high values of CHTC at engine and cowling surfaces were also attained, and the temperature of cowling was therefore low on the order of 287 K. In the rare part of the cowling compartment, the air reduces to almost 0 m/s resulting in worse heat transfer conditions than in the front part, hence temperature of the cowling above generator was high and around 312 K. Additionally, low mass flow rate of -0.0296 kg/s in the gaps between the cowling and exhaust vane. In the region of landing gear bay outlet highest CHTCs were observed. The maximum temperature of 373 K is observed over the exhaust cylinder

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particularly at on exhaust vane joint due to the low airflow at that region. In this case, the total heat transfer rate is -12.09 KW observed.

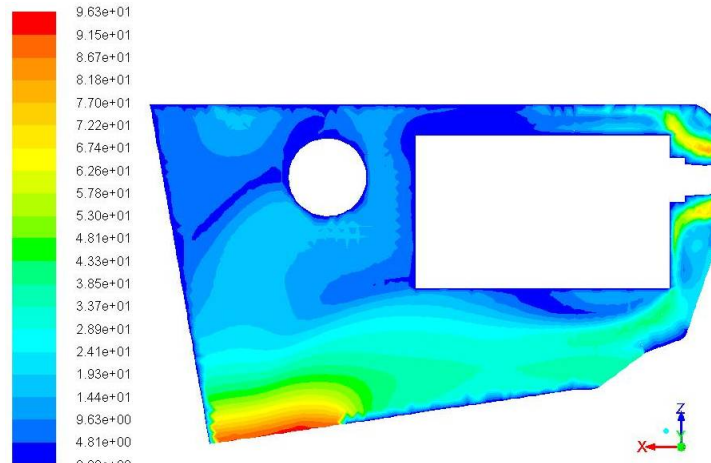


Fig. 5. Contours of velocity magnitude in cross section through engine bay for case D

For case D, the maximum speed of air in the hot compartment up to about 83.67 m/s and 96.2 m/s was observed in the region of open air inlets and landing gear bay respectively. Velocity air at bottom part of the cowl is more as compared to the top part, thus the maximum heat transfer rate at bottom side of cowl.

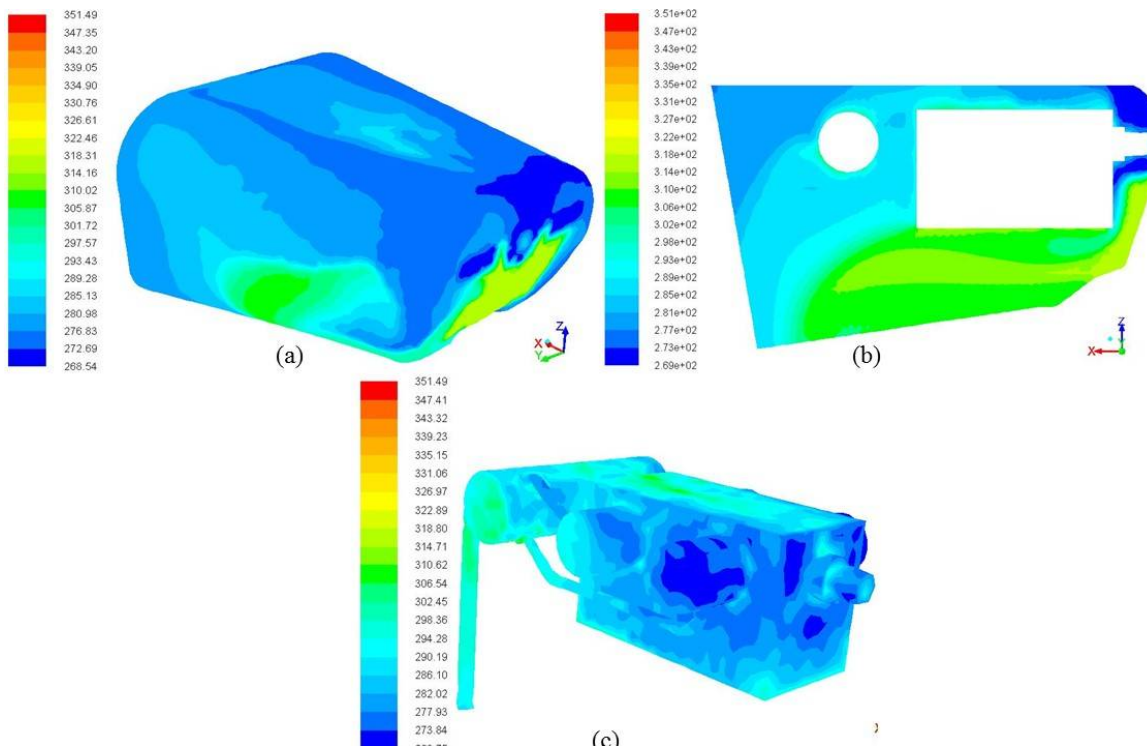


Fig. 6. Contours of total temperature distribution (a) over cowl (b) in cross section through engine bay (c) over the surface of engine and exhaust system for case D

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The maximum temperature of about 316.49 K at the cowling surface was observed at the just above and below of the engine due to thermal radiative heating and additionally, low mass flow rate of -0.0405 kg/s in the gaps between the cowling and exhaust vane. The maximum temperature of 349.58 K is observed over the exhaust cylinder particularly at on exhaust vane joint due to the low airflow at that region. In this case, the total heat transfer rate is -12.61 KW observed.

Table 5. Temperature, air mass flow and heat transfer rates of all the cases

| Case | Maximum temperature (K) |                |          |        | Mass flow rate (kg/s) |                         |              |                         |                                      | Heat transfer rate (KW) |
|------|-------------------------|----------------|----------|--------|-----------------------|-------------------------|--------------|-------------------------|--------------------------------------|-------------------------|
|      | Cowling                 | Exhaust system | firewall | Engine | Open air inlet        | Liquid coolant radiator | Oil radiator | landing gear bay outlet | gap between cowling and exhaust pipe |                         |
| A    | 319.72                  | 375            | 309.08   | 352.89 | 0.7991                | 0.6                     | 0.1639       | -1.5464                 | -0.0167                              | -11.160                 |
| B    | 336.99                  | 385.64         | 326.26   | 368.04 | 0.8259                | 0.611                   | 0.169        | -1.5884                 | -0.0177                              | -11.361                 |
| C    | 312.12                  | 371.68         | 301.43   | 373.06 | 1.5733                | 0.915                   | 0.335        | -2.7932                 | -0.0296                              | -12.093                 |
| D    | 316.49                  | 349.58         | 293.85   | 320.07 | 2.1931                | 1.125                   | 0.45         | -3.7272                 | -0.0405                              | -12.615                 |
| E    | 312.12                  | 374.26         | 301.73   | 372.31 | 1.5733                | 0.915                   | 0.335        | -2.7936                 | -0.0298                              | -12.201                 |

For case E, The simulated results and performance parameters are quite similar for both take-off and landing. Here the maximum speed of air in the hot compartment up to about 62.44 m/s and 70.78 m/s was observed in the region of open air inlets and landing gear bay respectively. The maximum temperature of about 312 K at the cowling surface was observed at the just above and below of the engine due to thermal radiative heating and additionally, low mass flow rate of -0.0298 kg/s in the gaps between the cowling and exhaust vane. The maximum temperature of 374.26 K is observed over the exhaust cylinder particularly at on exhaust vane joint due to the low airflow at that region. In this case, the total heat transfer rate is -12.20 KW observed.

#### 4.1 Comparing case study results with engine operating limits

The engine manufacturer has given operating limits for ROTAX 912 F 3 engine. As per the installation manual [7] from ROTAX 912 F 3, the cylinder head temperature should be maintained below 423 K and air cooled heat transfer should be maintained minimum of 6 KW in all flight conditions. In computational investigation, all five cases with respective flight conditions were simulated for cowling system and results are obtained. The maximum Temperature of 385 K in engine bay and minimum of 11.06 KW of heat transfer carried away by the cowling system is observed from all the simulated cases. By comparing both engine operating limits and case study results, it can be conclude that, the designed cowling system is suitable for ROTAX 912 F3 engine and can be used in proposed microlight aircraft.

## V. CONCLUSION

Configuration selection of cowling system:

- The configuration selection of cowling system is made by referring various types of globally certified microlight category aircrafts and British Civil Airworthiness Requirements (BCAR) for small light category aircrafts.



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- For proposed microlight aircraft, the cowling parts like radiators position, cowl air intake and exit sizing were decided.

Design of cowling system:

- The design work is carried as per configuration selection using CATIA V5 R20 modelling software.
- While modelling of cowling system, the sub systems like liquid coolant radiator, oil radiator, exhaust system and engine mount is assembled as per BCAR.

Computational investigation on cowling system:

- The computational investigation of fluid flow and heat transfer in the engine bay of the microlight aircraft in a tractor configuration were performed in this work using ANSYS 14.5 simulation software.
- The geometrical model is discretised using ICEM CFD and solved using FLUENT tool.
- Outcomes of these simulations specified that the open air inlets and round the spinner mount is advantageous and certifies good cooling of the engine and exhaust system.
- The total five cases with different flight conditions is simulated and it is observed that, the maximum temperature is 385 K over the surface of exhaust system and minimum heat transfer rate is observed as of - 11.16 KW.
- This results shows that, the maximum temperature and air feed cooling heat transfer of cowling system is below the limits provided by the engine manufacturer and satisfies the cooling requirements.

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