Technical Memo

A33 Duct Flow Optimization

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Originated: 02.08.2020

Change History	
Date	**Notes**

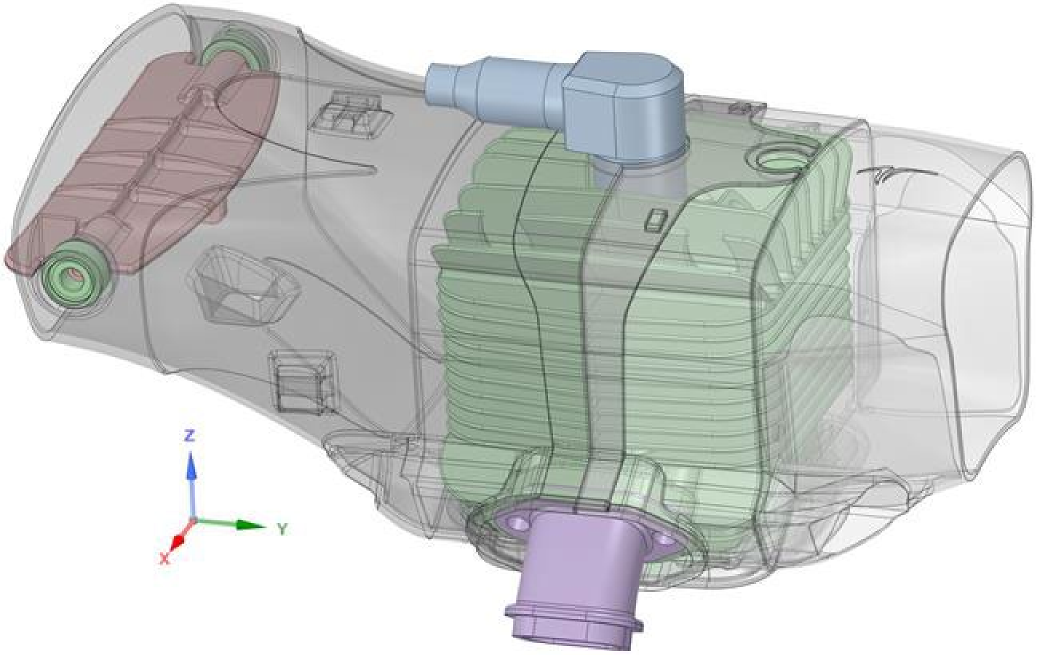


Figure 1. Overall A33 Duct Geometry

Ducts like the one shown in Figure 1 are typically used on air-cooled aircraft engines for three purposes:

1) They enhance cooling of the engine by accelerating air flow over the cylinder fins
2) They help steer air flow to critical 'hot spots' such as the cylinder head and exhaust area, and
3) They reduce engine cooling under certain operating conditions by closing the active inlet control flap. Such conditions include aircraft descents where the engine is typically running at a very low power condition.

This study was conducted to ensure that the duct was flowing cooling air over the cylinder as designed (i.e. no flow separation or 'dead zones'), and to further optimize the duct to improve cooling around the critical exhaust area. The results show success along both fronts.

Modelling approach

The modeling and the boundary conditions were both kept as simple as possible. Model complexity was reduced by eliminating some of the smaller fillets on the cylinder. This allowed a simpler mesh and reduced computational overhead. Furthermore, as a proxy for cooling effectiveness, our main output variable was local flow speed. We also interrogated visual flow lines to ensure that air flow remained attached to the walls through the diverging and bending inlet portion of the duct.

The atmosphere around the duct was kept at Standard Temperature and Pressure, and the inlet velocity was set at 18m/s. This was deemed to be low end of air speed for a Group 2 UAS that the A33 engine would typically be installed in, and that air speed presented a worst-case condition for the potential onset of flow separation inside the duct.

We modeled two duct geometries: The baseline geometry, and a geometry that we theorized would enhance cooling around the hot exhaust side of the cylinder. The duct modifications were all done on the downstream side of the cylinder by entirely removing the outlet dam on the exhaust side and enhancing it on the inlet side (Figure 2). This was done to flow more air around the exhaust port. This area is typically a hot spot because of the large amount of heat transfer from the high temperature, high speed gasses inside the port.

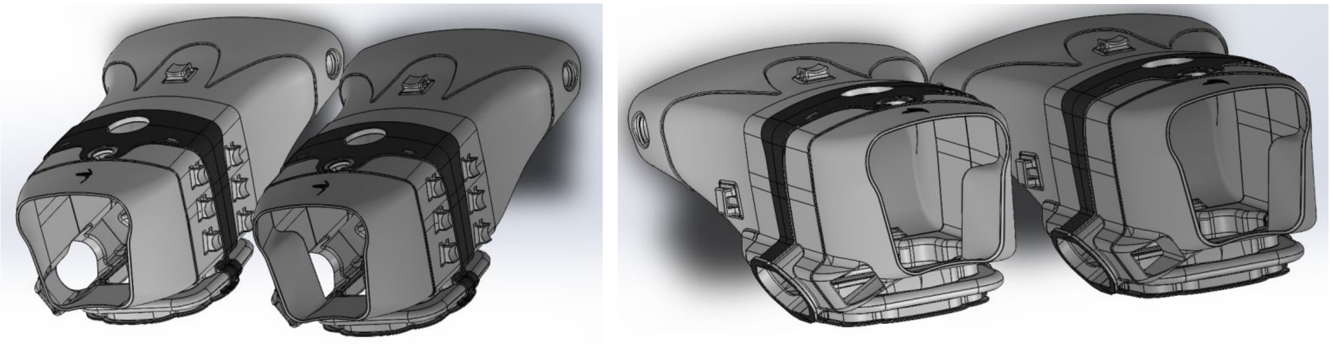


Figure 2. Baseline duct is on the right in both pictures. Air dam was removed from exhaust side, and air dam was increased in size on the intake side of the cylinder.

Results

The first area of interest was to determine if the duct was inducing flow separation between the inlet and the cylinder. The duct diverges downward to deliver cooling air to the base of the cylinder and the critical exhaust port area, so if flow separation was occurring, then this could starve this area of much needed airflow. The flow lines in Figure 3 show that even under the worst boundary conditions (airspeed of 18m/sec – Lowest Reynolds Number tested), that the flow maintains attachment to the bottom section of the duct.

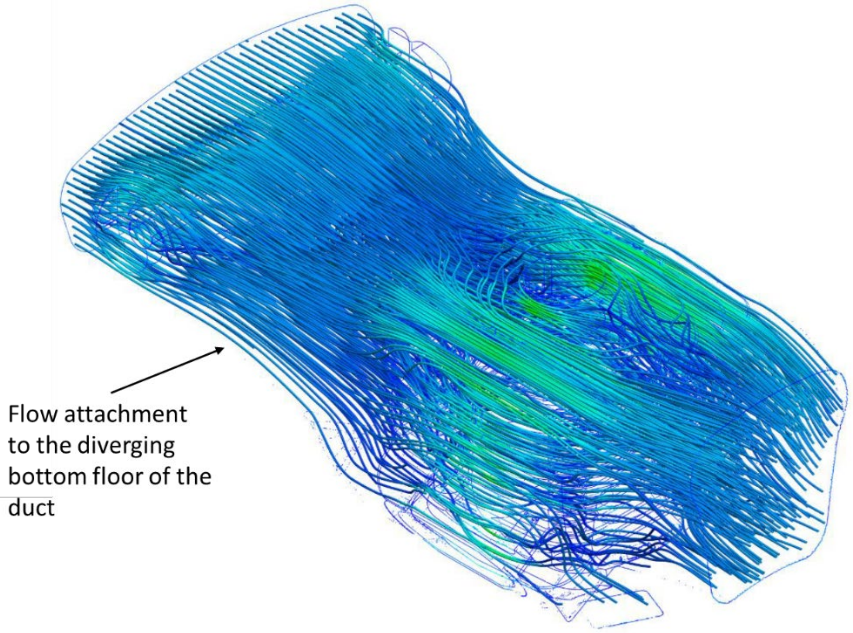
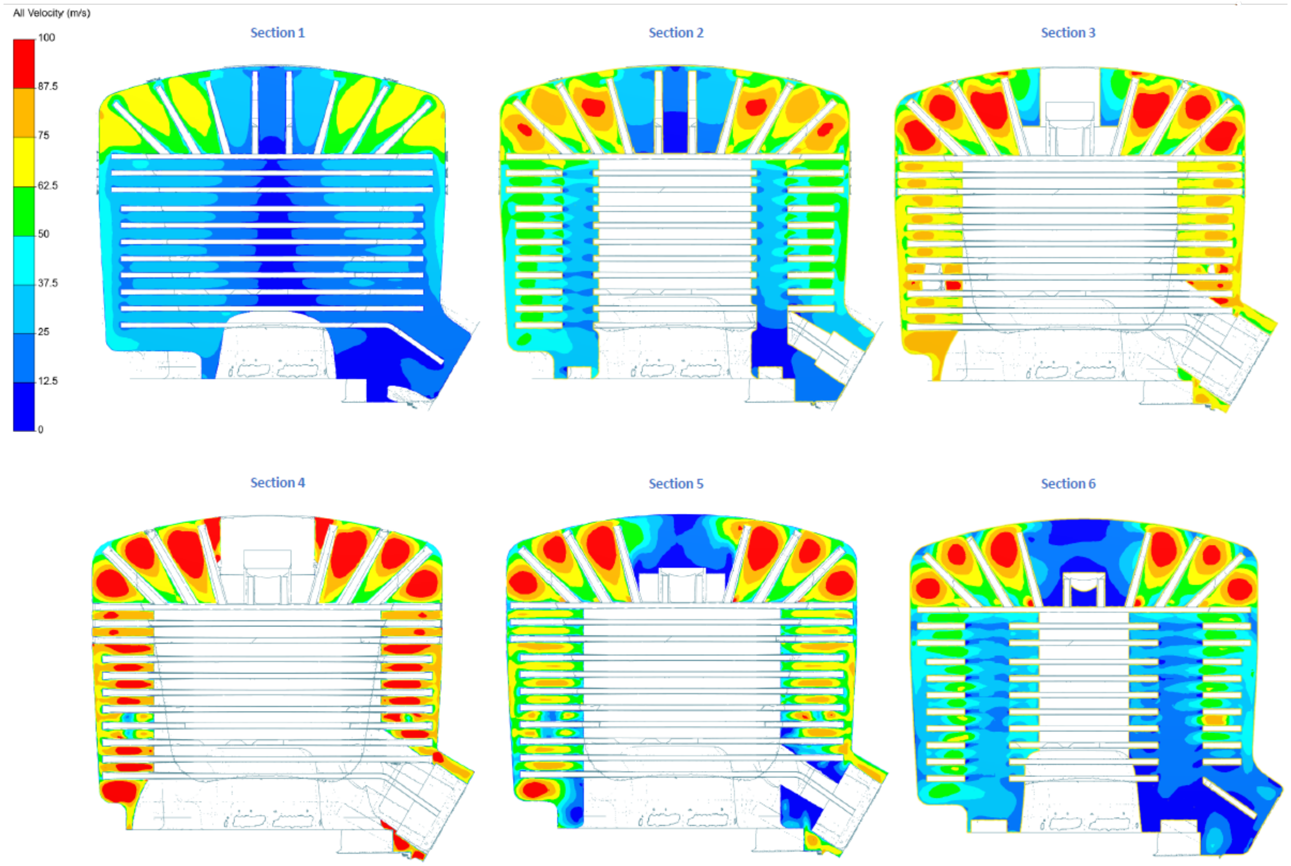


Figure 3. Particle Traces at inlet velocity of 18m/sec.

The next area of interest was flow around the cylinder itself. There are two areas of the cylinder that are most critical to cool well: 1) the cylinder head, and 2) the exhaust port area. The cylinder head carries a large heat flux since the turbulent combustion gasses transfer a relatively large amount of heat to the adjacent cylinder head metal. Similarly, hot and high-speed exhaust gasses transfer a large amount of heat to the walls of the exhaust port, and thus metal temperatures in these two locations are higher than in other parts of the cylinder.

To better understand how well the duct was cooling these areas, we took vertical slices of the flow area between the cylinder and the duct starting just before the exhaust port and moving in 10mm increments downstream until we reached behind the port. These views provide a map of local flow speeds, and thus provide a proxy for what the local heat transfer will be (higher flow velocities provide increased convective heat transfer over a surface).

Figure 4 shows this velocity map for our baseline geometry. Air speed at the inlet of the duct was set to 30m/sec, and the 'intensity map' illustrates a flow speed range of 0m/sec to 100m/sec.



Section cuts are made 10 cm apart perpendicular to direction of flow.
Velocity normalized to 100 m/s for relative comparison.

Iteration 1
Load Case 2: Inlet Velocity = 30 m/s

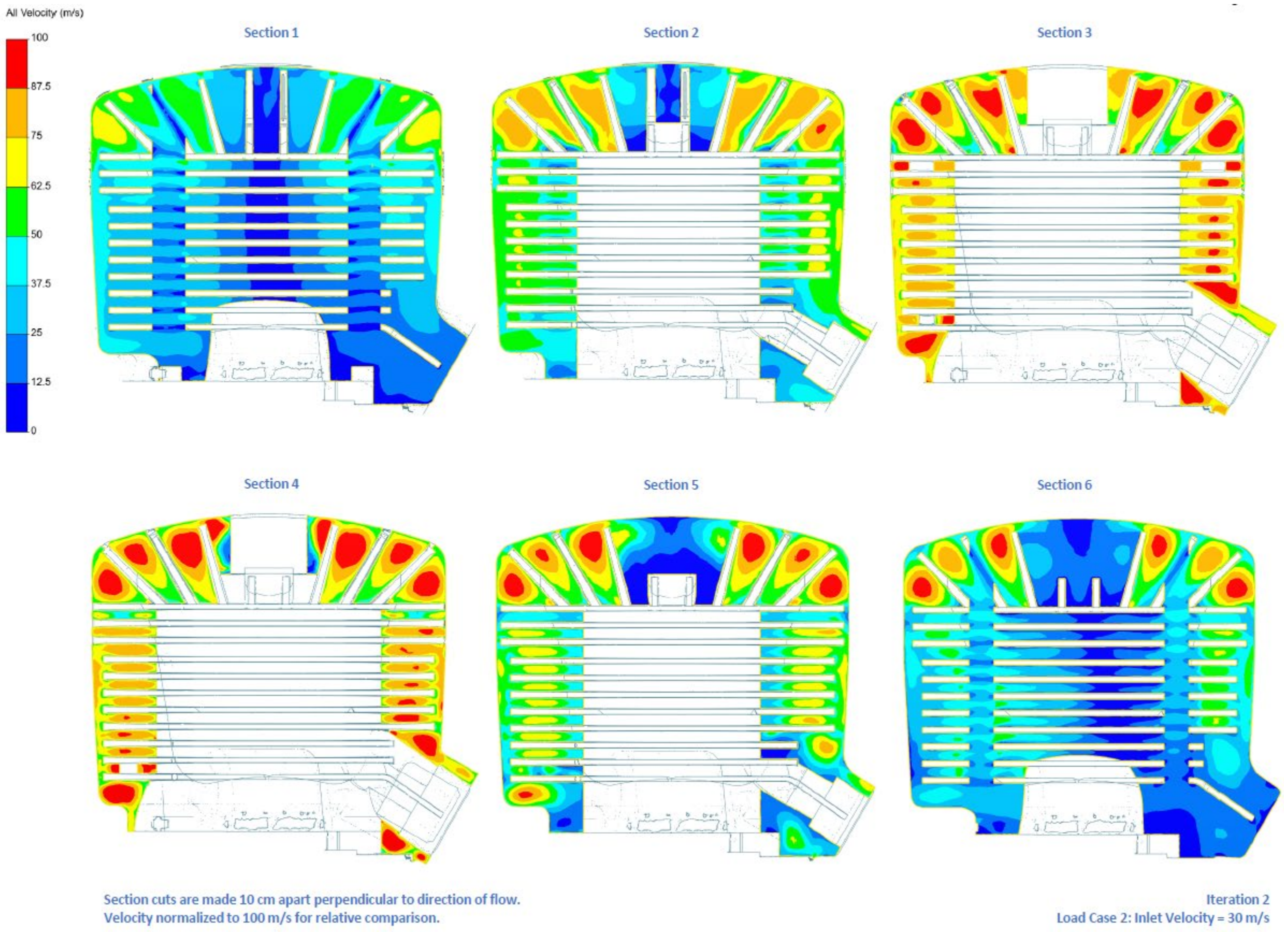
Figure 4. Baseline geometry flow speed map.

Observations:

- Flow accelerates over the head as designed.
- Intake to exhaust-side flow balance above the exhaust port is good.
- Flow over the exhaust port is almost stagnant

Based on these results, we modified the duct to bias more air flow over the exhaust side of the cylinder. To this end, two changes were made: a) we nearly doubled the size of the outlet side dam on the intake side of the cylinder, and b) we completely removed the outlet dam from the exhaust side of the cylinder. Our goal was to keep the positive flow characteristics of the duct above the port, and to entice more air flow above and below the exhaust port to improve cooling in this area.

Figure 5 shows the slice-by-slice air speed results for this configuration:



Section cuts are made 10 cm apart perpendicular to direction of flow.
Velocity normalized to 100 m/s for relative comparison.

Iteration 2
Load Case 2: Inlet Velocity = 30 m/s

Figure 5. Flow speed after cowl modifications.

Observations:

- Flow over the head remains balanced and at a high speed.
- Air flow remains balanced above the exhaust port on the intake and exhaust sides of the cylinder.
- Flow over the exhaust port shows increased speed and thus improved cooling performance.

As a final look at the exhaust side of the cowl, Figure 6 compares the baseline cowl with the modified one. The left-side shows the baseline condition, and on the right is the modified cowl. The modified cowl shows improvement in exhaust-side air flow both above and below the exhaust port.

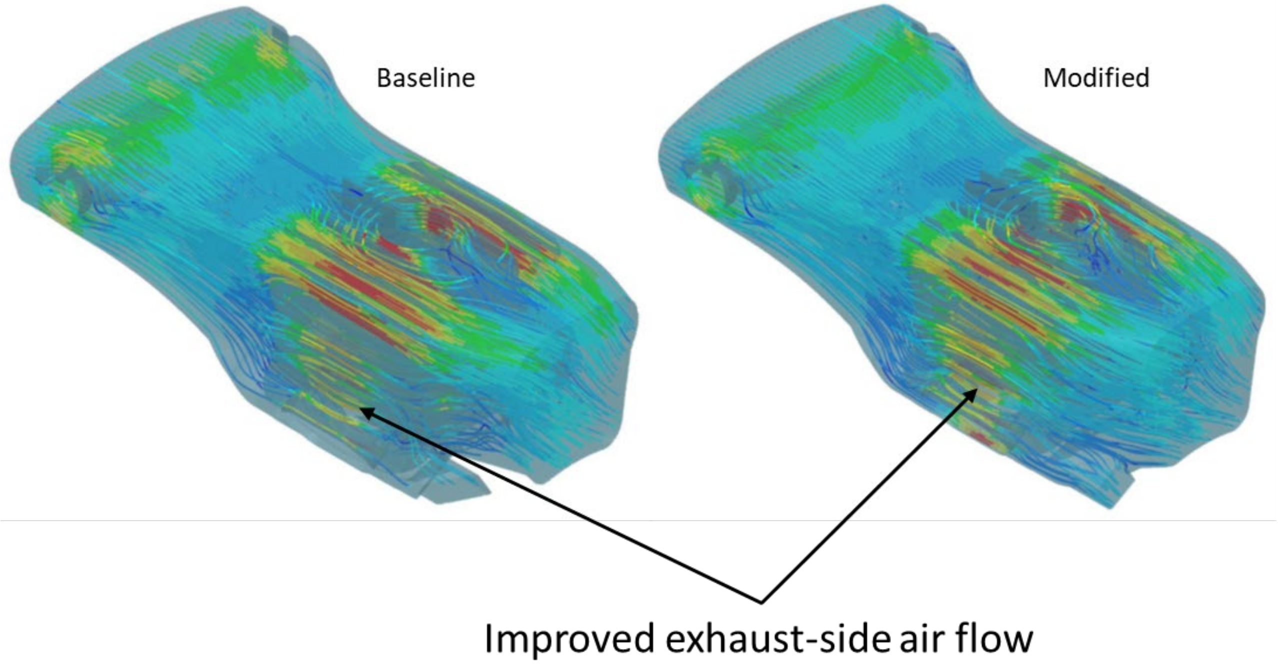


Figure 6. Baseline and as-modified particle tracking comparison.

Final Outcome

The modified cowl design was chosen for the production A33N engine.