Putting the Spin on Air Pre-Cleaners

Dust and dirt particles are removed from the air intakes of off-highway vehicles using a novel air pre-cleaner.

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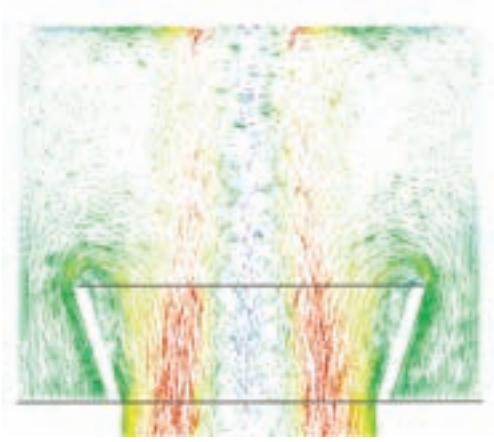
Off-highway vehicles spend much of their lives in dirty surroundings. This type of work environment poses a challenge for the engine and components, particularly the air pre-cleaner that separates dirt, sand and other large particles and debris from the air before it passes through the filter and into the engine. At Donaldson, an air pre-cleaner product line has been developed and optimized with the help of CFD. As a result of this effort, the TopSpin™ air pre-cleaner has been shown to extend air filter life and improve fuel economy for this special class of vehicles.

Air enters the TopSpin pre-cleaner chamber through stationary vanes that impart a tornado-like (free vortex) rotational velocity. This velocity generates centrifugal force that separates particle contaminants to the outside of the chamber. After the vanes, the air moving into the chamber passes through a conical section, which accelerates the flow. Accelerated air increases the particle separation efficiency and a larger chamber outlet decreases the system pressure drop. By the time the rotating air reaches the center of the pre-cleaner chamber, most of the particles from the incoming flow are spinning along the outer wall.

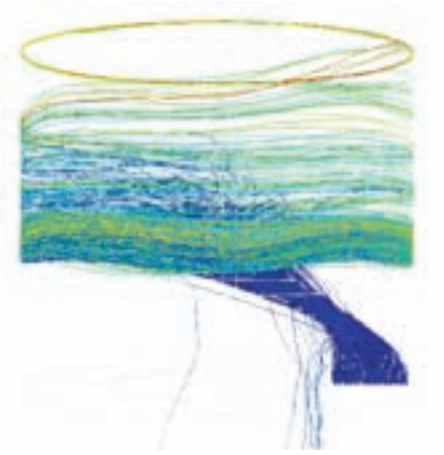
The Donaldson TopSpin air pre-cleaner

To remove the spinning particles, Donaldson engineers added a small number of paddles that sweep around the outer wall of the chamber. The inner vanes are designed so that the outer wall paddles rotate faster than the outer wall air flow. This causes each paddle to generate a positive pressure wave as it sweeps the outer wall of the pre-cleaner chamber. As the paddle assembly rotates, the particles are ejected by the positive pressure wave into the lower pressure atmosphere. In other words, dirty air is pushed out while the cleaned air moves inward and exits through the center of the pre-cleaner chamber.

Until very recently, the design of air pre-cleaners was much more of an art than a science. The only way to determine what dimensions were needed to optimize a design was to perform a long and expensive series of build and test cycles. Once a design was found, further testing was needed to see how the design scaled across a product line. The cost and time involved in building prototypes limited the number of prototypes that could be built and often forced engineers to settle for



Velocity vectors on the mid-plane of the air pre-cleaner



Particle trajectories in the air pre-cleaner, colored by residence time

good enough rather than optimized designs. The limitations in the physical measurements that could be obtained from an operating pre-cleaner meant that engineers gained minimal information from each build and test cycle, so many iterations usually were required to optimize the design.

Donaldson engineers have avoided these problems for the past several years by using CFD to evaluate new designs and optimize their performance prior to the prototype phase. CFD has allowed the engineers to quickly evaluate alternate configurations and get a much better understanding of why each one performs the way it does. For this project, simplified pre-cleaner designs were built using GAMBIT software. Unnecessary mechanical details were removed to save on computational time and focus on accurately depicting the passageways where fluids flow through the pre-cleaner. A rotating reference frame was used to model the rotating vanes and paddles.

Each of the 70 models was solved using four processors of a 32-processor Hewlett Packard Superdome computer. The paths of many differently sized particles were tracked and analyzed. Separation efficiencies were calculated for each particle size, and from the individual particle size efficiencies, an overall mass efficiency was calculated. The particle tracks also were used to graphically illustrate the path of each particle entering the pre-cleaner, providing valuable information that engineers used to improve separation efficiency on future designs.

Donaldson engineers first optimized the pre-cleaner design without including the rotating elements. The goal at this stage was simply to move as many particles as possible to the walls of the pre-cleaner chamber while minimizing the pressure drop. The very first simulation provided far more information about the flow regime inside the pre-cleaner than could have been gained from a dozen physical tests. It showed the transition of the flow inside the pre-cleaner chamber from irrotational near the outside walls to rotational in the center. FLUENT software predicted the size of the "eye of the hurricane," information that was subsequently used to place the rotating vanes and paddles.

Some other key design parameters that were adjusted at this stage were the dimensions of the pre-cleaner chamber, the angle of the conic section used to accelerate the air as it enters the pre-cleaner and the dimensions of the vanes used to swirl the flow. Donaldson engineers made adjustments to the chamber geometry to provide the highest spin velocity for the lowest pressure drop.

The model dimensions of the rotating assembly and paddle angles were adjusted so that the paddles rotate faster than the swirling air inside the chamber. This created a pressure wave high enough to remove the particles. They accomplished this by adjusting the number, size and shape of the paddles while also performing further fine tuning of the vane and conic section angles.

After each design change, they re-ran the simulation in order to measure the impact on the pre-cleaner performance and the flow regime. After completing their investigation of 70 configurations, Donaldson engineers were confident that they had optimized the design and had good knowledge of design trade-offs. Engineers also used the CFD results to calculate the forces acting on the paddles, which in turn provided loads for ANSYS finite element analysis software that was used to validate the mechanical design of the paddles.

The resulting TopSpin pre-cleaner is designed for use with many different types of equipment, ranging from crawlers and farm tractors to skid steer loaders. The TopSpin line is available in 13 models with outlets ranging from two to seven inches and air flow ranges from 100 to 1,600 cubic feet per minute. ISO 5011/SAE J726 tests showed that, as predicted by the simulation, the pre-cleaner separates 99 percent of contaminants 20 microns and larger. This greatly extends air filter service life. These performance benefits can largely be attributed to the use of CFD to optimize the design. ■