Nozzle Development for Dry Media Blasting Processes


ABSTRACT

The dry media blast nozzle has undergone little change over the past forty-five years. The Laval nozzle (mistakenly termed the Venturi nozzle) has been the basis of particle energization for nearly all dry media blasting processes. Indeed, in the brute force sand blasting erosion application (the first dry media blasting process developed), the inefficiencies of such a nozzle configuration may or may not necessarily be an important consideration. In the more refined paint stripping of aircraft, however, efficiency is the key to optimal productivity. The efficiency of a blast nozzle can be affected by several parameters from nozzle exit to throat area ratio to particle size distribution.

CAE Electronics Ltd. is in the process of developing a series of dry media blasting nozzles for aircraft stripping processes ranging from open blast manual systems to closed cycle automated systems. This development process has placed specific emphasis on the requirements of starch and plastic media based systems including delivery pressures, flow rates, particle velocities etc. This paper will deal with the tools and design approach utilized by CAE.

INTRODUCTION

Proper design of any subsonic-supersonic nozzle is a function of various judiciously chosen physical dimensions such as area ratios and nozzle length. These dimensions are in fact functions of such parameters as operating pressures, desired outlet velocity, fluid properties, etc. The successful subsonic-supersonic nozzle design will allow for the uniform, orderly acceleration of the flow from subsonic to supersonic conditions in the absence of any irreversible processes (i.e. shock waves). In the case of dry media blasting, this process is made all the more difficult by the presence of the abrasive particles which tend to disturb the flow. Adding to the complexity of the problem is the need to obtain a uniform particle distribution across the nozzle width.

REVIEW OF FLOW REGIMES

During nozzle operation, there are five possible flow outcomes: Subsonic flow throughout the nozzle, two cases of over expanded flow, the ideal uniform parallel flow and under expanded flow. In Figures 1 through 5 (pages 5 & 6) are shown cross sectional schematics of the convergent-divergent nature of a generic nozzle with given inlet to throat and outlet to throat area ratios. Particle effects on the flow are not shown for clarity of the figures. In Figure 1, the inlet pressure is so low that the flow accelerates to the throat and then decelerates to the nozzle outlet with the fluid remaining in the subsonic regime throughout its resident time within the nozzle domain. Clearly, particles cannot gain sufficient energy in this configuration in order to strip paint.

Figure 2 shows what occurs with an increase in the operating (inlet) pressure. Initially, the flow accelerates until a sonic condition exists at the nozzle throat. Upon further increase of the operating pressure, a weak shock wave is generated at the nozzle throat with the flow still remaining in the subsonic regime through the divergent portion of the nozzle. A slight increase in pressure from this value causes the normal shock wave to position itself downstream of the throat accordingly. Here, the flow accelerates to sonic values at the throat and continues to accelerate to supersonic values until it traverses the shock wave where it experiences an abrupt change in velocity (pressure, temperature, etc.) to subsonic conditions. Energy gained by the particles' presence within the supersonic flow field is quickly lost as they meet up with a pressure wall at the shock front interface. This is the first case of overexpanded flow.

Figure 3 shows that a further increase in pressure will tend to push the normal shock out of the outlet of the nozzle generating oblique shock waves in the post nozzle region. These oblique shocks are believed to be the cause of the pulsing that is often seen in nozzles that are operated below the design pressure. Again, some of the energy gained by the particles in the supersonic leg of the flow process is lost in traversing the oblique shock waves. This loss in energy is not as pronounced as in the normal shock case.

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therefore, individual particles are still able to strip paint but to differing degrees. This is the second case of overexpanded flow.

Figure 4 shows a uniform parallel supersonic flow field in the post nozzle region. This is obtained when the pressure is further increased from the values mentioned above. Here, the cutting potential of the particles is at a maximum with the greatest mass flow of air and dry media exiting the nozzle at high energy levels. This is the ideal case.

A final increase in operating pressure yields the flow pattern shown in Figure 5. The expansion waves in the post nozzle region arise due to the under expanded nature of the flow. While particles are still accelerated as they leave the nozzle in this configuration, less mass is able to pass through the throat of the nozzle yielding a lesser efficient energy transfer between the flow and the particles resulting in lower than ideal particle velocities. Nevertheless, it can be beneficial to operate the nozzle just beyond the onset of this regime.

FLUID DYNAMIC CONSIDERATIONS

In dry media blasting, all of the above mentioned factors affect the velocity at which the particles leave the nozzle. There are other factors which are important in determining the particle distribution in the blast trace. These include particle-flow, particle-boundary and particle-particle interactions.

Particle-flow interactions take into account the transfer of energy from the particle to the flow and from the flow to the particle. These effects become important when the mass loading (i.e. ratio of mass of the solid particles to the total mass of the conveying fluid and conveyed particles) becomes high. In most cases studied by CAE Electronics, for dry media blast, mass loading is on the order of 50% (i.e. for every kg of solid media flowing through the system, 1 kg of air accompanies it). Particle-boundary interactions include all interactions with external (nozzle walls) or internal (turning vanes, fins etc.) boundaries. These interactions tend to create a high loss in particle momentum thereby decreasing particle cutting potential and increasing media consumption in an improperly designed nozzle. Particle-particle interactions become important when volumetric loading (i.e. volume of solid particles to volume of conveying fluid) becomes high. Other physical phenomena that affect particle distribution include boundary layer formation, flow separation, recirculation and turbulence.

DESIGN APPROACH

At CAE Electronics, the overall goal of nozzle development is to maximize the productivity of the dry stripping process. In order to achieve this, work has focused on the design of energy efficient blast nozzles that generate a uniform particle distribution in terms of cutting potential of the particle laden flow. The final optimum design will be a compromise between the strip swath width, strip rate, media consumed and power consumed. Nozzle design has been geared towards open and closed systems, used in manual and automated modes, for both starch and plastic media processes. The end requirements of the developed nozzles include the ability to perform complete and selective stripping on both aluminum and composite substrates.

The approach taken by CAE to devise the optimum nozzle design for a particular application is fourfold. First, a rough design is obtained through hand calculations. These make use of compressible fluid dynamics as well as non-equilibrium flow gas dynamics. Once the rough stage is complete, designs are verified in a computational fluid dynamics (CFD) software package. The package presently being used is TASCflow published by ASC of Waterloo, Ontario. This CFD code is a fully compressible, turbulent Navier-Stokes solver with the capability of handling particle tracking and heat transfer for both transient and steady state 3-D problems. Some of the flow code outputs that are used to determine the qualitative superiority of one design over another include plots of the pressure field, velocity field and particle distribution in terms of size, velocity, kinetic energy and momentum. It should be stressed that this step of the design stage is used to determine the qualitative difference between a number of designs and serves to eliminate poor designs in the initial stages.

NOZZLE TESTING

Designs that pass the CFD stage go on to be manufactured and tested. Nozzle prototypes are manufactured at CAE with nozzle efficiency tests carried out at the CAE/Envirostrip Test Center in Montreal. Nozzles at the test center are evaluated using a number of methods. The two most important of these include stripping of painted panels and erosion of renshape material tests, both of which can be performed on an automated x-y table. Test panels are painted in accordance with USAF MIL spec T.O. 1-1-8. Nozzle operation in terms of actual paint stripping is verified using an accelerated travel method on the automated x-y table. Panels are accelerated linearly within a range of 0 to 6 in/sec while maintaining the nozzle operating parameters constant. At lower speeds the tendency is to remove paint and primer. At greater speeds, it is possible to remove only paint or nothing at all depending on the level of the cutting potential for the particular operating condition being verified. Continuously accelerating the panel linearly allows for a study of all paint stripping regimes that exist between these two extremes. In the particular example shown in Figure 6, the panel was accelerated from 0.5 to 3 in/sec. At the far right of the figure, we can see that paint and primer have been removed to the substrate. At the far left of the panel, it can be seen that over part of the width only the top coat has been removed while over the rest of the width, not even the top coat has been completely removed. Between these two extremes the pattern obtained allows for the determination of the cutting potential concentration across the nozzle width as well as the optimum travel speed for the particular paint removal regime. The arrowhead shape to the complete strip swath in Figure 6 coupled with the two narrow tracks at the lateral extents of the trace indicate that there is a higher cutting potential concentrated at the center and at the lateral extents of the blast jet.

The renshape is an isotropic polyurethane material that can be used to reflect the relative concentration of cutting potential in the blast jet. The material is readily eroded leaving behind a void which is in some way proportional to the cutting potential of the
blast trace. For example, examine Figure 7. This renshape void has been created using a double Venturi nozzle. We can see the hot spot at the center of the Venturi nozzle trace reflected in the greater amount of material removed from the center of the profile. It is also quite simple to see that selective stripping, a quite delicate process, would be difficult to perform efficiently with such a nozzle. Figure 8 shows the renshape trace obtained using one of the advanced engineered nozzles designed at CAE. It can be seen that the cutting potential of the particle trace has been spread out considerably. In an automated system, this would facilitate control of both the selective and complete stripping processes in paint removal.

Figure 9 shows a plot of the cutting potential for three nozzles obtained using the renshape material. (The ideal nozzle design is depicted as well.) Here it is seen that all of the cutting action provided by the Venturi nozzle is concentrated over a small width on the order of one inch. Further, a high proportion of the energy is concentrated at the center of the blast trace. Both nozzles A and B, however, deliver a better distribution of the cutting potential over a wider trace. Peaks at the lateral extents of the profiles are exaggerated in order to show the areas for improvement. The ideal case is one where the distribution of the particles is uniform and across the whole of the nozzle width.

The final step in the design process is one of reiteration.

CONCLUSION

Through the advanced engineering steps being taken by CAE Electronics, design of the dry media blast nozzle is being tailored to the specific process of aircraft paint removal. In order to accomplish this, the inefficiencies of the traditionally used Venturi nozzles are being corrected to allow for a more uniform distribution of solid particles over a much larger blast trace. Some of the benefits that have already been seen include improved productivity, better uniformity of treatment and more efficient use of the blast media. In short, the goal set out by CAE Electronics to obtain a superior dry media blast nozzle with a uniform even particle distribution is not only feasible, but is well on its way to becoming reality.

Figure 1. Schematic cross-section through a generic convergent-divergent nozzle. Subsonic operation.

Figure 2. Schematic cross-section through a generic convergent-divergent nozzle. Over expanded flow - case I.
Subsonic Supersonic Non uniform flow

Oblique shock waves

Figure 3. Schematic cross-section through a generic convergent-divergent nozzle. Over expanded flow - case II.

Subsonic Supersonic

Expansion waves

Figure 4. Schematic cross-section through a generic convergent-divergent nozzle. Ideal case. Uniform parallel supersonic flow at nozzle outlet.

Subsonic Supersonic

Figure 5. Schematic cross-section through a generic convergent-divergent nozzle. Under expanded flow.
Figure 6. Accelerated travel method using a MIL spec painted panel.

Figure 7. Double Venturi reshape material erosion test.

Figure 8. Nozzle B reshape material erosion test.

Figure 9. Cutting potential vs. swath width plot for 3 nozzles.

45° angle of attack
2" stand off distance
40 psi
12 lbs/min

Cutting potential vs. strip swath width

Venturi
Nozzle A
Nozzle B
Ideal

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