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ANALYSIS, DESIGN AND TESTING OF HIGH PRESSURE WATERJET NOZZLES

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Preface

This report summarizes research conducted by the author as a Summer Faculty Fellow for the Hydroblast Research Cell at Marshall Space Flight Center (MSFC) in 1995. The project is a continuation of work done at MSFC as a Faculty Fellow in 1994 [3] and has consisted of identifying and investigating the basic properties of rotating, multijet, high pressure water nozzles, and how particular designs and modes of operation affect such things as stripping rate, standoff distance and completeness of coverage. The study involved computer simulations, an extensive literature review, and experimental studies of different nozzle designs.

Introduction

The Hydroblast Research Cell at MSFC is both a research and a processing facility. The cell is used to investigate fundamental phenomena associated with waterjets as well as to clean hardware for various NASA and contractor projects. In the area of research, investigations are made regarding the use of high pressure waterjets to strip paint, grease, adhesive and thermal spray coatings from various substrates. Current industrial methods of cleaning often

From [3] we have a formula for the maximum number of orifices that can be placed on a nozzle for a given flow rate, pressure and orifice exit diameter. If F = flow rate, A = cross sectional area of orifice exit, v = exit velocity of waterjet, d = exit diameter of orifice, p = pump pressure, p_a = atmospheric pressure, ρ = density of water and n = number of orifices, then $n \leq \frac{4F}{\pi d^2}\sqrt{\frac{\rho}{2(p-p_a)}}$, where c_ν is an experimentally determined constant called the velocity coefficient which is usually between 0.9 and 0.95 [6]. For a conservative assessment of n, we set $c_\nu = 1$. Thus if $F = 13$ gpm $= 50\text{in}^3/\text{sec}$, $p = 36,000$ psi, and $d = .019$in, we have $n \leq 6.36$ (i.e. $n \leq 6$). Once the number of orifices for the nozzle is chosen, the effect of different placements can be studied, and in [3] we show that the optimum arrangement for cleaning applications is to arrange the orifices at an equal distance from the center of the nozzle with equal angular spacing (see Fig.1). Then, if the minimum trace width of all the orifices is denoted by w_t, sweep rate and angular velocity must satisfy the relation $\omega \geq \frac{2\pi v_0}{n w_t}$ if we are to have complete coverage [6]. For example, if

mm, then we require $\omega \geq 20\pi$ rad/sec for complete coverage.

The preceding analysis assumes that the centerline of the nozzle is aligned perpendicular to the target which is assumed flat as shown in Fig.1. A precise characterization of the jet shape is necessary to determine the trace width w_t. For practical purposes, a chart showing trace width w_t as a function of standoff distance for various operating pressures can be determined experimentally. We note here that the influence of gravity on the jet must also be accounted for, although this effect will be negligible for short jets.

Computer Simulation

A computer program consisting of a collection of *MATLAB* "m-files"(see Ref. [4]) has been written to assist operators of the Hydroblast Research Cell in selecting the fastest possible sweeprate allowed for a given set of system parameters. In addition to this operational computer program, Computational Fluid Dynamics (CFD) analysis has been initiated as a means of evaluating different nozzle and orifice designs.

Testing Procedures

The methods chosen for evaluating different orifice designs were stripping tests, high-speed video, high-speed film, still photography and pressure measurements. (We note here that filming high-speed waterjets requires extremely bright lighting conditions.) For the stripping test, 24 inch by 24 inch panels coated with MCC (Marshall Convergent Coating) were used as targets and stripping ability was determined at various standoff distances and water pressures. A test figure was designed for measuring the pressure delivered by the waterjet to the target (see Fig.4). (Fabrication of the fixture was not completed in time to use this summer.) As seen in the figure, water strikes a target disk and imparts a force, which is then transmitted through a lever to the load cell. By adjusting the position of the support, we can change the sensitivity of the system. By measuring the force on targets of different diameters, we can determine the force acting on thin annular regions at various radial distances. By selecting sweeprates for a given set of system parameters. CFD analysis has been initiated. Orifice geometries likely to produce highly compact jets have been designed and fabricated. Preliminary tests of these orifices have been conducted and indicate that some of these designs may provide an order of magnitude increase in the standoff distances that can be achieved with current waterjet cleaning systems.

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References

[1] R. Kobayashi, T. Arai and Y. Masuki, "Water Jet Nozzle Geometry and Its Effect On Erosion Process of Metallic Material", *5th American Water Jet Conference*, August 29–31, 1989, Toronto Canada, pp.59–68.

[2] S. J. Leach and G. L. Walker, "The Application of High Speed Liquid Jets to Cutting", *Phil. Trans. Roy. Soc. (London)*, Vol. 260, Series A, pp. 295–308.

[3] A. P. Mazzoleni, "Design of High Pressure Waterjet Nozzles", Report XXIX for the 1994 Summer Faculty Fellowship Program at Marshall Space Flight Center, Huntsville, AL.

[4] *MATLAB–High-Performance Computation Software*, The Mathworks Inc., 24 Prime Park Way, Natick, MA 01760

[5] M. J. McCarthy and N. A. Molloy, "Review of the Stability of Liquid Jets and the Influence of Nozzle Design", *The Chemical Engineering Journal*, Vol. 7, 1974, pp.1–20.

[6] P. J. Singh, J. Munoz and W. L. Chen, "Ultra-High Pressure Waterjet Removal of Thermal Spray Coatings", *Jet Cutting Technology*, Kluwer, 1992, pp.461–480.

[7] J. M. Sohr and M. L. Thorpe, "Stripping of Thermal Spray Coatings with Ultra High Pressure Water Jet", *28th Annual Aerospace/Airline Plating & Metal Finishing Forum and Exposition*, San Diego, CA, 1992, paper 920939.

[8] P. F. Thorne and C. R. Theobald, "The Effect of Nozzle Geometry on the Turbulent Structure of Water Jets – A Photographic Study", *Fourth International Symposium on Jet Cutting Technology*, Canterbury, England, 1978, paper A4.

Figures

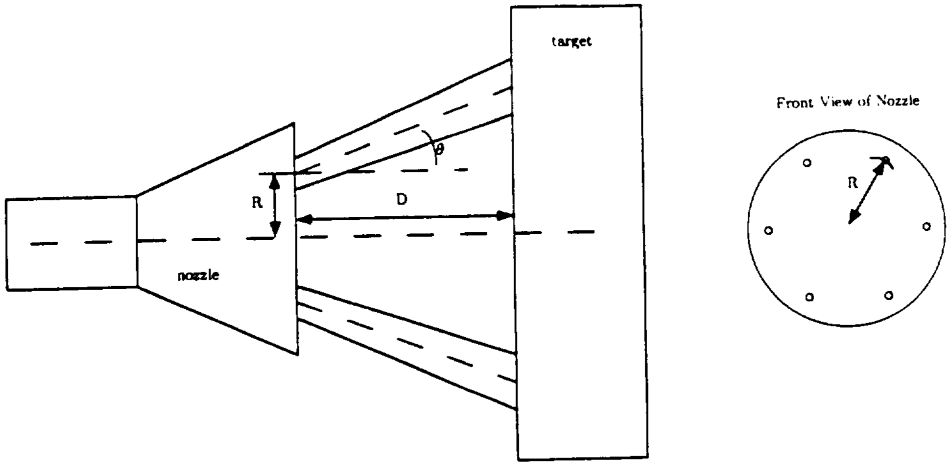


Fig. 1

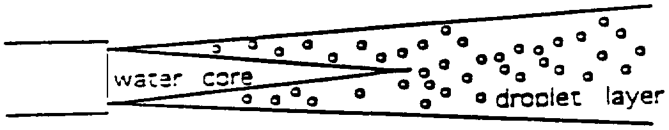


Fig. 2

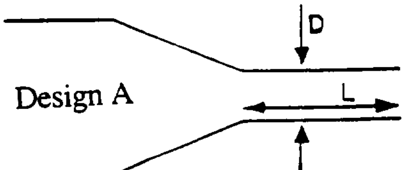


Fig.3a

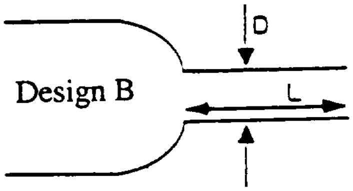
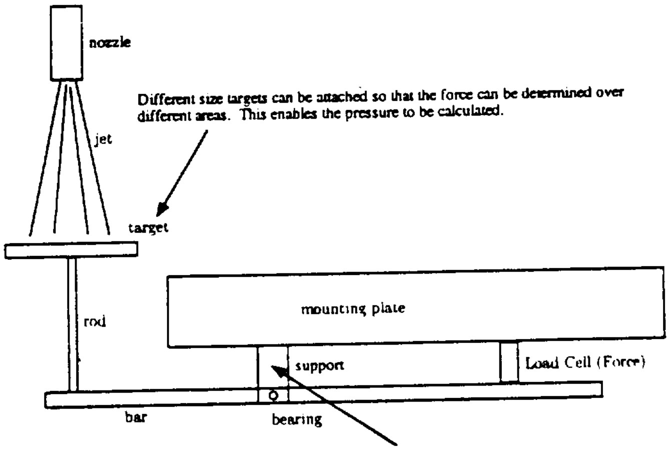


Fig.3b



Different size targets can be attached so that the force can be determined over different areas. This enables the pressure to be calculated.

The location of the support/bearing along the bar can be changed, thus changing the sensitivity of the force measurement.

Fig.4