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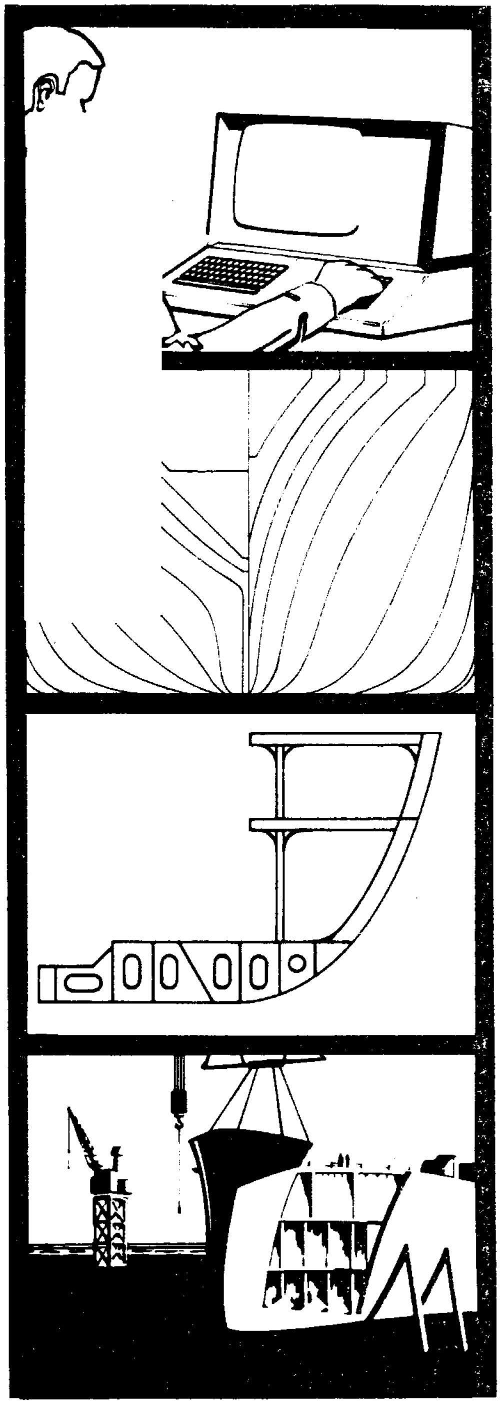

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IN
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APPLICATIONS OF WATER JET TECHNOLOGY
TO SHIPBUILDING

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INTRODUCTION

The use of hydraulic techniques for ship hull cleaning/surface preparation and cutting of primary metals has received considerable attention in recent years. Water jet cleaning of ship hulls has been investigated and utilized in conventional dry dock operations, but recent results have also shown that it can be used in the submerged condition and has selective material removal capabilities. Cutting of primary metals is a relatively new concept, due to increased capabilities of high pressure equipment. Thin metal sections have been cut and thicker sections can also be cut, but the economics of the process and some technical considerations have yet to be established.

Ship Hull Cleaning

Water jet systems can be used to prepare metal surfaces for initial painting or coating and to remove old coatings or fouling. As with any process there is a set of parameters which affect the overall system performance. Two types of jets have been investigated for the hull cleaning applications: 1) conventional continuous jets, and 2) cavitational jets. Performance of both jets are influenced by the following parameters:

- jet pressure
- nozzle diameter
- cleaning rate
- type of fouling
- standoff distance.

The cavitational jet is strongly influenced by nozzle geometry and standoff distance; while the continuous jet can be substantially augmented by the use of abrasives, the cavitational jet cannot. The basic difference between the two, jets centers in how the high pressures at impact are generated.. In a conventional continuous *jet,* the pressures are generated by the pump,,whereas in a cavitational jet the pressures are generated when the vapor bubbles, generated in the nozzle, are collapsed at the work surface. Generally, the pump pressure for a cavitational jet is less than that of a conventional jet. The cavitation is generated'in the . nozzle using a standard after body or turning vane configuration. The impact pressures of a cavitational jet can be from 10 to *40* times the pump pressure. Hence, the cavitating jet is an amplification technique. Both jets can be effectively applied in conventional dry dock operations and underwater."

Figures 1 and 2 show conventional dry dock utilization of conventional continuous water jets in the abrasive augmented mode and unaugmented. Both operations are manual using a single lance/nozzle configuration. Multiple nozzle configurations can be utilized but care must be taken to provide adequate reaction of the unbalanced forces. A mechanized system such as the Ruck-Zuck "Dockmaster" [2] carries a bank of jets on an extendable boom and provides the necessary structural support and parameter control to fully realize the capabilities of the jet cleaning system. Obviously in a mechanized system, the power requirements must be substantially higher than in *a* manually operated system, but the productivity is correspondingly greater. Typical production rates for a single nozzle unit range from 800 to 2,000 ft^2/hr with access to the hull being the major influence on the cleaning rate, (This is for marine fouling removal only.) Care must be taken to guard against damage to the hull coating by controlling cleaning rate and standoff_ distance. The foregoing discussion applies to conventional continuous jets only. These systems are commercially available (generally limited to single lance units) from manufacturers such as Aqua Dyne, American Aero, Parteck, etc. with operating pressures to 20,000 psi.

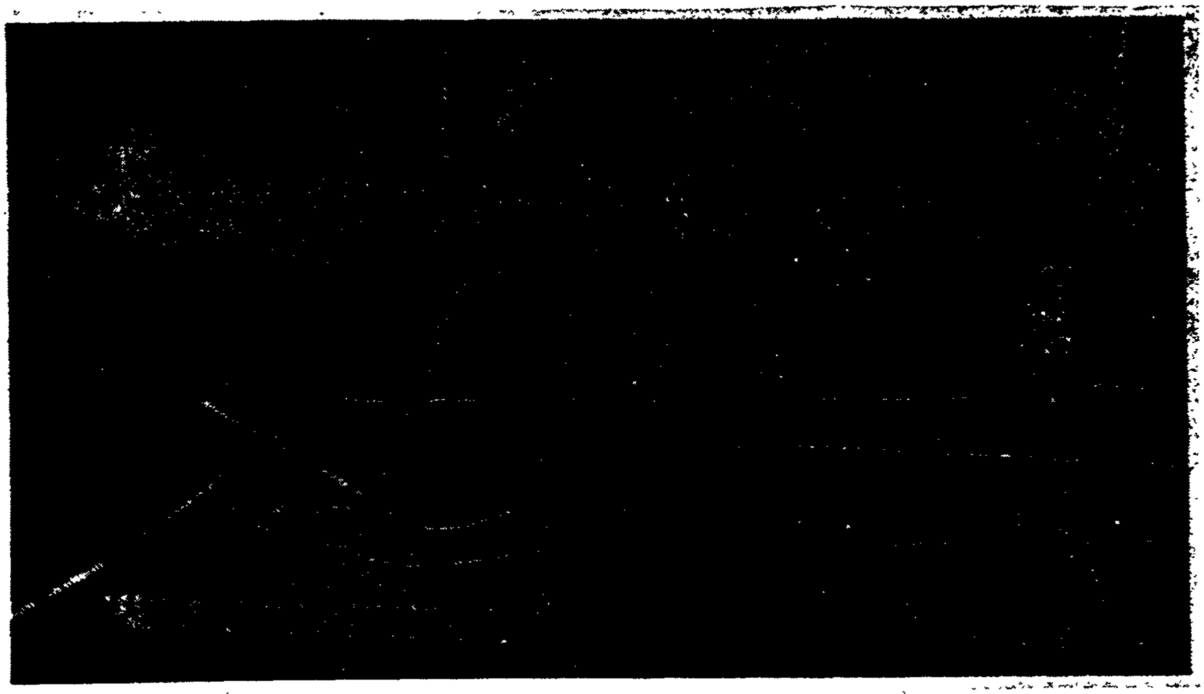

Figure 1. Cutting of marine growth from hull of car ferry showing use of hydraulically assisted jetting guns and extension lances. The operation was completed in 6 hours with two operators using a 120-HP diesel driven pump. (1)

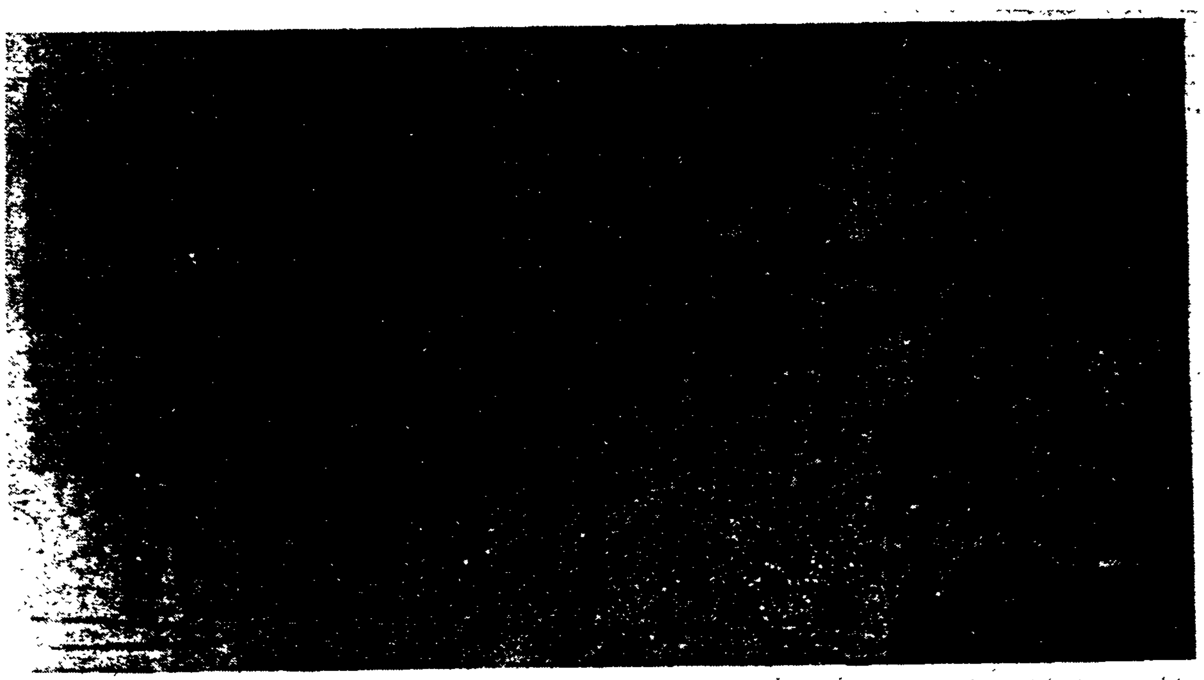

Figure 2. Cutting growth, paint and ferrous scale from hull of tanker using abrasive in water at 4,000 pounds (f)/ sq. in. (1)

As mentioned previously, abrasive injection can substantially enchance the capabilities of the cleaning jet. The abrasive provides an abrading mechanism to handle more difficult jobs than a water-only jet may be able to handle. With the advent of higher pressure systems (20,000 to 100',000 psi) the abrasive may. be eliminated, but ' the decision as to which to use is based on the economics of clean-up requirements and reliability of the abrasive system versus increased capital and operating costs of the higher pressure systems: To inject the abrasive into the jet stream a venturi type of nozzle using the high speed jet to create a vacuum and draw in the abrasive particles is used. By using a combination of water pressure and abrasives, the operating pressure may be reduced or production increased at a fixed pressure level. In comparison of the water-only and abrasive augmented jets the following data(3) apply:

Operating Pressure 6,000 psi (both cases)

> Water-only cleaning of barnacles, rust scale, oil stains, sea grass, were accomplished at the rate of 36.6 ft3/min.
>
> Water-abrasive blasting achieved a white metal surface at the rate of 161 to 194 ft^2/hr. Sand was the abrasive and consumption was 300 to 500 lb/hr(1).

All of the previous results have been for dry dock applications, but water applications have an equal if not greater potential. As stated previously, the operating parameters have a significant impact on the removal capabilities of the jet. Figures 3 and 4 show a damaged and undamaged test plate from which the marine fouling was removed while operating the jet in the submerged condition. From a series of tests (4) it was established that the following combination of parameters produced consistent fouling removal without damage to the antifouling coating for a jet operating in a submerged condition:

- pressure range - 7,000 to 9,500 psi
- nozzle diameter - 0.4 to 0.6 mm
- jet angle > 30° from normal
- translational velocity - 12 in/see.

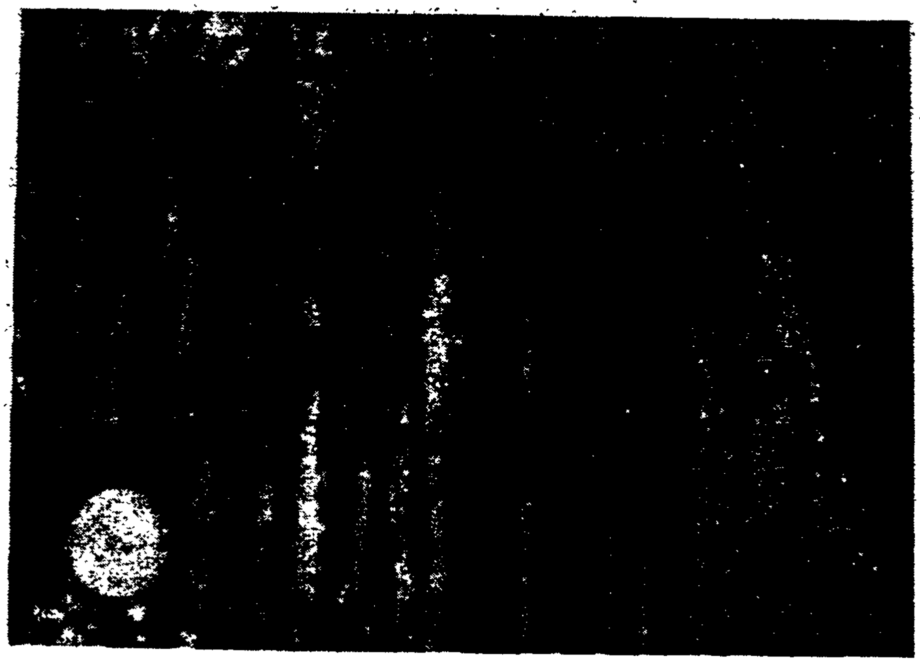

Figure 3. Coated Specimen Damaged y
Water Jet

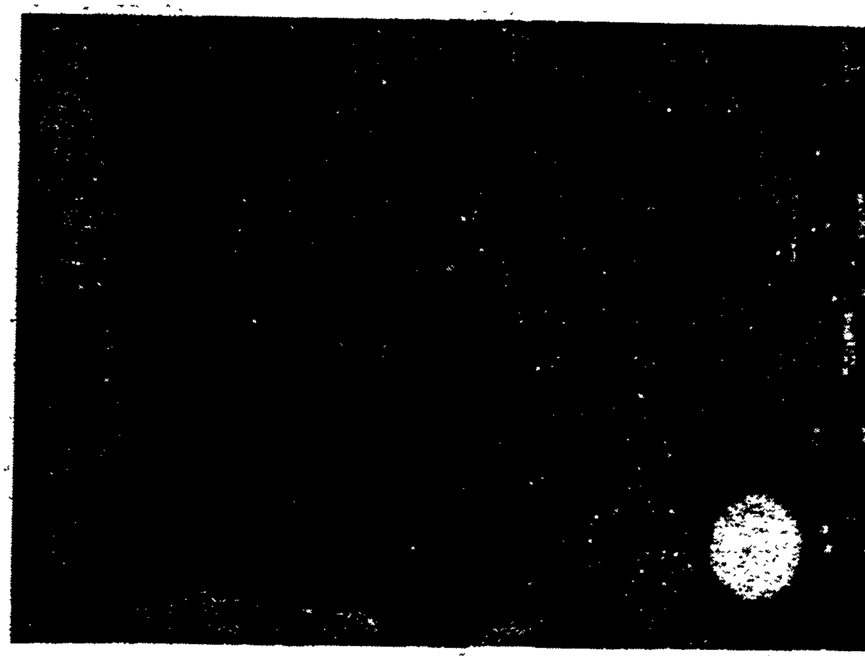

**Figure 4. Coated Specimen Cleaned By
Water Jet**

The jet angle is the most significant of the variables in this case, but it should be emphasized that this combination-of parameters is not an optimum, but a particular combination which. produced acceptable results. If the jet angle is less than” 30°, or the pressure increased while the cleaning rate decreased then damage to the undercoating can result as shown in Figure 3. To successfully implement this technology under water, two problems must be addressed. First, if a single lance unit is employed, then it must be thrust balanced for diver handling, or can be used unbalanced if work platforms are feasible. Second, visibility must be maintained so that the work surface is clear for operator inspection. Visibility can be maintained by using a low velocity jet at right angles to the cleaning jet and tangent to the cleaning surface to disperse the material away from the work area. Another approach would be to mechanize the cleaning operation similar to “SCAMP” whereby visibility is unnecessary and the unit compensates for the thrust automatically. Again, the automated approach will produce greater cleaning rates, but a single lance system would still be required in areas where the hull geometry changes abruptly.

Cavitating jets produce similar results, but at lower pump pressures which should increase the overall reliability of the system. Figures 5 and 6 show before and after photos of a fouled specimen cleaned using a cavitating jet. Note that there is some of the fouling still remaining which indicates too low pump pressure or an improper standoff distance. Figures 7 and 8 show the performance of two different sizes of cavitating jets at two operating pressures. The cleaning rate curves in Figure 8 exhibit classical performance trends. Note that the optimum translational velocity is a function of both pump pressure and nozzle size. The knee of the curves represents the minimum expenditure of energy per unit area cleaned. Operation below this point is inefficient since the dwell time of the jet is longer than necessary to achieve the desired results, while above this point the dwell time is not long enough to produce consistent material removal. (The cleaning rate is equal to the width of the cleaned path times the translational velocity.) The cavitating jet can be used both

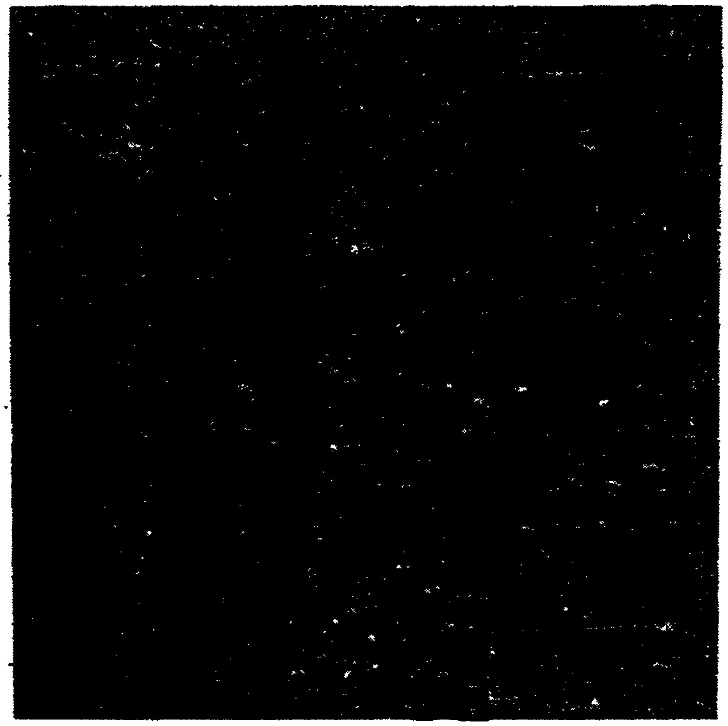

Figure 5. Plate 1, side A before test (5)

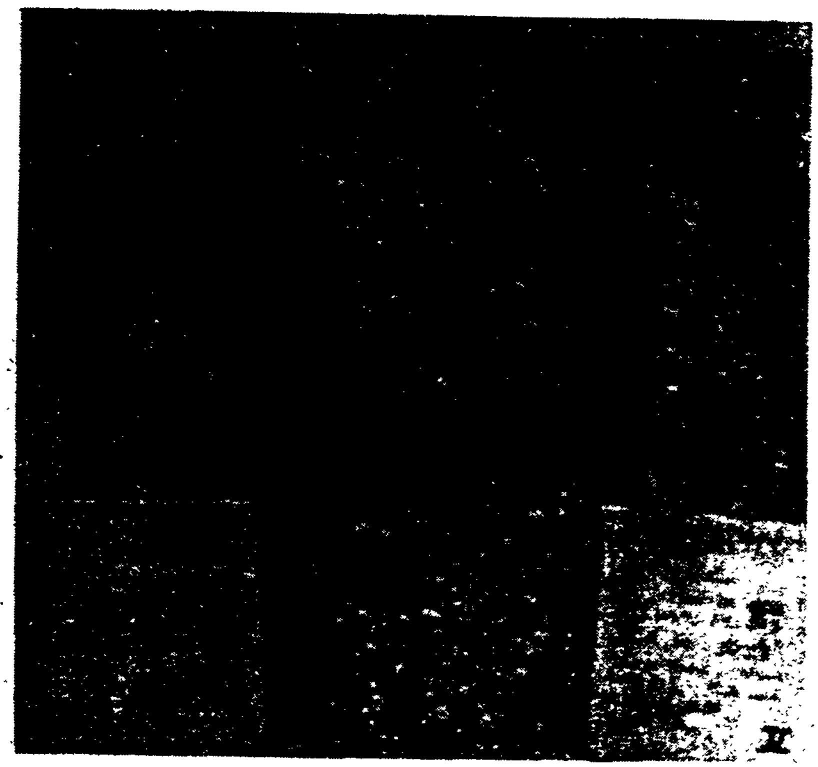

Figure 6. Fouled panel tested with 1/4 in. CAVIJET at 1500 psi (10.3 MPa). (5)

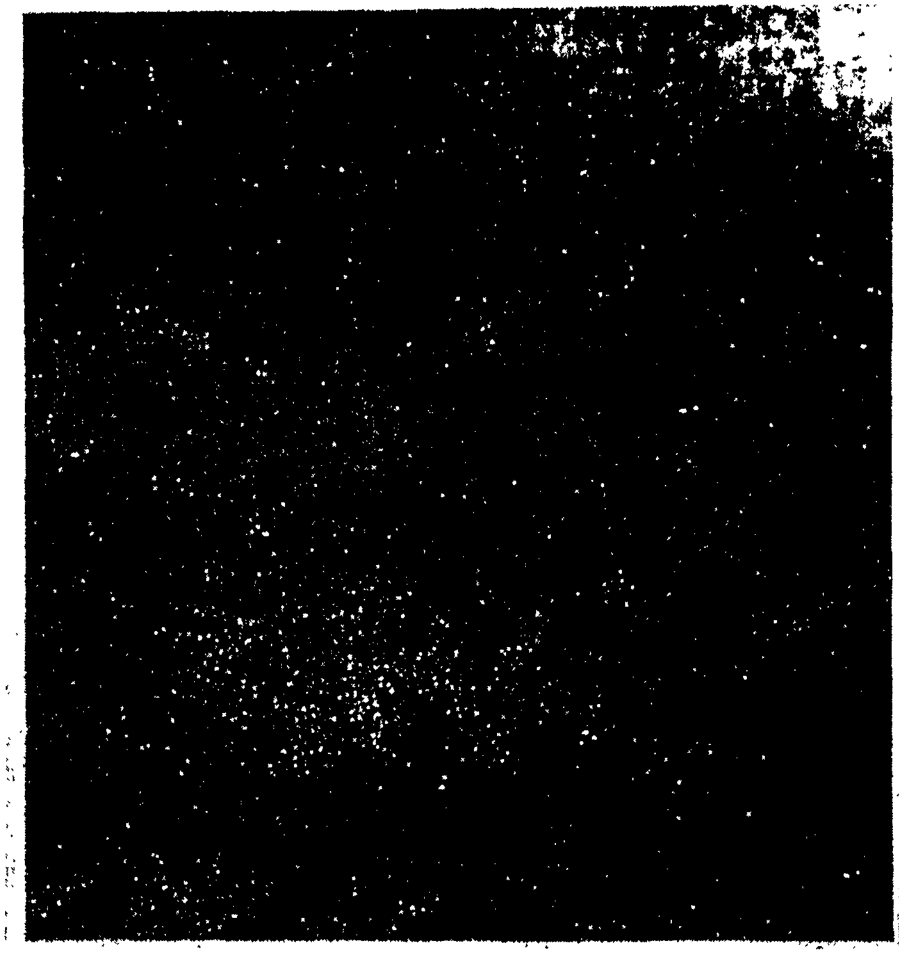

Figure 7. Comparing average fouling removal path widths of 1/8 in. (3.2 mm) and 1/4 in. (6.4 mm) CAVIJET submerged (5)

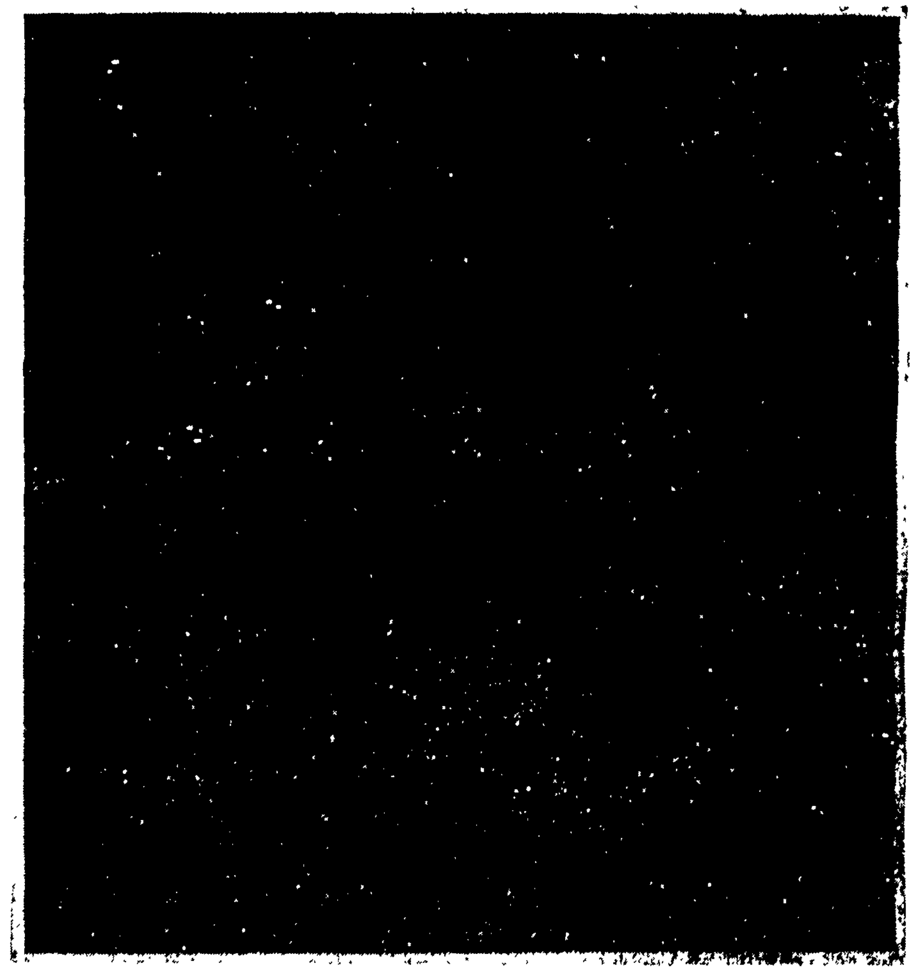

Figure 8. Comparing average fouling cleaning rates of 1/8 in. (3.2 mm) and 1/4 in (6.4 mm) CAVIJET submerged (5)

in dry dock and in the submerged condition. As Figure 9 indicates, it will give better performance in the submerged condition than under ambient conditions. The cavitating jet can be mechanized like the continuous jet, but the standoff distance must be controlled to give consistent results. Table 1 shows some rough economic considerations when using a cavitating water jet as opposed to " conventional practice. Performance (projected) is equivalent, (or better)to conventional practice and the preliminary costs seem attractive. Before an accurate costing of hydraulic removal can . be made, a system must be configured for a particular application so that direct costs (capital, operating, etc.) and indirect costs (loss due to down time, change-over costs, etc.) can be established and included in the analysis.

Based on the data presented, hull cleaning and surface preparation seem to be a natural application in which to utilize fully the capabilities of the fluid jet.

Metal Cutting Studies

The use of high pressure water jets to cut and remove metal is in the embryo stage. Initially it was postulated that to cut a' material of a given tensile or compressive strength a jet pressure of approximately 3 times the strength level would be required. During preliminary work[(4)] it was established that material could be removed at pressures. as low as 60,000 to 80,000 psi. To achieve these elevated pressures, conventional plunger pumps which were suitable for cleaning use are not appropriate. A linear intensifier as shown in Figure 10 provides a means of achieving these pressures. This particular unit is hydraulically driven (primary power package is not shown) and capable of 100,000 psi and 3.5 GPM output. The same jet parameters which controlled the cleaning process also influence metal removal. As shown in Figure 11, shallow depth cuts have been achieved for a single pass (material is 1020 steel). In its present configuration the jet is suitable for thin sections unless multiple passes are made. High strength ship hull material (HY80) can also be cut using the jet. These test results are for submerged conditions.

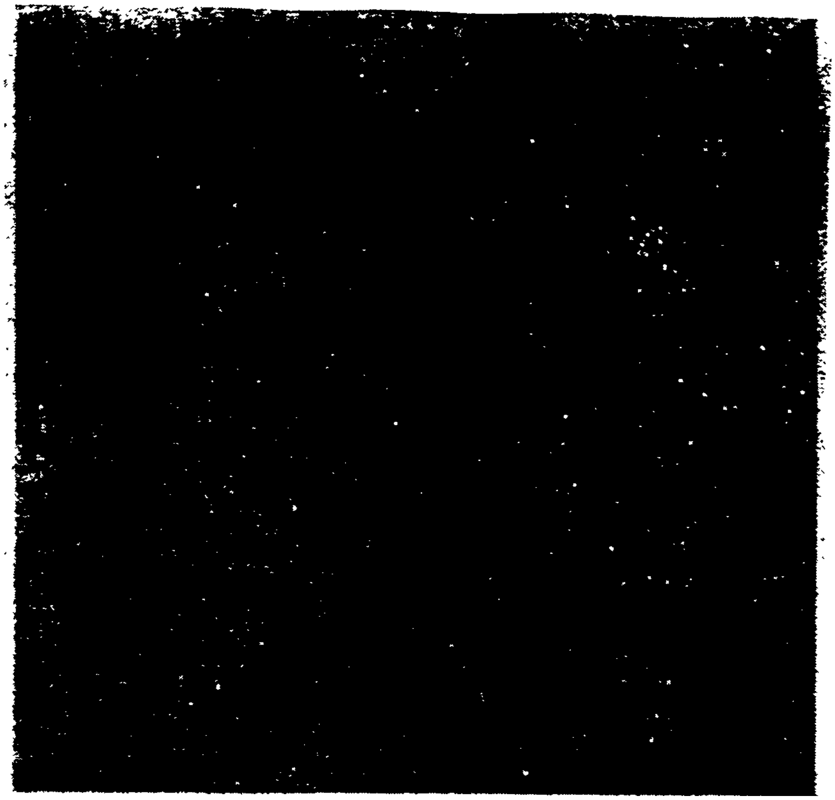

Figure 9. Effect of operating mode on path width for 1/4 in. (6.4 mm) CAVIJET at 2000 psi (13.8 MPa) (5)

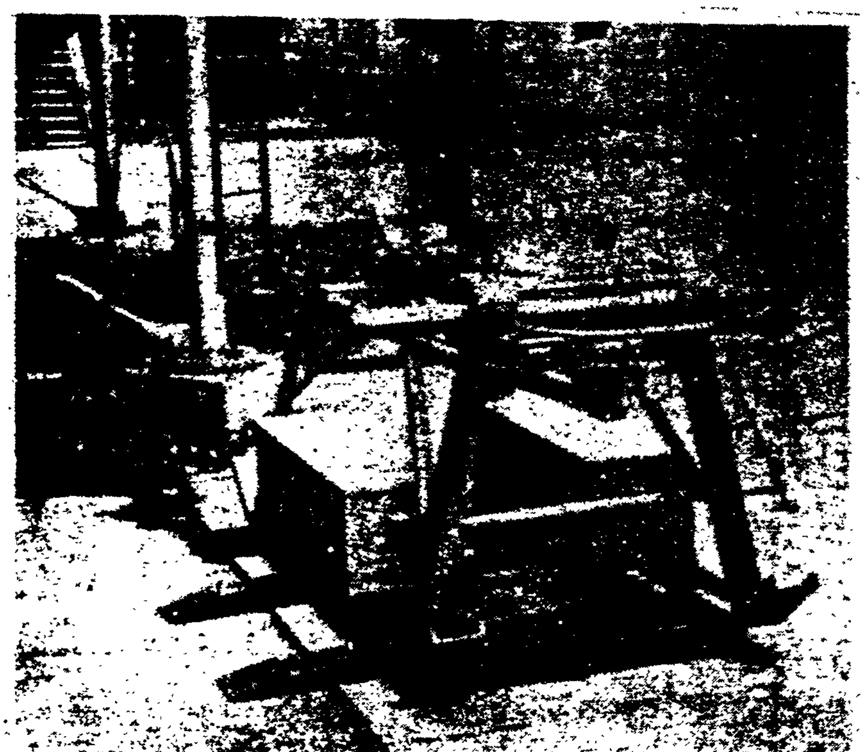

Figure 10. High Pressure Linear Intensifier

TABLE 1

COMPARISON OF HULL CLEANING TECHNIQUES (6)

METHOD	RATE OF CLEANING	OPERATING COSTS	ADVANTAGES	DISADVANTAGES
Wet Sandblasting	* 270 ft^3/hr.	Not Provided	Operational and accepted practice; will provide white metal finish.	Expense of "sand" material; cleanup; water pollution.
Hand-held Rotating wire brushes	* 400 ft^2/hr.	Not Provided	Use on submerged or dry-docked hulls	Slow; will not remove rust
Dry Sandsweeping	*1000 ft^3/hr	* $\$28/1000$ ft^2 for "sand" (slag), plus power, and labor for operating and cleanup	Fast; accepted practice; (At much slower rates: will provide white metal finish)	Expense of "sand" material; cleanup; must shield off other areas of ship; air and wate pollution
1/16" dia. CAVIJET at 1000 psi, 2.4 gpm, 1.4 hp	900 ft^3/hr	2¢/1000 ft^3 for power to the pump motor plus operating labor	No pollution from "sand"; rates comparable to sandsweeping; no expensive removal of "sand" after the job; Usable on submerged or nonsubmerged surfaces; lower pressures and higher efficiencies than ordinary steady water jet methods	Not accepted practice; further development needed to achieve operational system
1/4" dia. CAVIJET at 500 psi, 30 gpm, 9 hp	1500 ft^3/hr	13¢/1000 ft^2 for power to the pump, plus operating labor		

$: The sources for these data are private communications with various shipyar"d and Navy personnel.

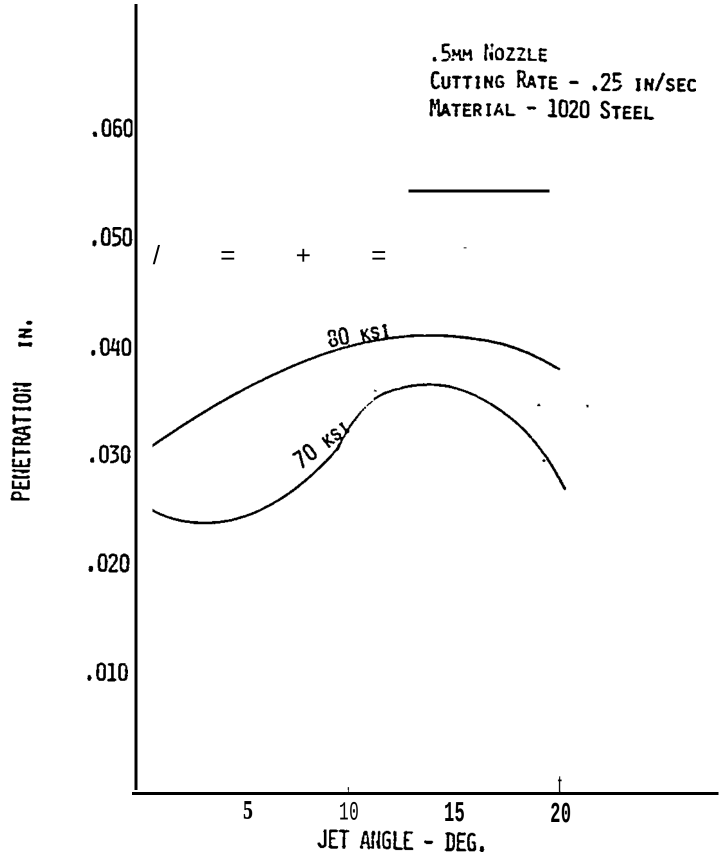

Figure 11. penetration vs. Jet Angle At Various Pressure Levels for 1020 Steel.

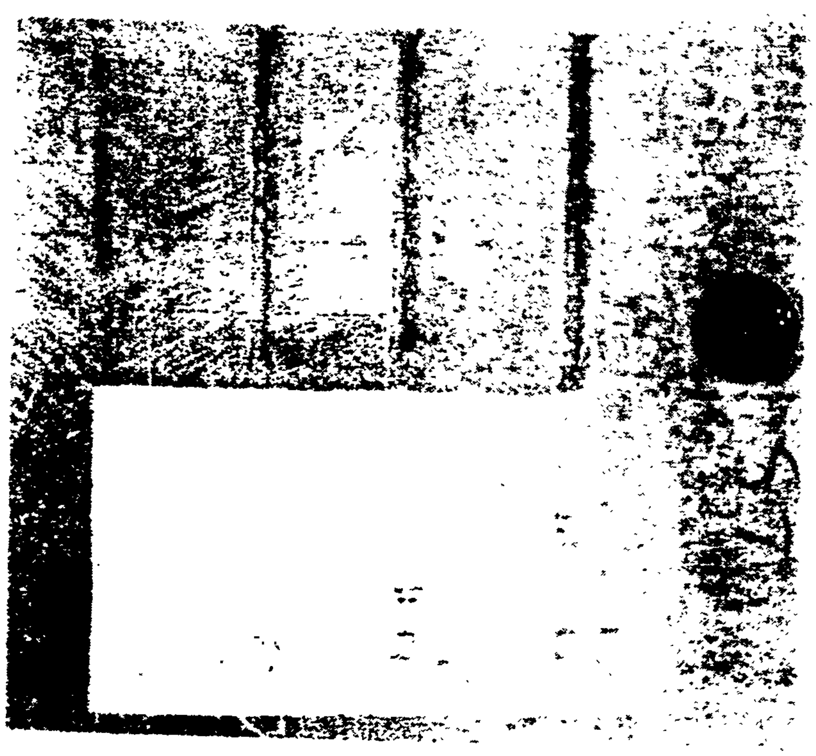

Figure 12. Metal Specimens (1020) attacked by Abrasive Jet.

Abrasive injection was investigated as a means of enhancing the material removal capabilities of the jet. Preliminary results produced penetrations greater than the water-only jet but not as deep as originally projected. Figures 12 and 13 show some results using the abrasive jet. During the testing it was noted that the area surrounding the cut had a shot blasted appearance, and upon examination of some high speed movies of the nozzle flow it was observed that the abrasive particles were concentrated mainly on the outside of the jet stream. Only a small percentage of the particles were in the core of the jet, which would explain the shot blasted area and small increase in total penetrations. A second approach of using a small supplemental high pressure injection pump to inject the abrasive before the nozzle is being evaluated. Preliminary results produced still further enhancement in the penetration, but the testing is not yet complete.

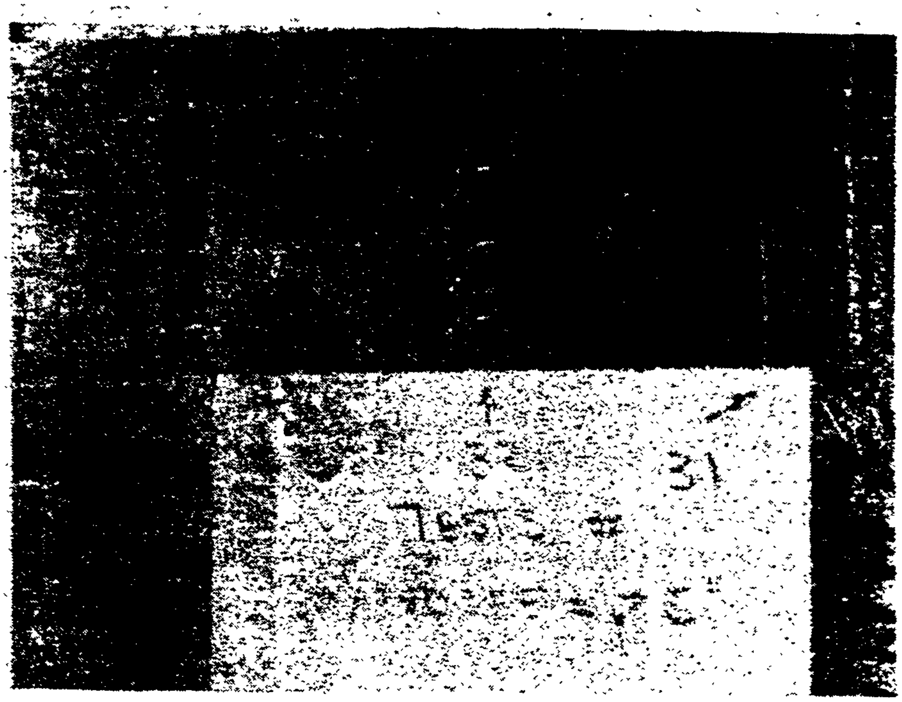

Figure 13 Metal Specimen Attacked by Abrasive Jet.

Heavy steel sections (3/8 in. to 5/8 in.) can be fully penetrated in a matter of milliseconds using a pulsed jet. This will be necessary for successful application of this type of jet to metal cutting. The effect of underwater operation on this jet is not known at this time.

Conclusions

The use of continuous jets, both conventional and cavitating for hull cleaning and surface preparation provides a viable alternative to conventional methods currently in use. Grit costs can be eliminated and the process can be used in conventional dry dock operations or underwater. Site pollution can be reduced since no grit is utilized, and if underwater operation is used the contaminates (i.e. , fouling, paint, etc) can be removed by conventional filtration methods (assuming the system is used in a flooded dry dock). Metal cutting development requires additional investigation to establish system performance capabilities and to assess its economic impact.

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