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Ultra-High Pressure Water Jetting for  
Coating Removal and Surface Preparation

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ABSTRACT

This paper shall examine the basics of water technology with particular attention paid to systems currently in use and some select new applications. By providing an overview of commercially available water jet systems in the context of recent case histories, potential users may evaluate the process for future applications.

With the on going introduction of regulations prohibiting the use of chemical paint strippers, manual scrapping and dry abrasive media blasting, the need for an environmentally compliant coating removal process has been mandated. Water jet cleaning has been a traditional part of many industrial processes for years, although it has only been in the last few years that reliable pumping equipment capable of ultra-high pressure operation have become available.

With the advent of water jet pumping equipment capable of sustaining pressures in excess of 36,000 psi, there has been a shift away from lower pressure, high water volume systems. One of the major factors in driving industry to seek higher pressures is the ability to offer higher productivity rates while lowering the quantity of water used and subsequently reprocessed. Among benefits of the trend toward higher pressure / lower volume systems is the corresponding reduction in water jet reaction forces making hand held water jetting practical and safe.

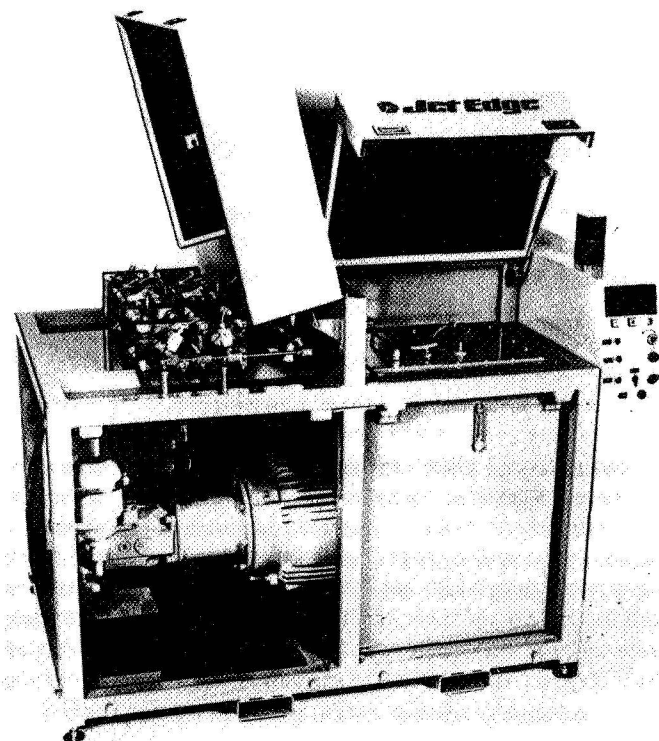
Other unique applications made possible by these new generation pumping systems include the use of alternative fluids including liquid ammonia for specialized and hazardous material removal applications. A review of the equipment used and the required modifications will be presented along with the conclusions reached during this test program.

#### EQUIPMENT BACKGROUND AND HISTORY:

Water jetting is a technology that can trace its roots to the Gold Rush era of the early 1900's. and placer mining. In the quest to uncover alluvial deposits of gold, miners found that by redirecting small creeks through a rudimentary piping system a concentrated stream of water could be utilized to speed erosion, exposing greater quantities of material. These early miners soon adapted the water pumps designed to keep under ground mines dry to the task of accelerating that water to higher and therefore more productive velocities.

Many of the pump designs in use today were originally developed to meet the demands of deep rock drilling , petroleum extraction and refining. Even today the US Bureau of Mines has an active water jet research program looking to increase safety while replacing conventional drilling and crushing technology.

In the petroleum industry the quest to maximize oil production spurred the development of pumping systems able to hydraulically fracture the well casing and surrounding rock to force more oil out of low producing fields. The most important offshoot of this "fracking" process was the development of the intensifier style pump.(Fig. 1) The intensifier pump is capable of generating enormous pressures with a minimum of moving parts and with significant safety features.

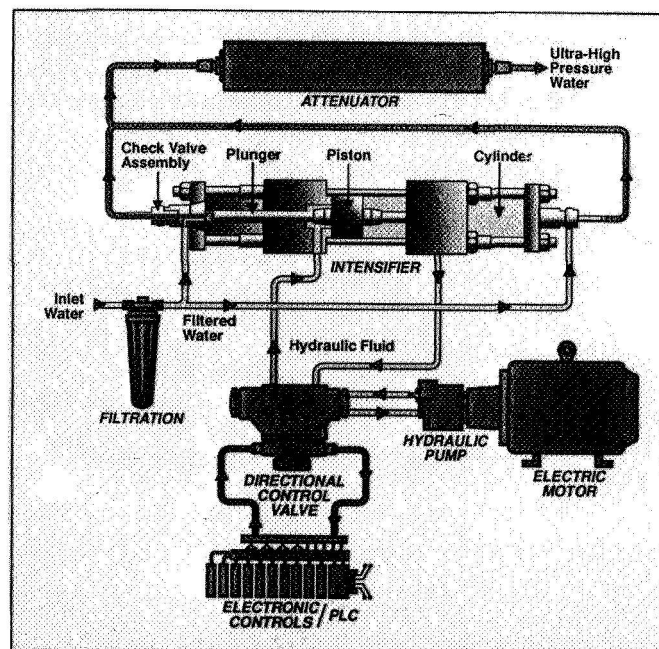


Intensifier Pump  
Fig. 1

This design concept was routinely available by the late 1960's for use in static pressure generation systems and the aforementioned well fracking. Industrial contractors using lower pressure crankshaft driven water pumps had recognized the increased cleaning potential offered by higher pressures and seized on the intensifier design as a likely candidate for their applications. Taking into account available materials, high pressure hose technology and desired reaction forces, 35,000 psi. and 6 gpm. flowrates were determined to be a practical set of parameters to design for in the early 1970's. As it has turned out these parameters have remained very nearly unchanged for 15 years in which time the equipment has become very reliable. A typical current generation pump delivers water jet outputs of 36,000 psi at 7.2 gpm. Early systems counted operating time in hours while today's pumps routinely deliver months of running time between scheduled maintenance.

It should be noted that the two largest domestic manufacturers of 36,000+ psi water jet cleaning and coating removal equipment have extensive experience in the design and manufacture of 60,000 psi. intensifier pumps. While those pressures are currently only being used in a few very specialized coating removal applications the technology is already well developed should the need arise.

In practice the intensifier pump consists of a piston driving a plunger. The piston has a large surface area and is driven by low pressure (3000 psi.) hydraulic fluid. (Fig. 2) Coupled to it, is a plunger with a much smaller surface area that acts against the water contained in a heavy walled cylinder. The piston / plunger surface area ratio is typically either 12:1 and 20:1, yielding output pressures of 36,000 to 60,000 psi., respectively. By attaching a plunger to either side of the hydraulically driven piston and installing simple check valves a continuous pressure output pump is achieved.

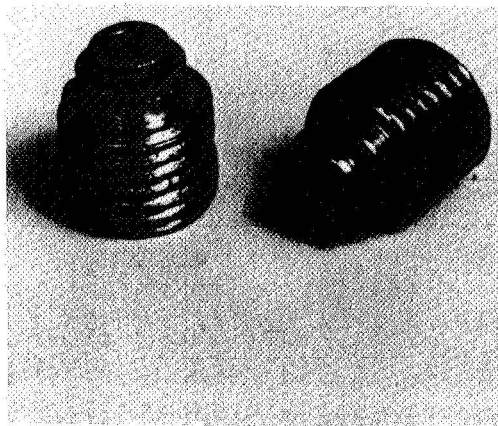


Intensifier Schematic  
Fig. 2

It therefore becomes a simple matter to regulate water output, flow and pressure by modulating the hydraulic fluid pressure. The variable displacement, pressure compensated hydraulic pump are designed for the specific task of maintaining a set pressure at varying fluid flow demand levels. This pressure compensation ability allows the intensifier pump to operate with dry shutoff blasting devices and to minimize water consumption.

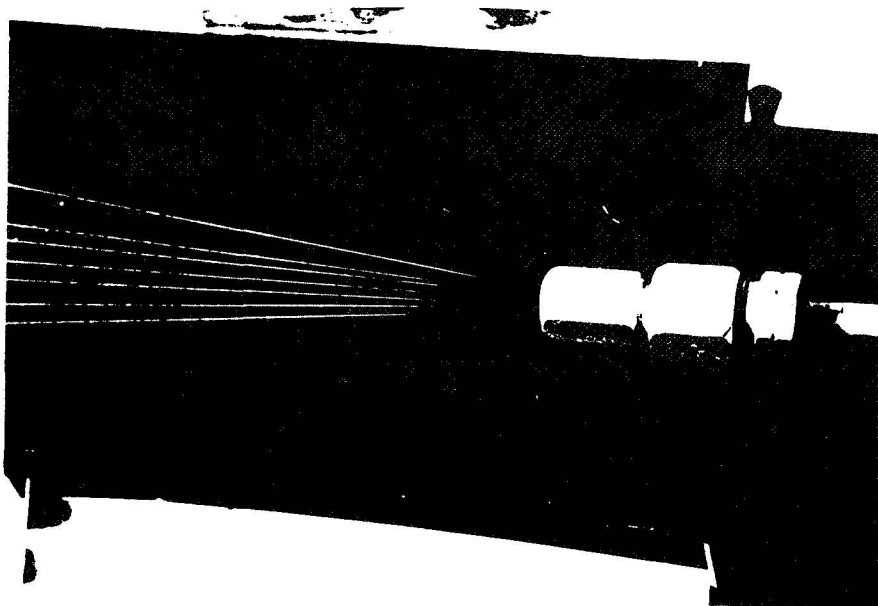
After the water (or other fluid) is pressurized it is directed to the point of use via stainless steel tubing or braided wire reinforced hose. For pressures of 36,000 psi. and above the tubing typically has an outside diameter three times that of the inside diameter. When hose is used, a minimum of seven spiral wrapped layers of wire are applied around a Delrin or Nylon core in addition to an outer abrasion resistant jacket. In situations involving long supply line distances or extreme pressure fluctuations, the stainless steel tubing is preferred due to lower flow restrictions and resistance to cyclic fatigue.

Once the high pressure fluid has reached the point of use a nozzle or manifold is required to generate individual coherent streams of water. These nozzles are then attached to the end of the tubing or hose using specially designed threaded fittings. At pressure below 20,000 psi holes drilled into a block of stainless steel will suffice for a nozzle. Due to the higher fluid velocities achieved at pressures above 30,000 psi., erosion of the nozzle material becomes unacceptable using the drilled hole design. In the majority of applications it has been found that a synthetic sapphire jewel works well in withstanding the erosive effects of the high velocity fluid stream. These jewels are available in .001" diameter increments and are pre-mounted in replaceable threaded mounts. (Fig. 3) Since fluid flow rate is directly related to the net area of the orifice through which it passes, an extreme level of precision and control can be applied to the sizing and layout of multiple orifice water jet nozzles. By varying the size and location of the orifices within a given manifold, material removal patterns and substrate preparation can be tightly controlled. In practice it has been found that by rotating a multiple orifice manifold (Fig. 4) at a controlled rate generates optimum coating or material removal rates while significantly reducing the chance of base material damage.



Pre-mounted Orifice, 3X scale  
Fig. 3



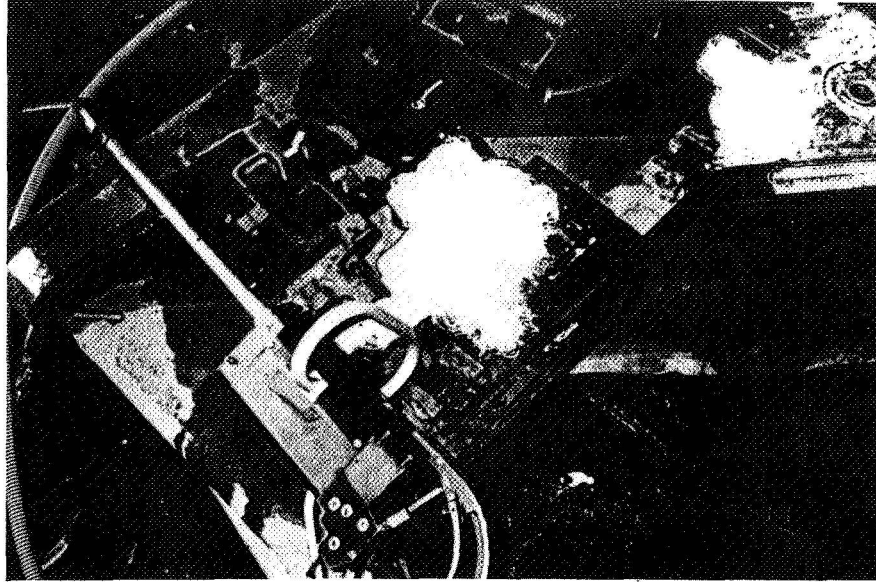


Multiple Orifice Nozzle

Fig. 4

Water jetting first found favor in the industrial maintenance sector for the removal of accumulated deposits found in boilers and heat exchangers. Other popular applications include storage tank and processing equipment cleaning. In each case a rotating nozzle is utilized. For boiler tube cleaning a rigid length of stainless steel tubing is threaded at one end to accept a nozzle tip containing one or more orifices. This "lance" is then attached to a powered rotary joint mounted on a sliding carriage. The lance and carriage are then advanced through the tube to be cleaned and then retracted. This process is repeated until all tubes in a boiler or heat exchanger are cleaned. The most widely used water jet cleaning method found involves the use of hand held "guns" attached to flexible hose. (Fig. 5) A typical hand tool contains an on / off valve, safety detented trigger and an air or hydraulically powered rotary joint. Depending on the material to be removed and the condition of the substrate any of several nozzle configurations are attached to the end of the rotating barrel. Tools designed for use at 36,000 psi. have 2 to 3 times working pressure design factor ratings and employ guards and shields for operator safety.

In the majority of 36,000 psi. hand held operations overall flowrate is limited by orifice selection to approximately 3 gpm. To achieve similar water jet energy transfer at lower pressures such a large increase in discharge volume is required that reaction forces become unmanageable and unsafe.



Gyra-Jet , 36,000 psi rated hand tool & APC Rear Hatch

Fig. 5

#### APPLICATIONS:

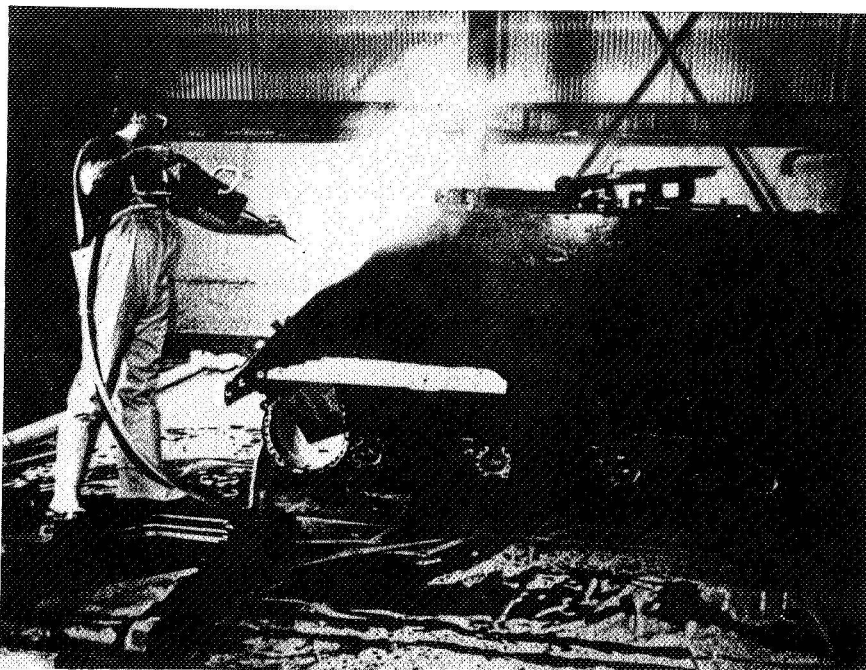
A typical hand held coating removal application is currently in use by a major defense contractor refurbishing M113 series armored personnel carriers( APC 's). Many of these units are nearly 20 years old and have been repainted and modified numerous times. Prior to refurbishment and upgrading the majority of existing coatings must be removed from the aluminum hulls with minimal base metal damage. In certain locations it is also required that the alodine wash primer be removed to facilitate welding.

Due to the cost of media collection and disposal grit blasting was rejected for such a large project. The large number of threaded holes and the inherent difficulty in removing all grit material from the confined interior spaces also weighed heavily in the decision to use water jets.

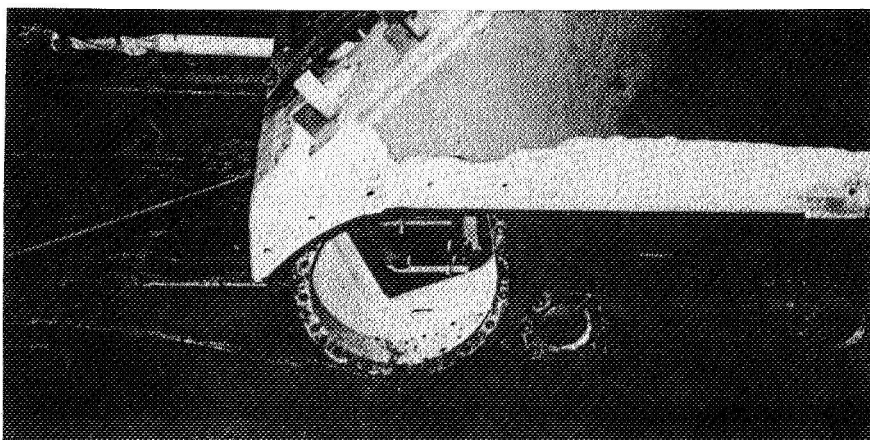
The water jet process is preceded by initial disassembly in which all component parts are removed leaving a bare hull which is essentially an aluminum box. This hull is then placed on a work stand in in a contained area dedicated to the water jet cleaning process. Included in this facility are water collection and filtration systems, air filtration, and the high pressure water jet pump and hand tools. The pump used is a 36,000 psi. 4 gpm. unit manufactured by Jet Edge to which are plumbed two hand held rotary nozzle tools called Gyra-Jets from the same vendor. Each hand tool is equipped with 4 orifice nozzle with the .011" diameter orifices arranged in a staggered pattern. Water flow rate though each tool is limited to 2 gpm.

In use the operator wearing a rain suit and eye and ear protection moves about the vehicle removing paint and other residues from marked areas.(Fig. 6) The coating system being removed consists of an alodine wash primer over which a zinc chromate paint primer is applied. The top coat(s) consist of a Chemical Agent Resistant Coating (CARC) paint. In many cases there may be as many as four addition layers of top coat material to remove. On average the operator is able to remove all paint and primer down to the alodine wash at rate of over one square foot per minute.

Due in part to minimal preparation during the previous repaints the water jet was able to yield even higher productivity rates on the more heavily coated surfaces. This is a marked contrast to the grit blasting method where coating thickness decreased productivity.



Water Jet Paint Removal  
Fig. 6



RTV removal and Bolt hole cleaning  
Fig. 7

An additional benefit was realized in terms of eliminating masking of threaded holes. It was found that the threaded holes used to mount drive train components could be completely cleaned without damage using the Gyra-Jet.(Fig. 7) The ability to completely remove the alodine conversion coating, RTV sealants along with grease and oil was also proven and has greatly improved the weld quality during subsequent operations.

## APPLICATION 2:

As a counterpoint to the previous conventional application an In the instance equipment originally designed for 36,000 psi. water jet cleaning was modified and adapted to use liquid ammonia as the fluid for material removal.

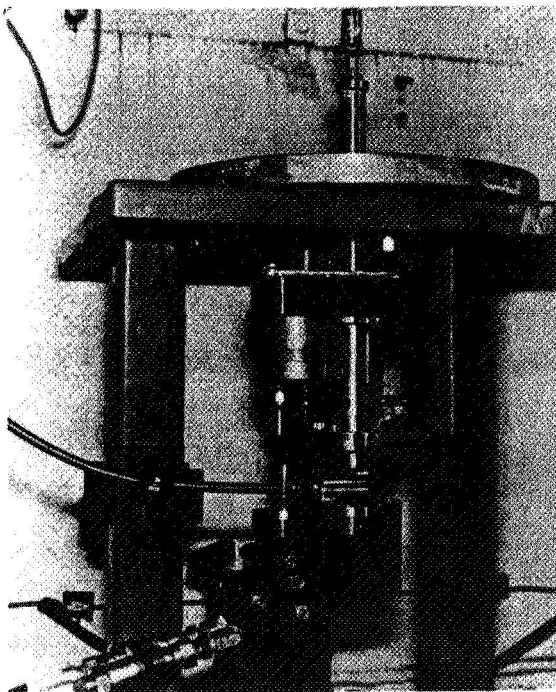
The recognized need to dispose of obsolete, over-aged and treaty limited solid rocket motors while meeting increasingly stringent environmental constraints lead to the initiation of this project. In the past these motors were destroyed by open burning or detonation both of which are incompatible with environmental concerns and preclude the recovery and reuse of the raw materials.

Global Environmental Solutions a division of Hercules Aerospace and Rust Engineering are planning a solid rocket motor decommissioning pilot plant system for Hercules' Magna Utah facility. This system is based on test work recently completed at the Bacchus Plant location.

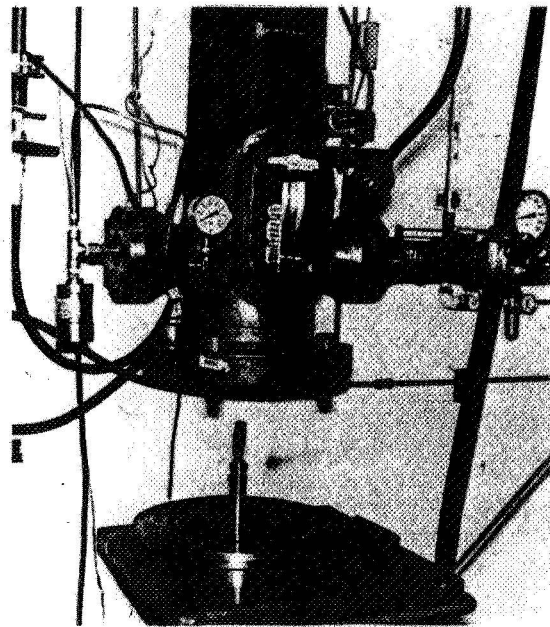
The test system utilizes a slightly modified Jet Edge 36,000 psi water jet pump and a highly modified Gyra-Jet Hand tool. Due to the extensive use of stainless steel in ultra-high pressure water jet equipment few modifications other than a change in o'ring material in the high pressure seals was needed within the pump unit. It was discovered that the liquid ammonia required additional cooling to avoid boiling within the pump and therefore a primitive alcohol and dry ice heat exchanger was installed on the inlet side of the pump.

In order to facilitate the use of the rotating jet tool originally designed for hand held use in a remote control setting a great number of modifications were made to the Gyra-Jet. Changes included the relocation of the water on / off valve and the integration of the rotational drive with a remote control station.(Fig. 8-9) The pump used featured a 40 Hp. motor driving both the intensifier and providing hydraulic pressure to operate the rotary nozzle.

A series of test were conducted on both MLRS and Chaparral (GCU-1) propellant with variations made in nozzle configuration and ammonia pressure. Hazard evaluation tests were conducted under conditions worse than expected in production and no ignition threshold levels were observed. The optimum configuration was found to be a 36,000 psi working pressure and a .8 gpm fluid flow rate. It was determined that propellant removal rates of 234 lb / hr using 36,000 psi. were possible with all propellants tested. The test method involved pumping pressurized ammonia through a rotating multiple orifice nozzle that was then advanced into the test sample.(Fig. 10)

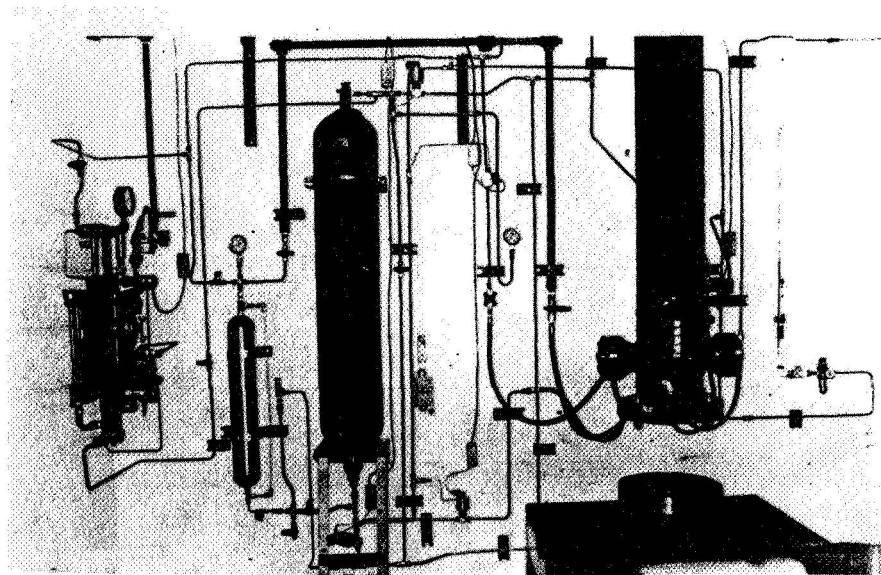


Modified Gyra-Jet Installed in Test Stand  
Fig. 8



Rotating Nozzle Fixtured in Base Plate  
Fig.9

In comparative testing ,conventional milling it was found that to ensure safe operation that the milling process would have to be slowed down greatly when operating near the motor case. Based on preliminary experience capital equipment cost appear similar for either method. This therefore gives an advantage to the ammonia jet method in terms of overall productivity and in motors having high case to propellant area ratios.



Amonia-Jet Test Facility  
Fig. 10

#### CONCLUSION:

As has been described the use of water under pressure as a cleaning method is hardly a new concept. In reality what the last ten to fifteen years have done is provide the time needed for the technology to catch up with the concept. By the manufacturers focusing on reliability and incremental product design improvement the hardware of ultra-high pressure water jetting has reached a point where the pumping and delivery equipment is not the limiting factor in a particular application. Most manufacturers and end users would agree that the equipment available today is well qualified to operate well into the next century without being obsoleted. This allows the end user to explore innovative nozzle designs and alternative fluids for specific cleaning and coating removal projects. In the case of the APC's mentioned the majority of evaluation and configuration time was dedicated to selecting a nozzle design that generated the best paint removal pattern while simultaneously allowing for selective layer by layer coating removal from a soft substrate. Those involved in the rocket motor demil project were similarly able to focus development effort on the handling of the ammonia and the disposal of the waste material rather designing a pumping system.

That the technology to go to much higher pressures with the same basic pump design already exists, the room for growth is virtually unlimited by the availability of hardware.

It can be anticipated that we have entered a new phase of high pressure fluid jet cleaning and coating removal development where the majority of time and effort is dedicated to perfecting existing concepts and applying that experience to the multitude of environmental cleanup challenges the future holds.

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## **ALTERNATIVE CLEANING TECHNOLOGY SYSTEMS**