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UNDERWATER POWER SOURCE STUDY

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This report is concerned with the development of an ultra low cost underwater propulsion unit that can horizontally deploy 500 -1000 feet of sonobuoy cable at depths between 500 and 1000 feet. A trade-off analysis shows that the best system is based on a gas driven water pulsejet (hydropulse) and that the best source of gas is a reaction between Lithium aluminum hydride ($LiAlH_4$) and seawater. The fuel →

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cost for 15 minutes of operation is about $2.00.

A design for the pulsejet engine was then prepared (the drawings are in Appendix C) together with reaction rate measuring equipment. This culminates Phase I of the contract.

PREFACE

This program had as its goal the identification of a small low-cost underwater propulsion device that could be used to horizontally align a horizontal sonobuoy array. This effort closely parallels one in which Payne, Inc. recently participated with the U.S. Navy personnel at the Naval Ocean Systems Center (NOSC) in San Diego, California. The results of that effort are presented in Reference 1. The evaluation of other devices during that program forms a large part of the basis for the final selection on this program.

The project manager for the Naval Air Development Center, Warminster, Pennsylvania was William H. Hazlett, Jr. The principal investigator at Payne, Inc. was Peter R. Payne. The design effort was accomplished by Harold L. Newhouse, and Edward Dick performed the testing and evaluation for the components.

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[1] McCartney, J.F., Shipman, W.H., and Payne, P.R. "Low Cost Underwater Propulsion", Proc. of AIAA/SAE/ASME 17th Joint Propulsion Conference, Colorado, Springs, Colorado, July 1981.

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SUMMARY AND INTRODUCTION

The tactical ASW forces of the U.S. Navy are continuously seeking means to improve their performance. Deployment time of an acoustic sensor is significant in the effectiveness of the system. As a means of improving this deployment procedure, reducing the time to become operational, and providing the ability to redeploy a system after a period of operation, a small, inexpensive, expendable thrust device is being considered as a candidate for the source of power.

Covered in this report are results of the Payne, Inc. effort to identify a likely contender for this low cost energy source and thrust device that would meet the constraints imposed by the contract. The requirements were:

a. be capable of operation at a minimum depth of 500 feet (150M) with a design goal of 1,000 feet (300M);

b. Be capable of continous operation for a minimum of ten minutes with a design goal of five additional minutes on an intermittent basis on command;

c. be capable of producing a nominal thrust of three (3) pounds for the entire period of operation;

d. be capable of being packaged in a cylinder with a maximum diameter of 4.75 inches (12.07 cm) and a total volume of 60 cu. in. (0.983 l).

In addition to the above, it was required that a metallic hydride be one of the power sources investigated.

A literature survey was conducted to identify previous work applicable to the task at hand. Because of the time available copies of all documents that might apply to this study could not be obtained. Within the program constraints of time and costs, however, it is believed that most of the significant data have been reviewed and the applicable portions are discussed in the appropriate parts of the text of this report. A bibliography of these articles is presented as Appendix A. As the program continues additional references undoubtedly will be received and if any information is presented to confirm or significantly affect the conclusions of this program, copies will be provided to the Navy Project Engineer.

An evaluation was made of the candidates for the segments of the low cost underwater propulsion system. As a result of the analysis of data contained in existing literature and recognizing the time and cost constraints of this program, it was found that the field of choice for viable contenders was quickly reduced. The complete propulsion system was divided into its principal components: Energy Storage, Energy Conversion, and Thrust Producer.

As a baseline a system consisting of a battery, electric motor and propeller was selected. This system was considered well within the state-of-the-art functionally even though its size might violate the desired volume requirement.

The results of the evaluation program concluded (as did Reference 1) that the most efficient Energy Storage means was lithium metal but that for a practical system Lithium Hydride and Aluminum was the most promising contender. The test plan to develop the necessary data for a gas generator is presented in Appendix B.

To convert the energy of the pressurized gas into usable power no system was found superior from a cost and simplicity standpoint to that of a pulsating jet of gas and consequently a pulsejet device was designed to fill this requirement. The operation and performance analysis of this device is presented in the text and the design drawings are presented in Appendix C. The test plan for evaluating the capabilities of this device is included in Appendix B.

EQUIPMENT EVALUATION AND SELECTION

The complete thrust device may consist of three principal components: Energy Storage system, Energy Conversion system, and Thrust Producer. It is reasonable to first look at contenders for each major component to determine what might be the most satisfactory selection. In the end the selected component must be integrated with the other two components to from an efficient operating unit.

The concept of using a low cost propulsion device for deploying a multi-element hydrophone array is in its infant stage. Specific restrictions as to cost, size, weight and performance are not firmly established. As the concept is now envisioned some criteria has been established as targets for guidance purposes. Deviations from these targets must be evaluated in terms of the gains offered by allowing the deviations. In the end, obtaining a system in the general vicinity of the design targets that can be used as the basis for the projection of data to larger or smaller systems, obtaining hardware for evaluation purposes and applying the study of this concept to possible applications would appear to be the primary benefits that might evolve from this effort.

Along with the contract constraints outlined in the Summary and Introduction it was decided at a meeting with Navy program personnel that a basis for cost estimating might be the production of 5,000 units per year and that trade-off studies from other programs should be used where applicable to avoid repeating that effort. Utilizing the results of these other studies eliminated duplication of their effort and allowed resources to be concentrated on portions of this program, such as component design and application, that are considered more significant to a successful conclusion.

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PROPULSION SYSTEM

For this program, cost has been identified as one of the more significant trade-offs. If cost were of secondary importance then a larger number of options would be open to the designer in the selection of a propulsion device. As outlined in Reference 1 (a joint paper by NOSC personnel and Payne, Inc. personnel) most state-of-the-art alternatives for underseas propulsion systems are limited to expensive and complex systems. Included in this expensive and complex category, and consequently eliminated for selection on this program, are such systems as magnesium-silver chloride seawater battery with electric motor, reserve-electrolyte zinc-silver oxide battery with electric motor, and the Otto Fuel II open cycle engine. Even more expensive than these state-of-the-art systems and still under development are the aluminum-silver oxide battery with high performance electric motor and the Stored Chemical Energy Propulsion System (SCEPS) (Reference 2).[2] Another advanced system under devlopment is the reserve electrolyte Lithium Thionyl Chloride Battery System (Reference 3).[3] It is likely to provide greater density and lower cost than the previous alternatives. The last three systems still in development however are not anticipated to achieve total procurement cost in the target range desired for the device sought here (less than $500 with ultimate cost approaching $100). Therefore these devices are eliminated from possible selection.

Of somewhat parallel interest is the effort being expended for energy storage studies and development for domestic uses. These include new battery developments presented in Table 1. These batteries also can be eliminated from further consideration here because of cost, weight and volume.

Although we must look at each segment of the propulsion system (Energy Storage, Energy Conversion and Thrust Producer), we must also look at the combination of these for a more complete answer. Obviously, a low cost energy storage device to be of any value must be married to an equally suitable energy conversion system.

Energy storage devices considered possible candidates are listed in Table 2. Candidate devices for the energy conversion system are listed in Table 3. The thrust producing candidate devices are listed in Table 4.

As indicated it is not practical to consider each component of the propulsion system entirely alone. The logical combinations of the above components were organized into viable complete propulsion systems. These candidate systems as studied in Reference 1 were evaluated on the bases of

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[2] Gottfredson, R.K. "Lightweight Torpedo Propulsion Systems", Paper 79-1335, AIAA/SAE/ASME 15th Joint Propulsion Conf., Las Vegas, Nevada, June 1979.

[3] McCartney, J.F., Shipman, W.H. "Water Cooled Bipolar Battery Apparatus", U.S. Patent No. 4,152,492, May 1979.

weight, size, risk and cost. These are all factors of interest in this study and the rejection criteria found in the previous study were considered valid for our selection purposes. Table 5 presents the candidates and rejection criteria as generated in the Reference 1 study.

TABLE 1. BATTERIES UNDER DEVELOPMENT FOR DOMESTIC STORAGE SYSTEMS [4]

Battery Type	Operating Temperature (degrees Celsius)	Energy Density (watt-hrs/kg)	Power Density (watts/kg)	Est. Cycle Life	Est. Cost $/kwh	Est. Availability (Year)[a]
Lead-Acid						
Utility Design	Ambient	--	--	2,000	80	1984
Vehicle Design (Improved)	Ambient	40	70	>1,000	70	1982
Nickel-Iron	Ambient	55	100	>2,000(?)	100	1983
Nickel-Zinc	Ambient	75	120	800(?)	100	1982
Zinc-Chlorine						
Utility Design	30-50	--	--	2,000(?)	50	1984
Vehicle Design	30-50	90	90	>1,000(?)	75	1985
Sodium-Sulfur						
Utility Design	300-350	--	--	>2,000	50	1986
Vehicle Design	300-350	90	100	>1,000	75	1985
Lithium-Iron Sulfide	400-450	100	>100	1,000(?)	80	1985

[a] Prototypes or early commercial models

A variety of advanced types of batteries are currently under development for electric-utility storage systems and electric vehicles because the lead-acid battery probably cannot be improved much further. The table lists the properties of batteries that may prove superior. The most important criterion for storage in electric-power systems is long life: the ability to undergo from 2,000 to 3,000 cycles of charge and discharge over a 10- to 15-year period. For electric vehicles the chief criteria are high energy content and high power for a given weight and volume. (The dashes indicate that these criteria do not apply to electric utilities.) Both the utilities and vehicles will require batteries that are low in cost (preferably less than $50 per kilowatt-hour of storage capacity), safe and efficient.

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[4] Kulhammer, F. "Energy Storage Systems", Scientific American, Vol. 241, No. 6, December 1979, p. 62.

TABLE 2. ENERGY STORAGE DEVICES

Water Reacting Metals
Lithium Batteries
Explosives
Cryogenic Liquids
Mono & Bi - Propellants
Buoyancy & Gravity
Compressed Gases

* * * * * * *

TABLE 3. ENERGY CONVERSION SYSTEMS

Linear Expanders
Rotary Expanders
Electric Motors
Combustion Engines
Fuel Cells w/Motor

* * * * * * *

TABLE 4. THRUST PRODUCING DEVICES

Pulsejet
Propeller
Pump Jet
Glide Surface
Electromagnetic Pump

TABLE 5. CANDIDATE PROPULSION SYSTEMS

CANDIDATES	REJECTION CRITERIA			
	Weight	Size	Risk	Cost
Series of Detonations U.S. Patent No. 3,229,458			X	
Gas Activated Water Pulsejet (Water Reacting Alloy)				
Steam Activated Eductor (Li-SF_6 Heat Source)				X
Lithium Battery, Electric Motor and Propeller				X
Lithium/H_2O Battery & Electromagnetic Pump				X
Buoyancy Vehicle (Glider)	X			
Flywheel and Propeller	X			X
Hydroduct (Alclo fuel) Ram Water			X	X
Hydroductor Engine Alclo fuel			X	X
Hydropulse (Molten LI + seawater)		X	X	
Solid propellant Gas Generator Expander Jet Propulsor	X		X	X
Rotating Barrel (Gatling-gun) and Gas Generator	X		X	
Gas Generator & Jet Tip Propeller	X		X	X
Cryogenic Propellant/Pulsejet	X			
Otto Fuel & HAP with Piston Expander				X
Laser Initiated Explosions (Gatling-gun)			X	X
Hydroturbojet (Li Reaction Chamber)		X		X

GAS GENERATOR

It was apparent from the results presented in Table 5 that the most promising device is the gas activated water pulsejet. Accepting this selection, an evaluation of the component parts of the system were then re-evaluated. It was recognized that the gas could be supplied by a number of alternate methods.

There are really only four approaches to generating gas efficiently:

a. Expand a liquid gas.
b. React a substance with water to produce a gas.
c. Decompose a compound.
d. Cause two compounds to react and produce a gas.

Of these, only a, b, and c are practical if volume of the gas generating compound is to be minimized.

Any gas generated will, to a first approximation, conform to the law of ideal gases, i.e.

$$PV = nRT \quad .$$

If P is expressed in atmospheres, V in cm^3 , and T in degrees Kelvin, then n equals the number of moles of gas present and R equals 82.07. From this equation it is clear that the volume of gas produced at a specified pressure and temperature is proportional to the number of moles present. If we wish to compare compounds for their volumetric efficiency as a gas generator, a simple function of density, molecular weight and moles of gas per mole of compound is:

$$n/cm^3 = \frac{k\rho}{MW}$$

where n/cm^3 = number of moles per cm^3
k = number of moles of gas produced per mole of substance
ρ = density of compound in g/cm
MW = molecular weight of compound.

Table 6 tabulates n/cm^3 for the leading choices of gas generating substances.

From Table 6 it can be seen that lithium hydride is the most volumetrically efficient of all of the simple compounds listed. It is interesting to note that by combining this compound with powdered aluminum in equal molar ratios, (about 8g to 27g) the high cost of the pure lithium hydride can be reduced and the hydrogen gas produced per cubic centimeter can be increased. When lithium hydride reacts with water, both hydrogen and lithium hydroxide are produced. The lithium hydroxide, in turn can react with the powdered aluminum to produce more hydrogen. The overall reaction is:

$$8\ LiH + 8\ Al + 16\ H_2O \rightarrow 20\ H_2 + 8\ LiAlO_2 \quad .$$

On the basis 12.72 grams lithium hydride mixed with 43.168 grams powdered aluminum would produce four moles of hydrogen gas which, at STP, would occupy a volume of 89.6 liters, yet the volume of the aluminum and lithium hydride is only 32.3 cm^3 . By replacing the lithium hydride with elemental lithium, the volumetric efficiency is almost as good as calcium hydride alone. The overall reaction is now:

$$Li + Al + 2H_2O \rightarrow 2H_2 + LiAlO_2 \ .$$

This means that about 3 1/2 grams of lithium metal mixed with 13 1/2 grams aluminum would produce one mole of hydrogen gas which by definition would occupy a volume of 22.4 ℓ at STP. The volume of the two metals would occupy a volume of only 11 1/2 cm^3.

It is clear that the combining of lithium hydride with aluminum is the best method of getting the most hydrogen from the smallest volume of reactants and at low cost. But it must be understood that some of this advantage is lost when the engineering problems of introducing water into the reaction chamber are considered.

It is not surprising that Table 6 shows lithium hydride as first choice of the simple compounds. This compound has a molecular weight of 7.95 and a density of 0.78 g/cm^3 . The very low molecular weight compensates for the unfortunate low density. It reacts with water by the following equation.

$$LiH + H_2O \rightarrow H_2\ (g) + LiOH \ .$$

From this equation and the gas law equation it can be calculated that at a depth of 100 meters, 1 cm^3 of lithium hydride would require 1.8 cm^3 water to produce 222.7 cm^3 hydrogen gas. But that is not the entire picture. The 2.395 grams of lithium hydroxide which is also produced must be dissolved and removed from the reaction site or the reaction will not go to completion. The amount of water necessary to dissolve the lithium hydroxide is about 18.9 cm^3 . Since high concentrations of the lithium hydroxide strongly suppresses the reaction rate between water and the lithium hydride, it must be removed in order to allow hydrogen production to proceed. The engineering complications of water introduction and lithium hydroxide removal from the reaction chamber must be taken into consideration if lithium hydride is to be used as a gas generator In fact, all gas generating substances that rely on water to generate a gas have this same problem to some degree.

The third choice as seen in Table 6 is calcium hydride. If cost is a consideration then it becomes second choice since the second most efficient gas producer on a volumetric basis costs consierably more. Calcium hydride has a molecular weight of 42.1 and a density of 1.902 g/cm^3 . It is the high density that overcomes the high moelcular weight and also the fact that two moles of hydrogen gas are produced on reacting it with water. The equation for the reaction with water is:

$$CaH_2 + 2H_2O \rightarrow 2H_2\ (g) + Ca(OH)_2 \ .$$

This equation shows that, like its lithium counterpart, fairly large amounts of water are needed to produce hydrogen. Unlike its lithium counterpart,

TABLE 6. VOLUME OF GAS PER GRAM AND PER CUBIC CENTIMETER OF MATERIAL

COMPOUND	n/cm^3	n/gm	H_2O gm/gm fuel
Equal Molar Lithium Hydride-Aluminum	0.1239	0.0716	1.03
Lithium Hydride	0.0981	0.1258	2.27
Lithium Aluminum Hydride	0.0967	0.1055	0.95
Calcium Hydride	0.0904	0.0475	1.71
Equal Molar Lithium-Aluminum	0.0871	0.0590	1.06
Liquid Neon	0.0595	0.0496	
Hydrazine	0.0525	0.0521	
Calcium Metal	0.0387	0.0250	0.90
Lithium Metal	0.0385	0.0720	2.60
Iron Penta Carbonyl	0.0382	0.0256	
Sodium Peroxide	0.0360	0.0128	0.23
Liquid Hydrogen	0.0347	0.4960	0
Calcium Carbide	0.0346	0.0156	0.56
Liquid Nitrogen	0.0287	0.0357	
Liquid Xenon	0.0236	0.0076	
Potassium Oxide "super"	0.0226	0.0106	0.19
Liquid Methane	0.0211	0.0498	

TABLE 7. SOME GAS SUPPLY SYSTEMS

	Weight of Material, lb	Volume of Material, in^3	Estimated Weight of Apparatus, lb
Pressurized gas: helium at 5,000 psi	0.67	325	18
Liquid CO_2	9.2	340	2
$Fe(CO)_5 + \text{heat} \rightarrow Fe + 5\ CO$	6.5	127	3
Burning rocket grain to form a gas	5.36	98	5
Hydrazine decomposition: $3\ N_2H_4 \rightarrow NH_3 + 2.5N_2 + 4.5H_2$	2.3	65	1
Lithium Hydride plus free water: $LiH + H_2O \rightarrow LiOH + H_2$	1.35	50	0.5

calcium hydroxide is not very soluble. At zero degrees celsius only 0.12 grams will dissolve in 100 cm^3 water. In contrast, under the same conditions 12.7 grams of lithium hydroxide would dissolve. This lower solubility of calcium hydroxide would cause precipitation and hence the reaction between the hydride and the water would not be strongly suppressed. Its utilization still is complicated by the engineering demands of maintaining hydrogen pressure and transporting water into, and reaction products out of, the reaction vessel.

The fourth choice is liquid neon. It, like liquid nitrogen, presents all the problems of cryogenic substances. A liquid gas does not require moving water but does need heat for vaporization. Neon is the best of all liquid gases because of its high density. Liquid neon has a density of 1.2 g/cm^3 compared to the 0.804 g/cm^3 for liquid nitrogen. In the use of liquid gases, an alloy of lithium and aluminum external to the gas volume could react with the water to produce the heat necessary to boil the liquid gas. Its primary disadvantage is logistic. The problems of supply and storage are difficult. Of the liquid gases, nitrogen would be the only one not presenting logistic and storage problems since an air liquefaction plant would not be difficult to establish on site.

A fifth choice is iron penta carbonyl. This heavy liquid will at very high temperature decompose into elemental iron and carbon monoxide by the equation below.

$$Fe\ (CO)_5 \xrightarrow{heat} Fe + 5\ CO\ (g)\ .$$

The use of this compound is complicated by the need for a very high temperature decompostition chamber to produce the gas from the liquid carbonyl. This complication could be eliminated if a suitable catalyst could be developed. The n/cm^3 listed in Table 6 is a high estimate because the weight of a furance or thermite mixture to decompose the compound is not considered; it does offer the simplicity of being a liquid and does not need any complicated pumps to introduce water and remove reaction products while maintaining pressure.

From Reference 5 we find that an evaluation of some gas supply systems gave an indication of the relative weight of apparatus required. This evaluation is shown in Table 7. Since the weight of the apparatus can often be related also to cost, we can suspect that the lightest will possibly also be the lowest cost.

Based on the studies of References 1 and 5 and a current cost of materials at \$30/lb*, it is concluded that the most promising method of storing

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[5] DeVries,, G. "High Pressure Gas from Lithium Hydride and Sea Water", U.S. Naval Ordnance Test Station, AD 625513, December 1975.

*It is anticipated that 30.14 gm of fuel will be required for 15 minutes, corresponding to a cost of roughly \$2/mission.

energy for the generation of hydrogen gas is to use lithium or lithium hydride along with aluminum. Previous work[6,7] has shown that it is feasible to provide this material in different shapes and with materials that allow more controlled reactions of the lithium, aluminum and water and the generation of the hydrogen gas to be produced.

Based on preliminary calculations it is estimated that the propulsion unit would require about 1,292 in^3 of gas at STP for 15 minutes of operation. This would theoretically require a volume of about 3.7 in^3 of solid material plus water for the 15 minutes of operation. (In practice, larger quantities of water are required in order to maintain a reasonable temperature.)

A feed water pump, driven by the pulsing of the pilot valve piston, will inject water into the gas generator at approximately the correct rate to produce one pulse quantity of gas. When Al is included in the initial composition, the end product ($LiAlO_2$) is a solid and is simply allowed to collect in the bottom of the generator.

The internal design of the gas generator will include a gas collecting system which functions regardless of the system's orientation. Otherwise, excessive products of incomplete reaction might be injected into the gas stream and pass out through the tail pipe. This collecting system may be accomplished using a weighted intake tube which always seeks the upper portion of the generator, with a separator to keep out the major solid material particles. It is proposed that the solids be in pellet form so these and the water are free to migrate to the low side of the generator. The high thrust peaks of the pulsejet wll keep the materials agitated. The solids may tend to migrate to the rear of the gas producer, but this is not seen as a major problem since the waste will travel there also.

The shape of the gas generator may be readily adapted to fit the available internal space requirements of the propulsion system package. Its location relative to the pulsejet is also not too critical, although care must be exercised to provide adequate gas supply lines to avoid any choking or timing problems with the pulsejet. The jet exhaust tube of the pulsejet need not be straight, If desired it could be bent to fit a particular packaging requirement.

As a part of Task II Payne, Inc. proposes to conduct experiments with the lithium and aluminum materials already on hand. These materials in their current form must be handled in a very low moisture environment. A glove box constructed at Payne, Inc. is available for transfer of the materials to the test device.

Measured quantities of the lithium/aluminum material and water will be mixed in the test device. The rate of generation of hydrogen will be determined and plotted against time. Using this data a test hydrogen gas generator will be constructed and evaluated.

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[6] Beumel, O.F. Jr. "Hydrogen Generating Composition and Use", U.S. Patent No. 3,346,506, October 1967.

[7] MacKenzie, G.L., Mosher, P.R. "Hydrogen Gas Generating Composition and Method for the Same", U.S. Patent No. 3.674,702, July 1972.

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PULSEJET EVALUATION

The pulsejet incorporates the energy conversion and thrust producer sections into one unit. We can conveniently then evaluate these two major components together. The selection of the pulsejet configuration was based on the work of Reference 1 which compared this form of a propulsor to other types of devices.

Water Breathing Engines

An extensive amount of experimental work was carried out during the late 1940's on water breathing engines by Aerojet Corporation under a Navy contract (References 13 through 24). The engine, which Aerojet called the "hydropulse" engine was fashioned after the design of the German Vergeltungswaffe No. 1 (V-1 Buzz-Bomb Engine) that flew during World War II. The hydropulse engine appears to have the type of features necessary for this application. It is simple, size efficient, and can operate over a range of very low to very high velocities. The original hydropulse reacted molten lithium with seawater to produce a sudden pressure rise in a duct that expelled the water from the duct. The duct then refills under ram pressure, due to the forward motion, and lithium is injected again. One version which used reed check valves at the forward end to contain the thrust pressure and open automatically to permit rapid refilling, produced thrusts of 4500 N and a speed of 32 m/s and demonstrated a fuel consumption rate of 36 N of lithium per thrust kWh. This fuel comsumption rate indicates that the fuel requirement for an 18 m/s, 6 minute run may be satisfied with 14 N of lithium having a volume of 2.6 liters. Additional volume must be allocated for the lithium melter, lithium injecter, and the duct. With substantial development of the lithium supply and control portions of the hydropulse engine, the minimum requirements of this application may be met.

The fact that lithium had to be melted and then injected added a large amount of complication to the machinery of the engine. Also, lithium is extremely energetic on the basis of volume. These facts led Aerojet to investigate other water breathing engines. Aerojet's philosophy was "for every air-breathing engine there exists an analogous water breathing engine". This philosophy led Aerojet to the discovery of the hydroduct, hydroductor, hydroturbojet and a substitute for lithium fuel called Alclo fuel (a compressed mixture or aluminum and potassium perchlorate particles).

One type of hydropulse which received almost no attention was a solid fueled engine. It was investigated in a small way by Aerojet but given up due to problems with controlling the reaction. Aerojet surrounded a hydropulse duct with a cast sodium cartridge which is held tightly against a per-

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[8-18] Aerojet-General Corporation Reports Nos. RTM-27, RTM-45, R60,R68, R69,R77, 387, 419, 727, 1106, 2462 (1946 - 1963).

[19] Gongwer, C.A. "Water Propulsion Devices Without Primary Rotating Machinery", presented at the Symposium of Hydraulic Jet Propulsion under the sponsorship of Navy Dept. Office of Naval Research and Bureau of Ordnance, 1950.

forated partition which adjoins a reaction chamber. The pulsing action is started by intermittent injection of water in a fine spray against the sodium cartridge. The advantage of a solid fueled hydropulse is that the machinery for the injection and heating of the fuel is eliminated thus simplifying the engine.

Another form of the hydropulse engine which did not receive analysis is the compressed gas hydropulse. With this type of hydropulse no water reacting fuel is used. Instead, a compressed gas is introduced into the barrel and allowed to expand pushing out the slug of water in the barrel. With today's high strength materials it might be practical to carry enough compressed gas to fulfill mission requirements. The advantage of using a compressed gas instead of a water reacting fuel is that thermodynamic losses during the expansion of the gas are minimized.

The hydropulse is an open-cycle engine and hence depth sensitive. The efficiency of the engine will degrade with depth.. However, the calculations have shown that even 10% efficiency is acceptable performance from a volume standpoint. The hydropulse should be applied to shallow depth applications not exceeding 200 meters unless pressure can be increased as depth increases.

In summary, the hydropulse engine is a simple, size efficient jet engine. In order to use the hydropulse, development work needs to be done in the areas of fuels and fuel delivery. The gas-water interface needs to be investigated in a basic way and the hydropulse's performance with depth evaluated.

PULSEJET DESIGN

The pulsejet proposed for this application is designed to be used with a gas generator. The generator is fueled by lithium aluminum hydride or similar type material reacting with water and produces hydrogen gas under pressure.

The proposed pulsejet assembly is shown in Payne, Inc. drawing 329D15. This drawing and the detail components are included as Appendix C.

Operation Cycle

This propulsion system is a pulsed jet device. By means of a pilot operated valve, carefully sized to open at a specific pressure ratio and closed by spring forces, a charge of compressed gas is injected into the propulsion tube. Here the gas expands and forces a pulse of water from the discharge end. When the main gas valve closes the differential pressure across the water column eventually becomes negative, and an exhaust valve is "sucked" open; however a check valve prevents external water intake into the tube. The differential pressure stops the water column, causes it to reverse its flow direction and move toward the exhaust valve forcing the initial gas charge out past the check valve. During the period of time the exhaust valve is open a detent lock keeps the main gas valve from opening. As soon as the water column reaches the head of the expansion chamber it strikes the exhaust valve and forces it closed. This unlocks the main gas valve which has now built up a sufficient head of pressure to "pop" open and allow a new pulse of gas to enter the expansion chamber. The cycle now repeats.

Component Operation

Gas pressure is allowed to enter the main accumulator from the high pressure gas source through a needle valve. This needle valve limits the flow rate so the accumulator pressure build-up is delayed long enough to allow a period of time for the main gas valve to close after initial gas discharge. This period of time must be greater than the time required to discharge the accumulator pressure into the expansion chamber but less than that required for the discharged air to expand, the water column to stop and reverse direction and impinge on the exhaust valve head. This needle valve can be used to limit the cycle frequency below the natural frequency determined by that of the expansion/exhaust cycle.

The gas pressure builds up in the accumulator to a maximum equal to that in the gas source. The total accumulator volume is that in the main accumulator section plus the volume behind the pilot valve and the connecting passageway. As pressure builds in the accumulator it bleeds into the space behind the pilot valve. Here the pressure acts on the pilot valve piston. Besides overcoming the O-ring friction, the initial pressure causes motion which forces trapped air from behind the pilot piston into a passage connecting with the exhaust valve positioning piston. If the exhaust valve is open then it is forced to move to a closed position by this low pressure air. Note: this portion of the pilot valve motion occurs only on start up.

The design of the pilot piston is such that after start-up the return motion is damped by the small clearance between the piston and cylinder bore so that the air is partially trapped. This delay should be sufficient to eliminate excursion of the piston into this area during normal operation but on shutdown the trapped gas will bleed off to provide a new charge on the back side of the pilot piston for the next start-up if it is required.

As the pressure builds up in the accumulator and behind the pilot valve, the pilot valve moves to the right (as shown in drawing 329D15). The piston contacts the shoulder on the stem which limits the piston travel until the pressure is high enough to open the main valve. As soon as the main valve cracks open, the pressure differential across the effective piston area decreases reducing the force that was holding it closed. The pressure on the pilot piston forces the valve wide open dumping the "slug" of air into the expansion chamber. The pressure bleeds off the back side of the pilot valve and the springs force both the main gas and the pilot valve to the closed position. A new charge of gas starts to build from the flow through the needle valve.

The air in the expansion chamber accelerates the water in the tube producing a propulsive jet from the discharge end. After the pressure in the expansion chamber reaches ambient the inertia of the water column causes its motion to continue until the differential pressure across the water column (created by the now lower than ambient chamber pressure) arrests the water motion. This low chamber pressure creates a "suction" on the exhaust valve and it opens. When the exhaust valve opens a plunger, moved by a cam on the end of the exhaust valve stem, engages a detent in the main gas valve stem and locks the main gas valve closed. A one-way valve in the exhaust system prevents water entering the exhaust port.

As the water column reverses direction and accelerates toward the head of the expansion chamber it pushes the trapped gas past the exhaust valve and the one-way valve and out the exhaust port. When the water reaches the exhaust valve head the impact is sufficient to push the exhaust valve closed. This motion allows the lock plunger to disengage from the main valve stem and the main valve is then free to open. Normally at this time the pressure will be built up so that the main gas valve "snaps" open; however if the needle valve adjustment restricts the flow into the accumulator sufficient to delay this build-up then there could be a momentary pause before the next pulse. As soon as the main valve opens the next charge of gas is injected into the expansion chamber and the cycle repeats.

Since this pulse jet is intended to operate with high pressure gas from a gas generator which requires an injection of water, a pump has been incorporated on the main gas valve stem. Each time the main gas valve "pops" open a small charge of water is injected into the gas generator at a controlled rate to produce the hydrogen gas.

Component Performance Calculations

These calculations are based on the following assumptions:

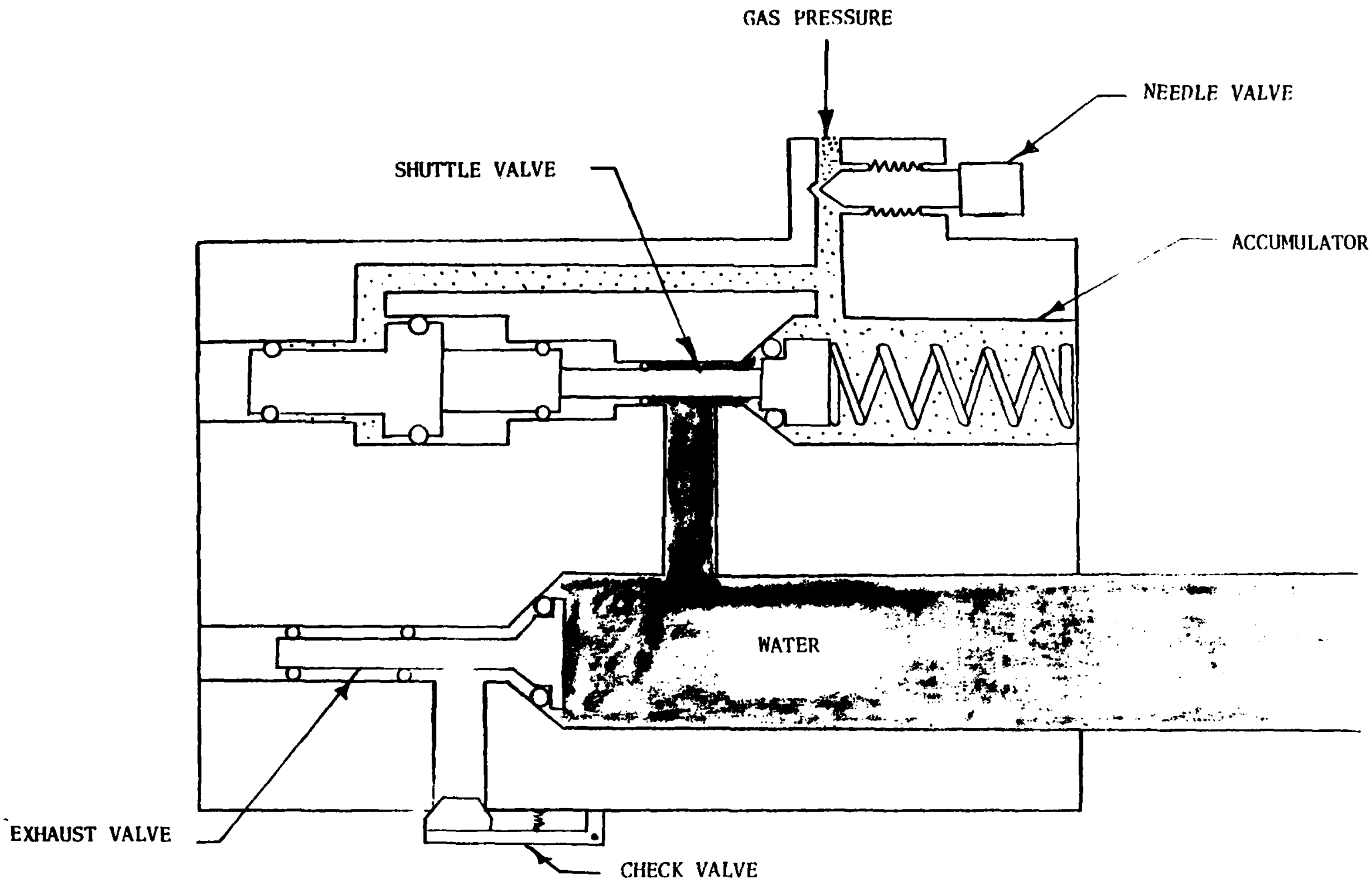

Figure 1.

Step #1. Time for accumulator to reach discharge pressure is adjusted with needle valve. This allows pulsejet cycle to be completed before next discharge.

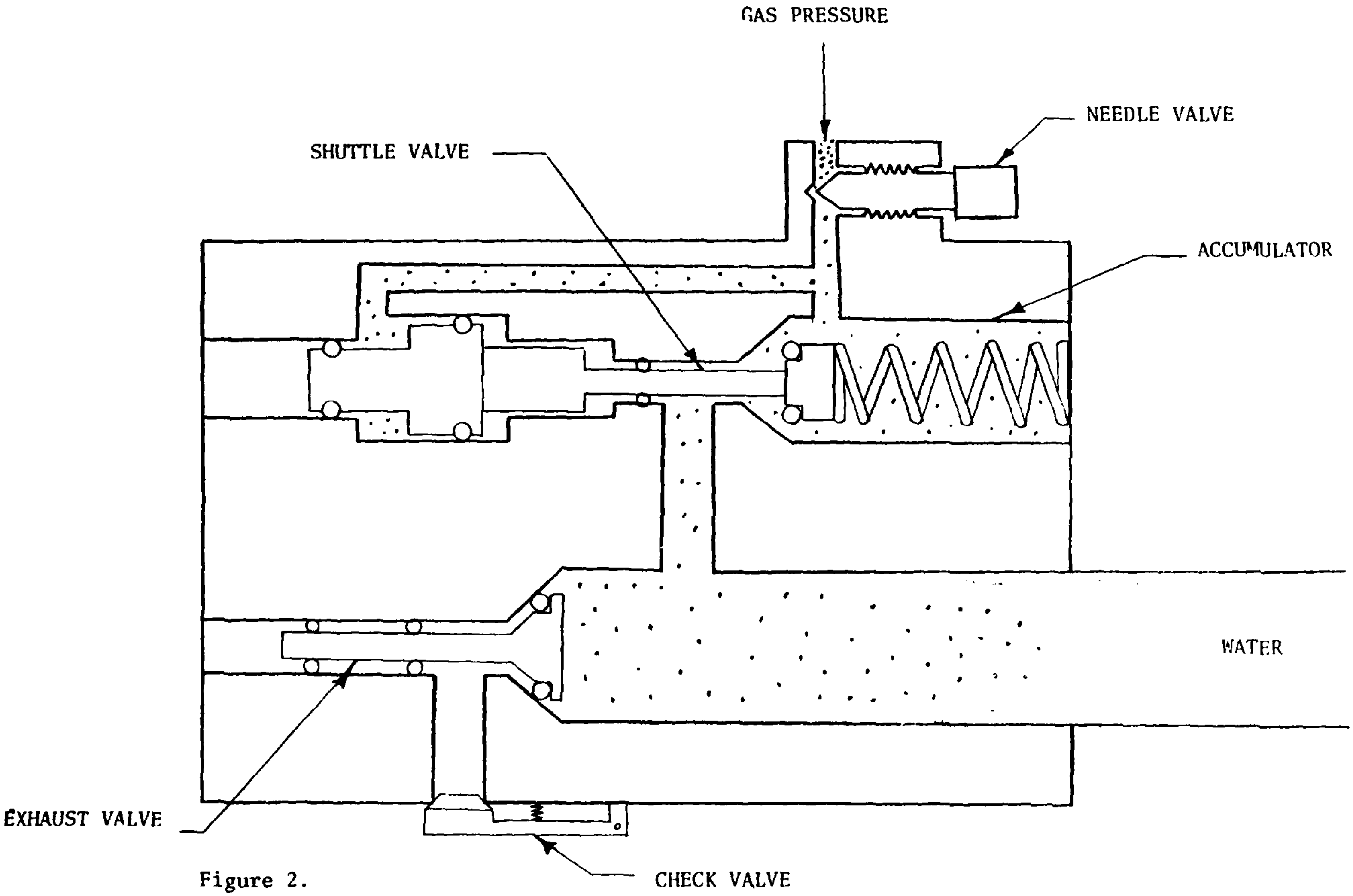

Figure 2.

Step #2. At maximum accumulator pressure, spring force is overcome and pressure discharge accelerates water column out of duct.

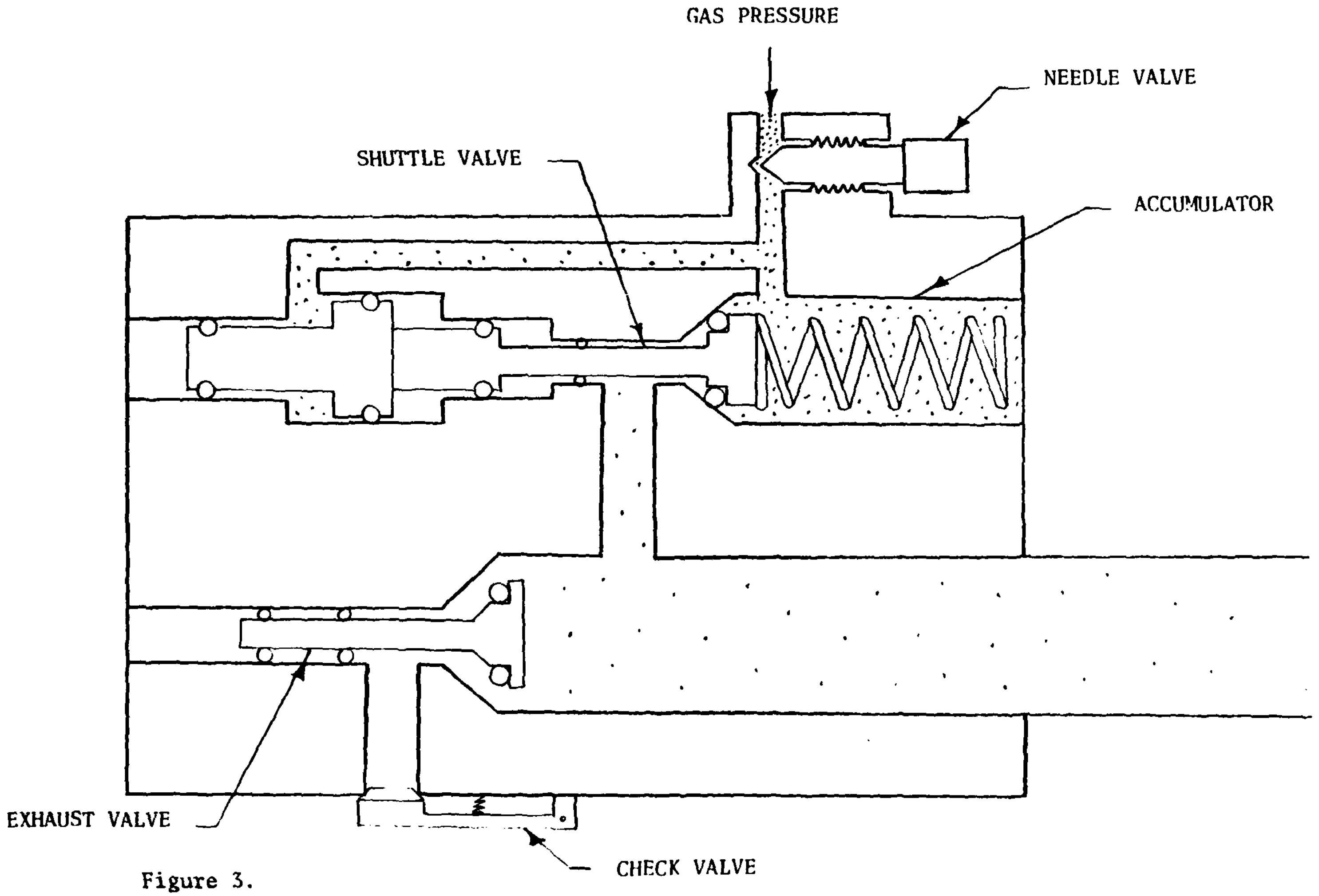

Figure 3.

Step #3. Shuttle valve closes with pressure drop and water momentum creates sub-ambient pressure which opens exhaust valve.

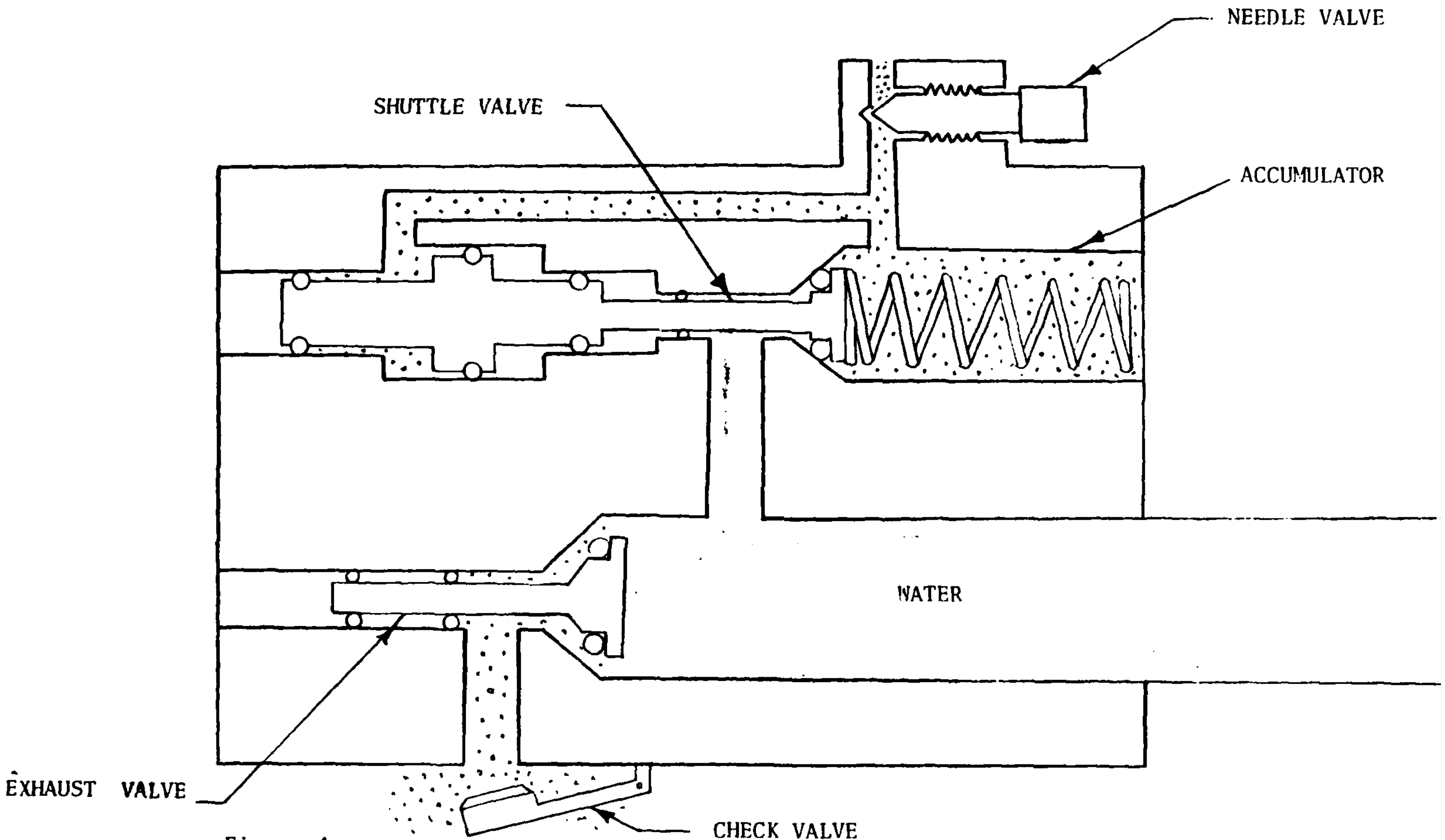

Figure 4.

Step #4. Water pressure forces gas out the exhaust valve and water impact closes exhaust valve.

1. Unit operating at sea level.
2. Gas supplied at 500 psig.
3. Approximate total gas stroke equals 6.0 inches with 3.0 inches expansion and 3.0 inches at or below ambient pressure.
4. Operation at greater depths may be accomplished by maintaining the gas source pressure relative to the depth pressure at approximately 500 psig.

Accumulator Volume

The formula for average thrust is

$$T_{av} = \tfrac{1}{4}\,\rho x_o^2 \omega^2$$

where T_{av} is in pounds

ρ = mass density of water (slugs/ft^3)
x_o = the semi stroke (ft)
ω = oscillation frequency (rads/sec)

$$\therefore \quad \omega^2 = \frac{4T_{av}}{\rho x_o^2} = \frac{4 \times 3}{1.00 \times (\tfrac{1}{4})^2} = 96.5$$

$$n = \frac{\omega}{2\pi} = \frac{9.82}{2\pi} = 1.56 \text{ Hz.}$$

The gas volume in the duct at STP is 0.92 in^3. Thus the total volume required for 15 minutes operation is

$$0.92 \times 1.56 \times 60 \times 15 = 1292 \text{ in}^3 \text{ at STP}$$

$$= 1292 \times \frac{14.7}{514.7} = 36.9 \text{ in}^3 \text{ at 500 psig}$$

$$= \frac{36.9}{1.56 \times 60 \times 15} = .026 \text{ in}^3\text{/stroke at 500 psig.}$$

This calculated volume is so small that it is impractical to limit the total volume to this amount. It is anticipated that the pulsing action of the main valve will be rapid enough to limit the volume of gas passing to approximately this amount by restricting passage sized from the "outlying" volume of the pilot cylinder and the valve ports. Initial testing will be needed to verify this assumption. If this is not so then restrictions will be added to the passageways to reduce the back flow of gas from the more distant accumulator volumes.

Force across Main Gas Valve due to Differential Pressure

$$\Delta p = 500 - 0 = 500 \text{ psig}$$

$$A_v = \frac{\pi(D_o^2 - D_i^2)}{4}$$

$$= \frac{\pi(0.56^2 - 0.375^2)}{4} = 0.136 \text{ in.}^2$$

$$F_m = \Delta p\, A_v = 500\ (0.136) = 68 \text{ lbs.}$$

A_v = effective area of main gas valve, in.^{2}

D_o = 0.56 in.

D_i = 0.375 in.

F_{mv} = force main gas valve, lbs.

Friction Forces on the Pilot Valve Piston

- Assume major friction is due to O-rings and seals.
- Also assume friction on Block Vee type seals is approximately 60% times that of a comparable size O-ring.

Seal	Parker O-ring	For Piston Groove						
		f_c	L_p	f_n	A_p	F_c	F_H	F
711806	2-113	.7	2.36	23	.19	1.65	4.57	6.02
711825	2-210	.7	3.15	23	.34	2.21	7.82	10.03
--	2-106	.7	1.18	23	.06	1.38	.04	1.42

(From Reference 20)

$$F_c = f_c \times L_p$$

$$F_H = f_h \times A_p$$

$$F = F_c + F_H$$

$$F' = .6(6.02) + .6(10.03) + 1.42$$

$$= 11.05 \text{ lbs.}$$

Note: F' is applicable when the piston is sliding on the stem. When the two move together F' = 11.05 - 1.42 = 9.63 lbs.

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[20] *O-Ring Handbook OR 5700*, Parker Seal Company, Revised August, 1971.

Force Due to Water Pump

Area of Pump Piston = $A_{pp} = \frac{\pi(D_o^2 - D_i^2)}{4} = \frac{\pi(.5^2 - .321^2)}{4} = .12 \text{ in.}^2$

For 500 psi water (P_w) the force (F_w) would be:

$$F_w = A_{pp} P_w = .12(500) \approx 60 \text{ lbs.}$$

Friction on Stem due to Seals

(See calculation on Pilot Piston)

Seal	O-Ring	For Piston Groove						
		f_c	L_p	f_h	A_p	F_c	F_H	F
711803	2-109	.7	1.57	23	.08	1.10	1.84	2.94
	2-008	.7	.98	23	.05	.69	1.15	1.84

Force on stem = $F_s = (.6)2.94 + 1.84 = 3.60$ lbs.

Starting Pressure Force on Back Side of Pilot Piston

Area of Pilot Piston Back Side = $A_{ppB} = \frac{\pi(D_o^2 - D_i^2)}{4} = \frac{\pi(1.02^2 - .375^2)}{4}$

$$= .67 \text{ in.}^2 .$$

Volume displaced by piston movement of .3 in. = $V_s = A_{ppB} S = .67(.3)$

$$= .201 \text{ in.}^3 .$$

Total Volume at end of starting stroke = V_{s_2}

$$V_{s_2} = V_{ps} + V_p + V_{sc}$$

$$V_{ps} = \frac{\pi[D_1^2(.2) + D_2^2(.36)] - D_i^2(.56)]}{4}$$

$$= .23 \text{ in.}^3$$

$$V_p = \frac{\pi(D_p^2)}{4} L = \frac{\pi(.093)^2}{4} (.8) = .005 \text{ in.}^3$$

$$V_{sc} = \frac{\pi(D_o^2 - D_i^2)}{4} L_s = \frac{\pi(.437^2 - .312^2)}{4} (.05) = .004 \text{ in.}^3$$

$V_{s_2} = .23 + .005 + .004 = .239 \text{ in.}^3$

$V_{s_1} = .239 + V_S = .239 + .201 = .44 \text{ in.}^3$

where

V_{ps} = Volume of pilot cycle (start side)

V_p = Volume of passage

V_{sc} = Volume of start cycle

D_1 = 1.0 in.

D_2 = .80 in.

D_i = .50 in.

$p_1 V_{s_1} = p_2 V_{s_2}$

$p_2 = \frac{14.7(.44)}{.239} = 27$ psia.

p_1 = 0 psig = 14.7 psia

$V_{s_1} = .44 \text{ in.}^3$

$V_{s_2} = .239 \text{ in.}^3$

$p_2 = 27 - 14.7 = 12.3$ psig.

F_{ppB} = force on pilot piston = $A_{ppB}\, p_2 = .67(12.3) = 8.24$ lbs.

Force on starting piston = $A_{sp}\, p_2 = \frac{\pi(.437^2 - .312^2)}{4}(8.24) = .6$ lb.

Pilot Piston Spring
9435K149 (McMaster Carr, Chicago, IL)
O.D. = .720 Wire Diameter = .072
Free length = 1.25 in. Rate = 27.5 lb/in.
Solid Height = .470

Spring Condition	Deflection (in.)	Load (lbs.) = (F_{prs})
Initial start	.37	10
End of start	.67	18.4
Main valve open	.77	21.2

Main Gas Valve Spring - Force = F_{ms}

9623K11 (McMaster Carr, Chicago, IL)

O.D. = .53 I.D. = .28 Free length = 1.0 in.

Solid Height = .56 in. Rate = 260 lb/in.

Wire .125 x .062

Initial Deflection =	.10	Initial Load	= 26 lbs.
Final Deflection =	.20	Final Load	= 42 lbs.

Area of Pilot Piston Front Face (A_{ppF})

$$A_{ppF} = \frac{\pi(D_o^2 - D_i^2)}{4} = \frac{\pi(1.0^2 - .75^2)}{4} = .344 \text{ in.}^2$$

Pressure Sequence

- Gas enters Accumulator and Pilot Piston through needle valve.
- Initial Pressure (P_i) to move must overcome pilot piston O-ring friction and force air into starting cylinder.

$$P_i = \frac{F' + F_{ppB} + F_{prs}}{A_{pp}} = \frac{11.05 + 8.24 + 10}{.344} = 85 \text{ psig.}$$

- Pressure to open main gas valve = P_o ; combined seal friction forces = F_f .

$$P_o = \frac{F_f + F_w + F_m + F_{prs} + F_{ms}}{A_{ppF}}$$

$$P_o = \frac{(11.05 - 1.42 + 3.60) + 60 + 68 + 18.4 + 26}{.344} = 540 \text{ psig.}$$

Note: this pressure can be varied by skimming to adjust the force on the main gas spring.

- After opening the pressure differential across the main valve decreases. Assuming this reduces to zero then the pressure for wide open would be:

$$P_w = \frac{F_f + F_w + F_{prs} + F_{ms}}{A_{ppF}}$$

$$P_w = \frac{(11.05 - 1.42 + 3.60) + 60 \quad 21.2 + 42}{.344} = 397 \text{ psig.}$$

This would indicate that the valve will first crack open, then will rapidly open to full position.

The pressure at which the valve starts to close will be (P_{sc}):

$$P_{sc} = \frac{-F_f + F_{prs} + F_{ms}}{A_{ppF}}$$

$$P_{sc} = \frac{-(11.05 - 1.42 + 3.60) + 21.2 + 42}{.344} = 145 \text{ psig.}$$

The pressure at which the valve closes (P_c) will be

$$P_c = \frac{-F_f + F_{prs} + F_{ms}}{A_{ppF}}$$

$$P_c = \frac{-(11.05 - 1.42 + 3.60) + 18.4 + 26}{.344} = 91 \text{ psig} .$$

CONCLUSIONS AND RECOMMENDATIONS

Based on the literature survey, a review of pertinent data and the preliminary design and calculations it is concluded that a propulsion system can be constructed and demonstrated to meet the requirements of this program.

It is proposed that the prototype pulsejet unit be constructed, that development of the gas generator be carried out and that a demonstration be conducted in accordance with the test plans presented in Appendix B.

APPENDIX A

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APPENDIX B

GAS GENERATOR TEST PLAN
and
DEMONSTRATION TEST PLAN FOR THE GAS OPERATED PULSEJET

GAS GENERATOR TEST PLAN

Our literature survey has failed to discolse any data on the <u>rate</u> at which hydrogen is released in the reaction

$$8\ LiH + 8\ Al + 16\ H_2O \rightarrow 20\ H_2 + 8\ LiAlO_2 \quad (1)$$

DeVries gives some data for

$$LiH + H_2O \rightarrow H_2 + LiOH \quad (2)$$

which shows that the reaction rate increases with pressure. We would also expect the rate to double for every 10° C, and for a substantial amount of heat to be liberated.

In order to quantize these effects it is necessary to initiate the reaction in a pressure vessel and monitor pressure with some kind of dynamic recorder, utilizing an apparatus of the type shown in Figure B.1.

Our calculations indicate that a full fifteen minutes run at 3 lb. average thrust (six inches total stroke in the pulsejet) requires an operating speed of 1.56 Hz and a total gas charge of 2.16 grams at 500 psig. The total fuel charge is thus 30.14 gm and the heat released by the reaction is 430 Btu, corresponding to a rate of 1714 Btu/hr. This heat flow rate is easily managed if the outside of the reactor is liquid (water) cooled but could cause problems in the lab without special cooling provisions.

We plan to monitor flask temperature as well as recording the pressure dynamically. We initially assume that the reaction rate (k) will depend primarily on temperature, in accordance with the Arrhenius equation, but DeVries has shown that the $LiH + H_2O$ reaction also increases with pressure. If this is so for the $LiAlH_4 + H_2O$ reaction, then we need to quanize this in order to permit the reaction rate equation to be appropriately modified.

Since the purpose of these tests is to determine the constants in the Arrhenius equation, so that temperature and pressure constraints can be defined for the reactors, measurements of rate will be made at temperatures of 0°, 32°, 60°, and 100° F, and pressures of 0, 50, 100, 200, and 500 psig.

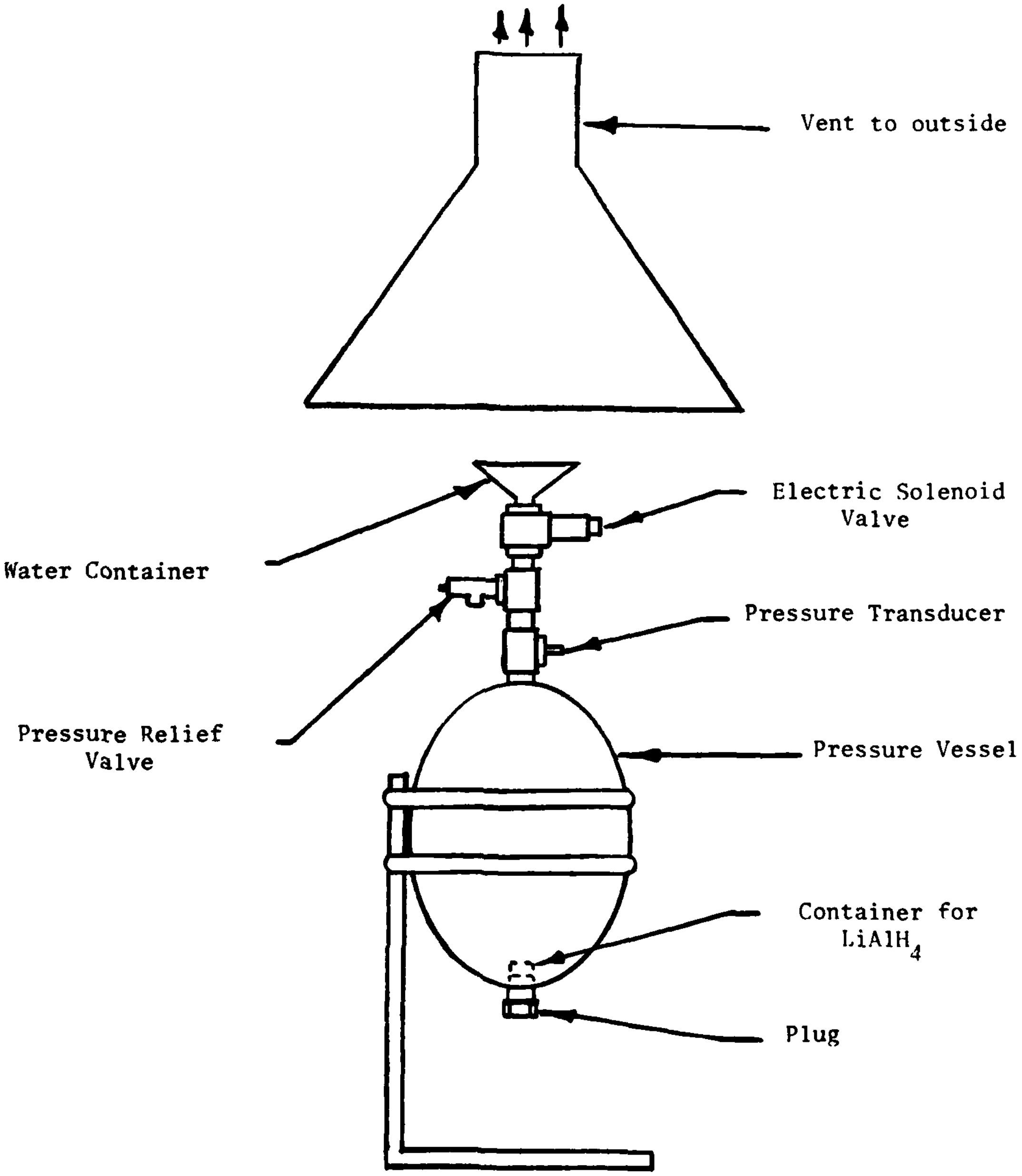


Figure B.1. Test set-up for determining reaction rate.

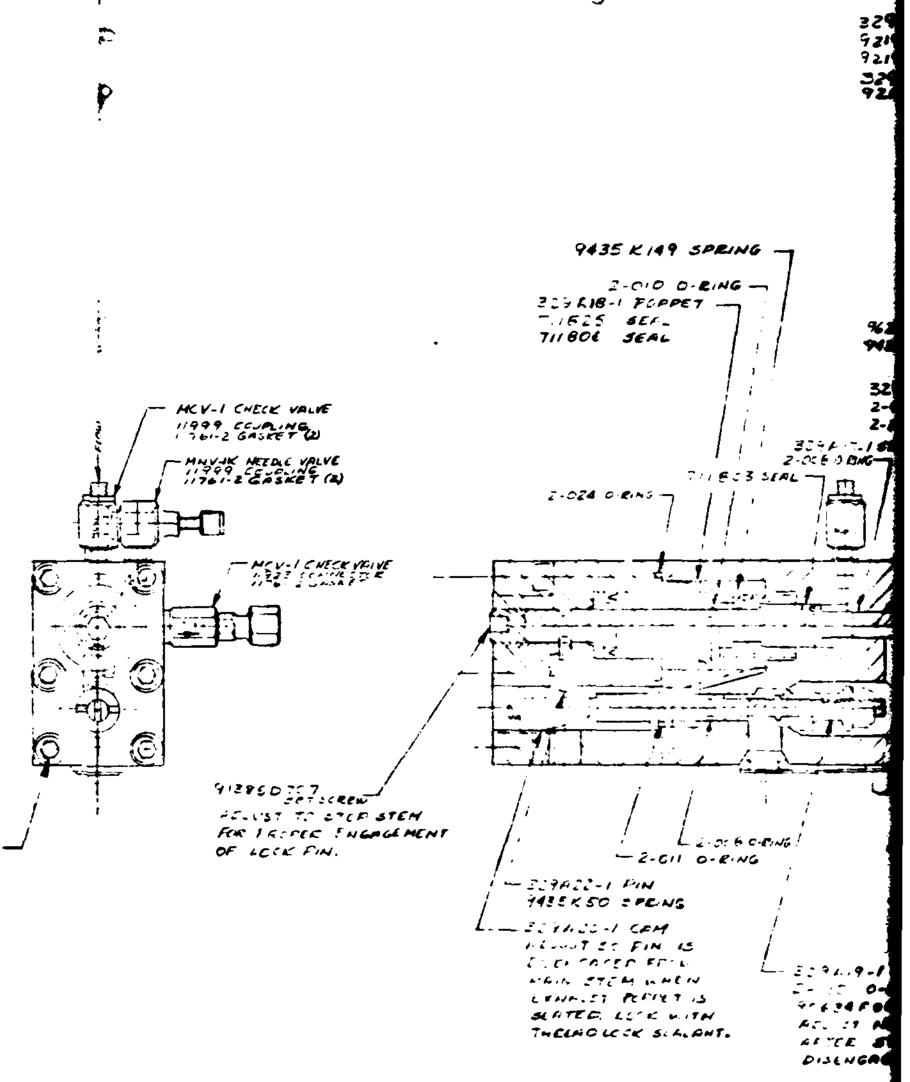
ENGINE TEST PLAN

The exhausting hydrogen represents a fire hazard in a normal lab environment. Also, while the proposed fuel ($LiAlH_4$) is harmless when loaded into the reactor, recharging requires sophisticated equipment. And since it is unlikely that a demonstration test can be completed in fifteen minutes, it is proposed to employ a separate gas source, such as a compressed nitrogen bottle for most of the demonstration. Hydrogen will be employed for a few seconds merely to demonstrate that its lower atomic weight does not influence the engine's ability to operate.

Thrust measurement is notoriously difficult with a pulsejet because of its transient nature. And since the mission is to deploy a line of transducers underwater, an adequate test would be to deploy a 500 foot line in water. This can best be accomplished on the surface (like the NOSC tests) since we are not then faced with the complications of guidance. It is therefore proposed to fashion a simple boat, large enough to hold a small gas cylinder (at least 40 in^3 capacity) with the pulsejet mounted underneath. The deployment of 500 ft of line will then be demonstrated in a sheltered body of water, or, given inclement weather, in an indoor swimming pool, the model being turned around at each end, in the latter case.

APPENDIX C

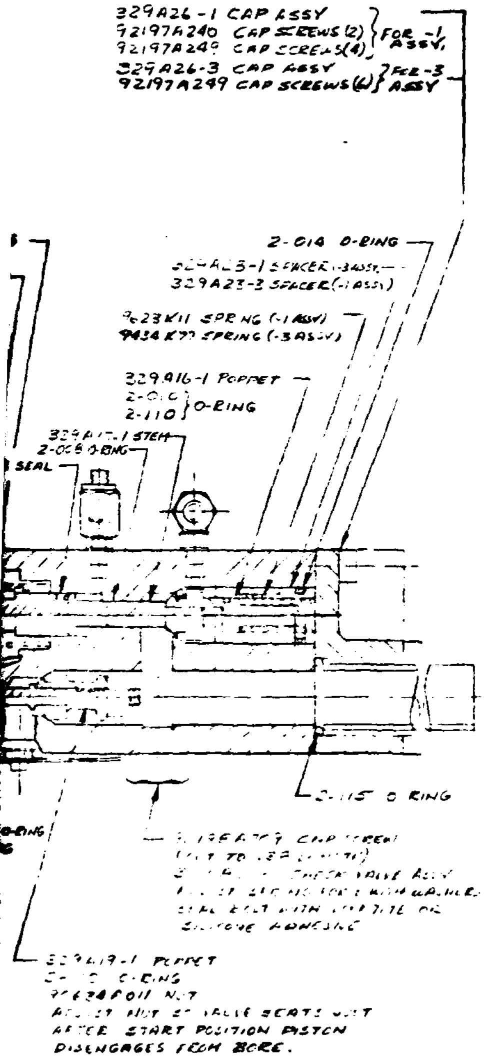
DETAIL DRAWINGS OF THE PULSEJET



1. -1 ASSY. IS MADE OF CRES. STEEL & INTENDED TO OPERATE AT APPROX 600 PSIG.
-3 ASSY IS OF ACRYLIC FOR DEVELOPMENT AND SHOULD NOT BE OPERATED ABOVE 100 PSIG.

NOTES.

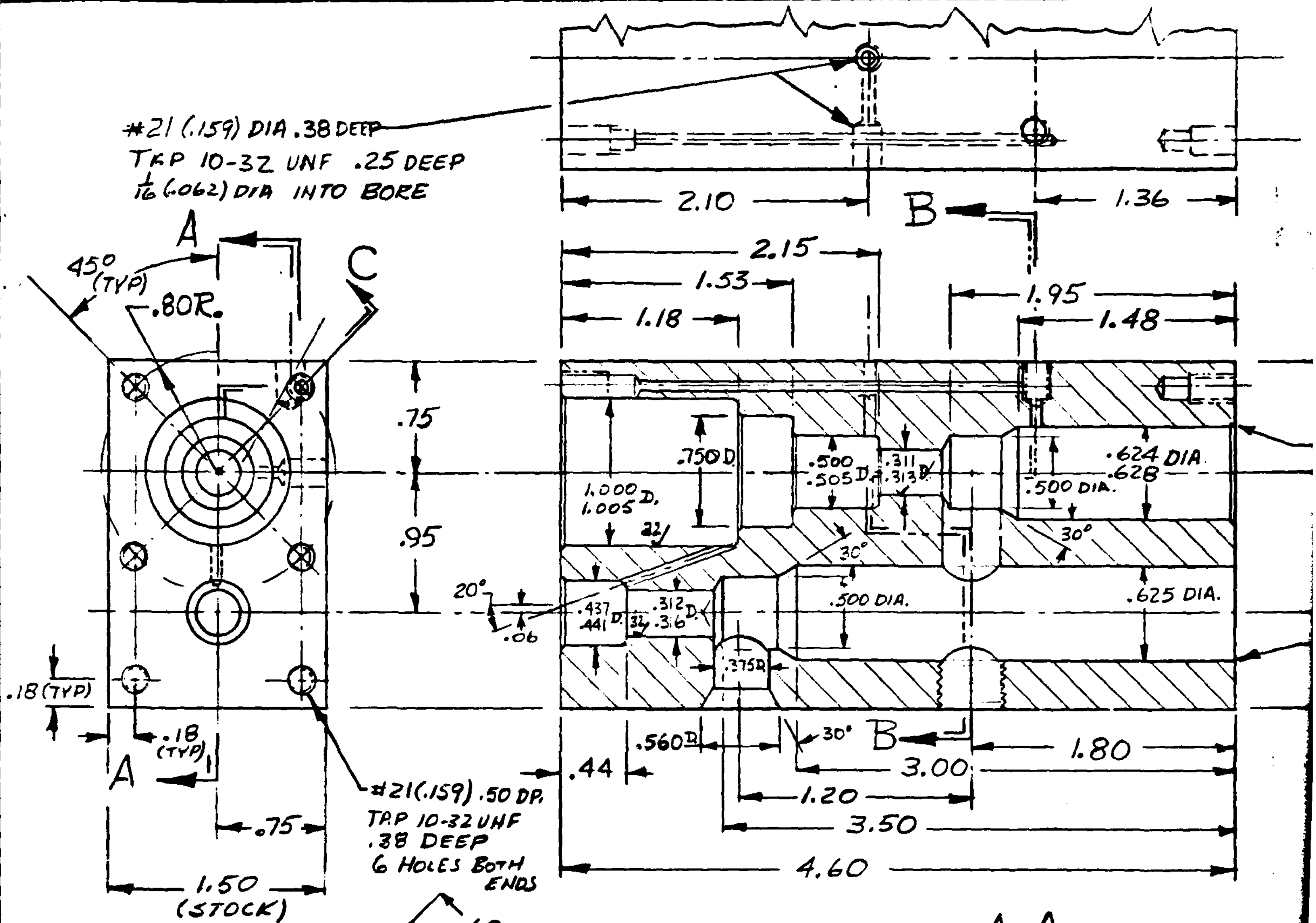
ZONE	LTR	DESCRIPTION	DATE	APPROVED



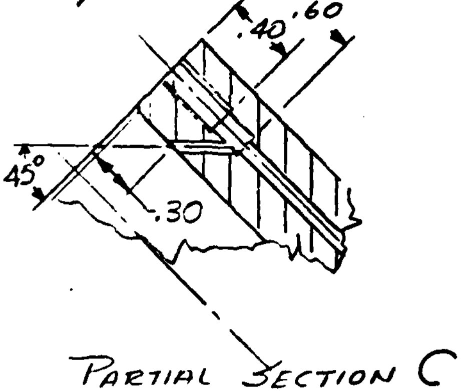
		CODE IDENT NO	PART NO	NOMENCLATURE	STOCK SIZE AND MATERIAL OR VENDOR	SPECIFICATION	UNIT WT	ITEM NO
1	1		90634A011	NUT				
1	1		92198A709	CAP SCREW				
6	6		92197A251	CAP SCREW				
6	4		92197A249	CAP SCREW				
	2		92197A240	CAP SCREW				
1	1		91375C757	SET SCREW	McMASTER CARR			
1	1		9435K50	SPRING	ELMHURST, IL. 60126			
1	1		9435K149	SPRING				
1			9434K77	SPRING				
	1		[illegible]	SPRING				
	1		711BC6	SEAL	BLOCK VEE SEALS			
1	1		711B23	SEAL	CR INDUSTRIES			
1	1		711B25	SEAL	ELGIN, IL. 60120			
1	1		2-024	O-RING				
1	1		2-115		PARKER SEAL COMPANY			
2	2		2-110		CULVER CITY, CAL.	90230		
1	1		2-014		NITRILE (BUNA N) COMPOUND			
1	1		2-011		SHORE A HARDNESS 70 DUROMETER			
2	2		2-010					
2	2		2-008	O-RINGS				
2	2		[illegible]	GASKET				
	1		11973	CONNECTOR				
1	2		11999	COUPLING	CLIPPARD INSTRUMENT LABORATORY, INC.			
1	1		MNV-1K	NEEDLE VALVE	CINCINNATI, OHIO	45239		
	2		[illegible]	CHECK VALVE				
1	1		329A27-1	CHECK VALVE ASSY.				
1			329A26-3	CAP ASSY.				
	1		329A26-1	CAP ASSY.				
1			329A25-3	HEAD				
	1		329A25-1	HEAD				
1			329B24-3	BODY				
	1		329B24-1	BODY				
	1		329A23-3	SPACER				
1			329A23-1	SPACER				
1	1		329A22-1	PIN				
1	1		329A21-1	STEM				
1	1		329A20-1	CAM				
1	1		329A19-1	POPPET				
1	1		329A18-1	POPPET				
1	1		329A17-1	STEM				
1	1		329A16-1	POPPET				
			-3	PULSE JET ASSY. (PLASTIC MODEL)				
			-1	PULSE JET ASSY. (CRES ST...)				

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DO NOT SCALE	CONTRACT NO	**Payne inc.** Annapolis MD 21401
TOLERANCES 2 PLACE ± / 3 PLACE ± / ANGLES ±	SIGNATURES / DATE DRAWN CHECK ENGINEER	PULSE JET, GAS POWERED
	DESIGN ACTIVITY APPROVAL	SIZE D / CODE IDENT 27453 / DRAWING NO [illegible] / REV LTR
		SCALE / WEIGHT / SHEET / OF

C-1



SECTION A-A



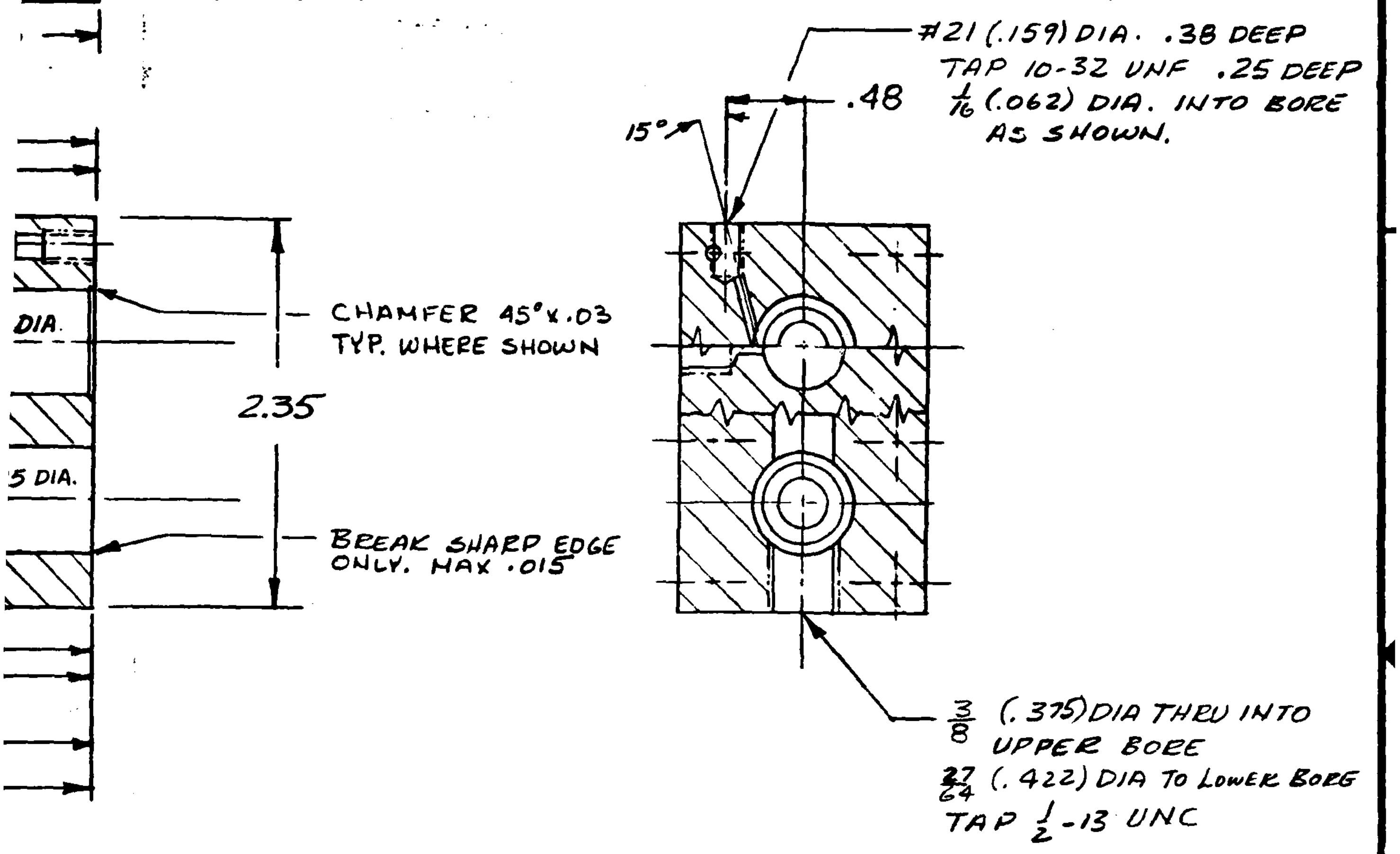
PARTIAL SECTION C

PART NU
ODD DASH NOS
EVEN DASH NO
UNLESS OTHE
DIMENSIONS
TOLERANC
TOLERANC
TOLERANC
MEET DIM
BURR ALL
CORNER R
& SPOTF
UP TO 1.2
GREATER
MAK PER

ABOVE: NO. REQ/ASSY NOTED
BELOW: N.A. & PROJ.

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED



-3	BODY	1.50 PLATE ACRYLIC	CLEAR, MIL-P-21105		
-1	BODY	1.50 PLATE CRES STL	TYPE 304 [illegible]		
PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID NO.	UNIT WT.	ZONE

ODD DASH NOS. SHOWN
EVEN DASH NOS. OPPOSITE

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCE ON .XX DIM. ±.03
TOLERANCE ON .XXX DIM ±[illegible]
TOLERANCE ON ANGLES ± ½°
MEET DIMS. BEFORE PLATING
BURR ALL EDGES
CORNER RADII ON C'BORES & SPOTFACES:
UP TO 1.25 DIA. .062
GREATER THAN 1.25 .093
MAX. PER MIL-STD 10

CONTRACT NO.

SIGNATURES & DATE
DRAWN NEWHOUSE 10-28-81
CHECK
STRESS
WEIGHT
PROJ.
CUSTOMER

Payne, Inc. | ANNAPOLIS, MARYLAND 21401

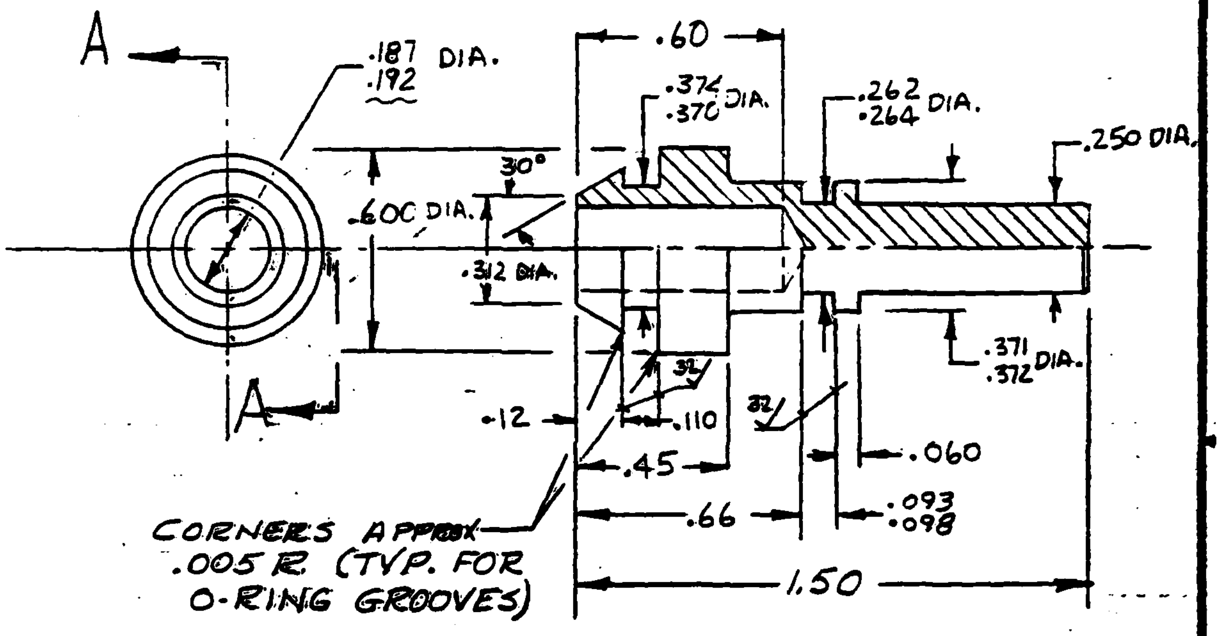
BODY, PROPULSION UNIT

SIZE	FED. CODE NO.		CHGE LTR
B	57433	329B24	

SCALE: FULL SIZE | WT: EST: ACT: | SHEET 1 OF 1

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30



PARTIAL SECTION A-A

NOTE - TWICE SIZE

☒ -1	POPPET	.75 DIA BAR CRES. STL.	TYPE 303 OR EQUIV.	
PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID. NO.	UNIT WT.

329A16-1

329D15

ODD DASH NOS. SHOWN
EVEN DASH NOS. OPPOSITE
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOL. ON XX DIM. ± .03
TOL. ON XXX DIM. ± .010
TOL. ON ANGLES ± ½°
MEET DIMS. BEFORE PLATING
BURR ALL EDGES
CORNER RADII ON C'BORES & SPOTFACES
UP TO 1.25 DIA. .002
GREATER THAN 1.25 .005
63 MAX PER MIL-STD 10

CONTRACT NO.
SIGNATURES & DATE
DRAWN Newhouse 10-27-81
CHECKED
STRESS
WEIGHT
PROJ.
CUSTOMER

Payne inc.
Annapolis, Md.
21401

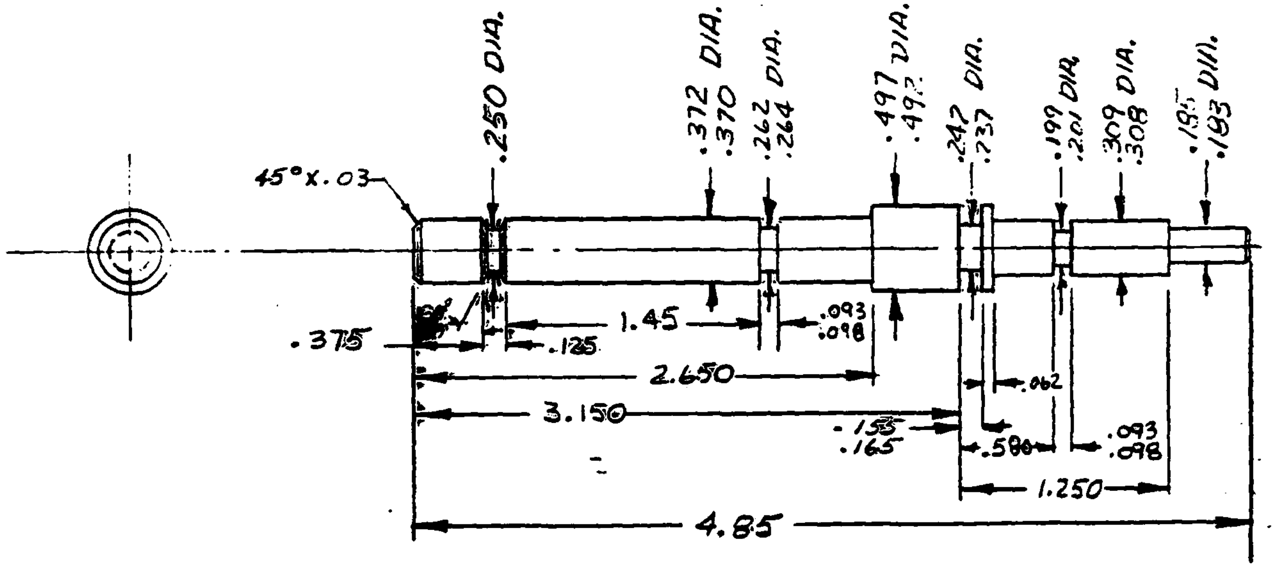
POPPET, MAIN GAS
VALVE

SIZE A
FED. CODE NO. 57433
329A16
CODE IDENT.
SCALE TWICE SIZE
WT. EST. ACT.
SHEET 1 OF 1

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30



1. REMOVE SHARP CORNERS APPROX. .005 R. ALL RADII .005/.015.

NOTES:

☒	-1	STEM	.50 DIA. CRES. STL.	TYPE 303 OR EQUIV.
	PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID. NO.

329A17-1

ODD DASH NOS. SHOWN
EVEN DASH NOS. OPPOSITE
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOL. ON .XX DIMS. ± .03
TOL. ON .XXX DIMS. ± .010
TOL. ON ANGLES ± 1°
MEET DIMS. BEFORE PLATING
BREAK ALL EDGES
CORNER RADII ON C'BORES & SPOTFACES
UP TO 1.25 DIA. .002
GREATER THAN 1.25 .005
32 MAX PER MIL-STD 10

CONTRACT NO.

SIGNATURES & DATE

DRAWN 10-27-81

CHECKED

STRESS

WEIGHT

PROJ.

CUSTOMER

Payne inc. Annapolis, Md. 21403

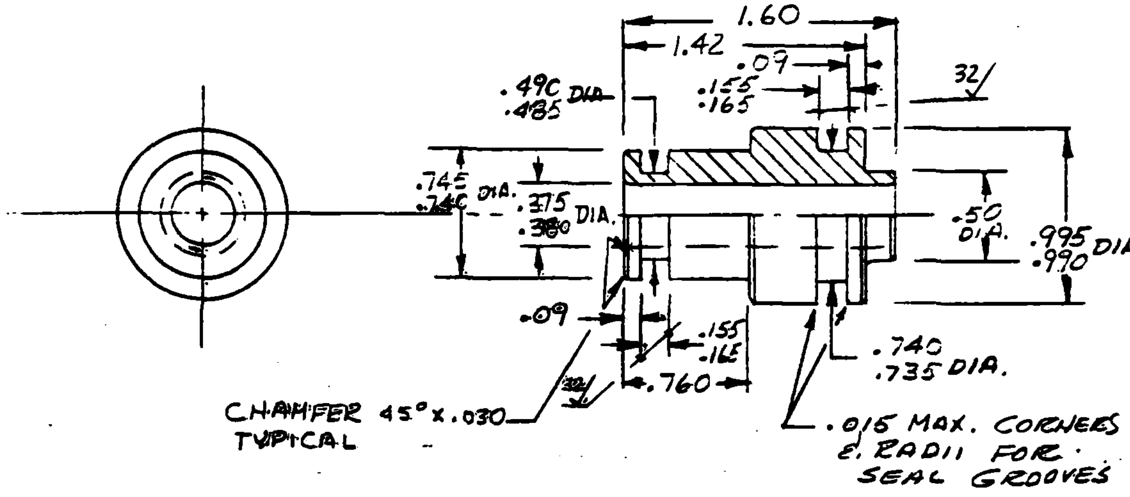
STEM, MAIN AND PILOT VALVE

SIZE A | FED. CODE NO. 57433 | 329A17 | CHGE LTR

SCALE FULL SIZE | WT: EST: ACT. | SHEET 1 OF 1

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED



PARTIAL SECTION

-1	POPPET	1.00 DIA. CRES. STL.	TYPE 303 or EQUIV.
PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID NO.

UNIT WT.

329A18-1

329 D15
NEXT ASSY / USED ON

ODD DASH NOS. SHOWN
EVEN DASH NOS. OPPOSITE
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOL. ON XX DIM. ± .03
TOL. ON XXX DIM. ± .010
TOL. ON ANGLES ± ½°
MEET DIMS. BEFORE PLATING
BURR ALL EDGES
CORNER RADII ON C'BORES
& SPOTFACES
UP TO 1.25 DIA. .01
GREATER THAN 1.25 .03
63 MAX PER MIL-STD 10

CONTRACT NO.
SIGNATURES & DATE
DRAWN Hennessee 10-27-81
CHECK
STRESS
WEIGHT
PROJ.
CUSTOMER

Payne inc.
Annapolis, Md.
21401

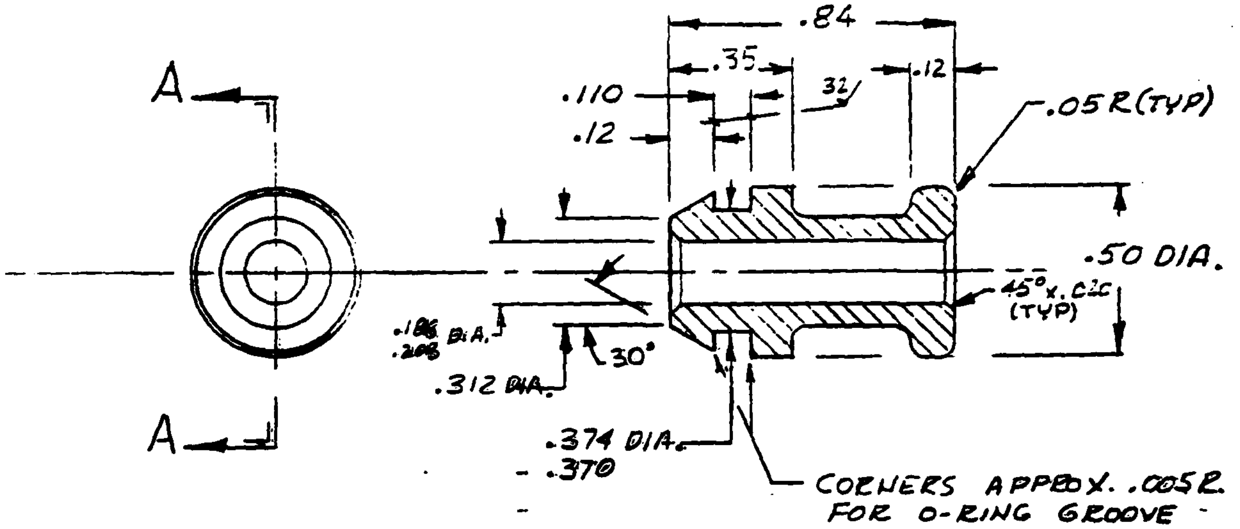
POPPET, PILOT VALVE

SIZE	FED. CODE NO.		CHGE. LTR.
A	57433	329 A 18	

SCALE: FULL SIZE WT: EST: ACT. SHEET 1 OF 1

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30



SECTION A-A

NOTE: TWICE SIZE

☒	-1	POPPET	.50 DIA CRES. STL.	TYPE 303 OR EQUIV
	PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID. NO.

329A19-1

ODD DASH NOS. SHOWN
EVEN DASH NOS. OPPOSITE
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOL. ON [illegible] ± .03
TOL. ON [illegible] ± .010
TOL. ON ANGLES ± ½°
MEET DIMS. BEFORE PLATING
BURR ALL EDGES
CORNER RADII ON C'BORES & SPOTFACES
UP TO 1.25 DIA. [illegible]
GREATER THAN 1.25 [illegible]
MAX PER MIL-STD 10
23

CONTRACT NO.
SIGNATURES & DATE
DRAWN [illegible] 10-27-81
CHECKED
[illegible]
WEIGHT
PROD.
CUSTOMER

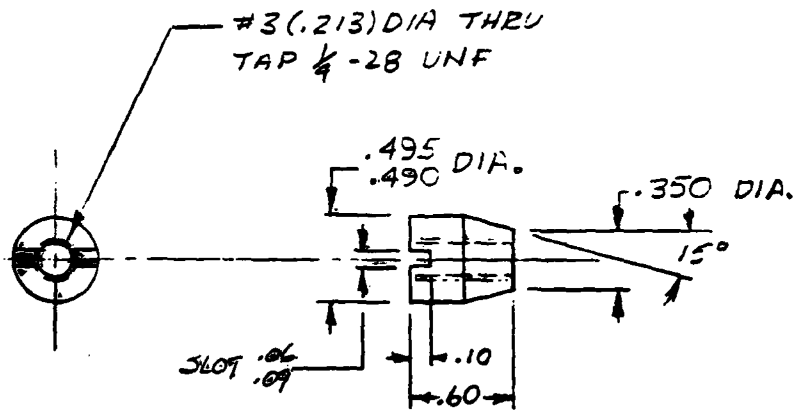
Payne inc. Annapolis, Md. 21401

POPPET, EXHAUST VALVE

SIZE	FED. CODE NO.		CHGE LTR
A	57433	329A19	

SCALE TWICE SIZE | WT: EST: ACT. | SHEET 1 OF 1

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



☒	-1	CAM	.500 DIA CRES. STL	TYPE 303 OR EQUIV.
	PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID. NO.

329A20-1

ODD DASH NOS. SHOWN
EVEN DASH NOS. OPPOSITE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOL. ON .XX DIM. ±
TOL. ON .XXX DIM. ±
TOL. ON ANGLES ±
MEET DIMS. BEFORE PLATING
BURR ALL EDGES
CORNER RADII ON C'BORES & SPOTFACES
UP TO 1.25 DIA. [illegible]
GREATER THAN 1.25 [illegible]
MAX PER MIL-STD 10

CONTRACT NO.
SIGNATURES & DATE
DRAWN [illegible] 10-27-81
CHECKED
ENGR.
DESIGN
PROD.
CUSTOMER

Payne inc. Annapolis, Md. 21401

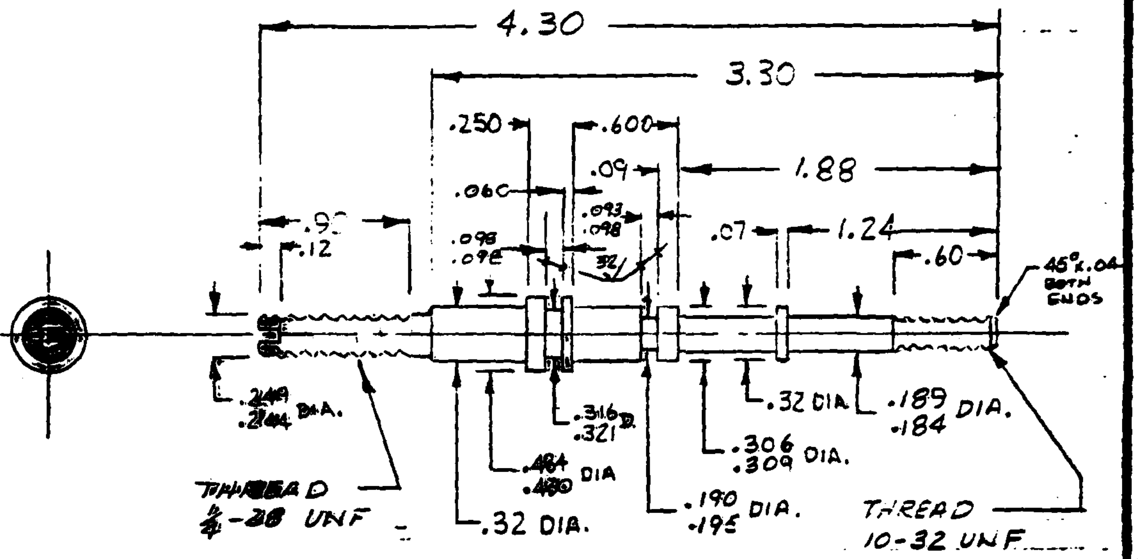
CAM, VALVE STEM LOCK

SIZE	FED. CODE NO.		CAGE LTR
A	57433	329A20	

SCALE FULL SIZE | WT: EST. ACT. | SHEET 1 OF 1

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED



1. CORNERS & RADII .005 APPROX.

NOTES:

☒	-1	STEM	.50 DIA CRES. STL	TYPE 303 OR EQUAL	
	PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID. NO.	UNIT WT.

329A21-1

ODD DASH NOS. SHOWN
EVEN DASH NOS. OPPOSITE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOL. ON .XX DIM. ± .03
TOL. ON .XXX DIM. ± .010
TOL. ON ANGLES ± 1/2°
MEET DIMS. BEFORE PLATING
BURR ALL EDGES
CORNER RADII OR C'BORES & SPOTFACES
UP TO 1.25 DIA. .005
GREATER THAN 1.25 .005
MAX PER MIL-STD 10
63

CONTRACT NO.
SIGNATURES & DATE
DRAWN New Hause 10-28-81
CHECKED
APPROVED
WEIGHT
PROD.
CUSTOMER

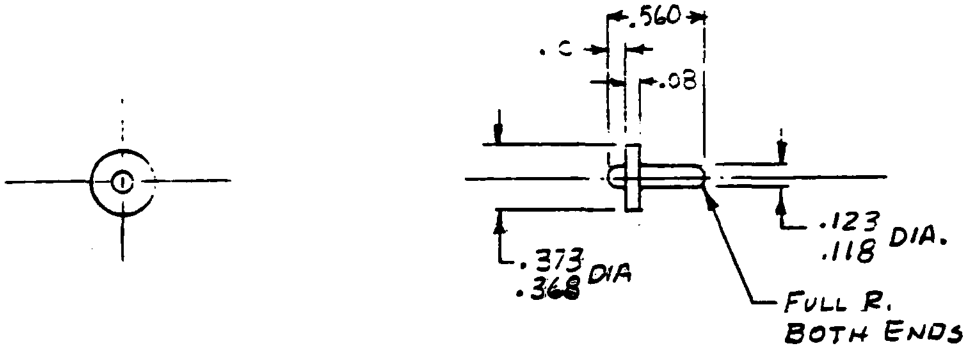
Payne inc. Annapolis, Md. 21401

STEM, EXHAUST VALVE

SIZE	FED. CODE NO.		CHGE LTR
A	57433	329A21	

SCALE FULL SIZE | WT: EST: ACT: | SHEET 1 OF 1

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



1. CORNERS & RADII
APPROX .015.
NOTES:

☒	-1	PIN	.50 DIA. CRES. STL.	TYPE 303 OR EQUIV.	
	PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID. NO.	UNIT WT.

329A22-1

ODD DASH NOS. SHOWN
EVEN DASH NOS. OPPOSITE
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOL. ON XX DIMS.± .03
TOL. ON XXX DIMS.± .010
TOL. ON ANGLES ± ½°
MEET DIMS. BEFORE PLATING
BURR ALL EDGES
CORNER RADII ON C'BORES
& SPOTFACES
UP TO 1.25 DIA. .005
GREATER THAN 1.25 .005
63 MAX PER MIL-STD 10

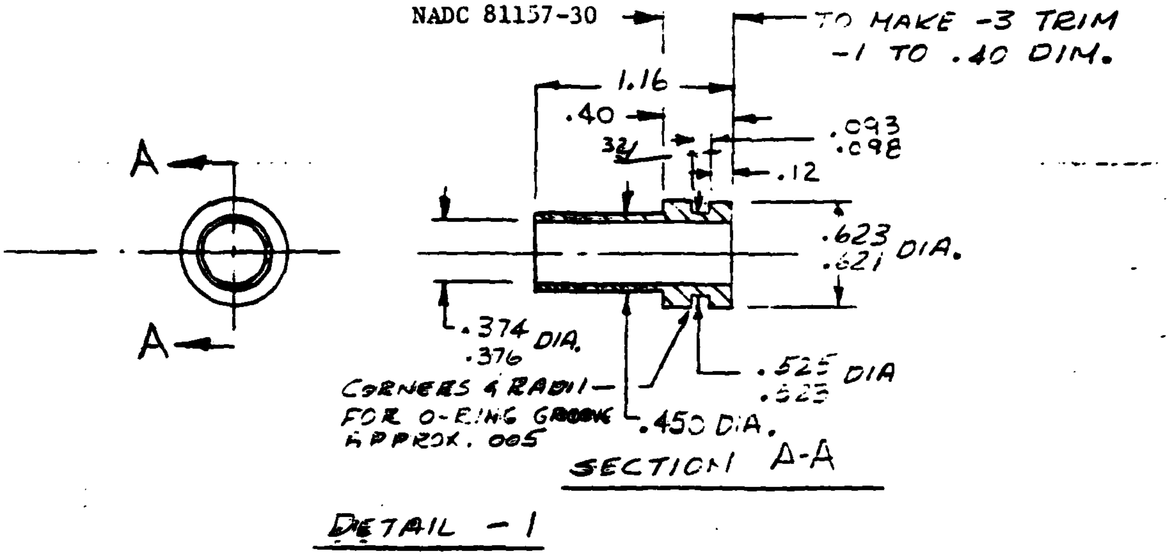
CONTRACT NO.
SIGNATURES & DATE
DRAWN 10-28-81
CHECK
STRESS
WEIGHT
PROJ.
CUSTOMER

Payne inc.
Annapolis, Md.
21401

PIN, MAIN VALVE STEM
LOCK

SIZE A
FED. CODE NO. 57433
329A22
CHGE LTR
SCALE FULL SIZE
WT. EST. ACT.
SHEET 1 OF 1

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



☒		-3	SPACER	MAKE FROM -1	
	☒	-1	SPACER	.75 DIA. CRES. STL.	TYPE 303 OR EQUIV
		PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE IDENT.

329A23-3
329A23-1
(1) 329D15

ODD DASH NOS. SHOWN
EVEN DASH NOS. OPPOSITE
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOL. ON .XX DIMS. ± .03
TOL. ON .XXX DIMS. ± .010
TOL. ON ANGLES ± 1°
MEET DIMS. BEFORE PLATING
BREAK ALL EDGES
CORNER RADII ON C'BORES & SPOTFACES
UP TO 1.25 DIA. .002
GREATER THAN 1.25 .005
63 MAX PER MIL-STD 10.

CONTRACT NO.
SIGNATURES & DATE
DRAWN Newhouse 10-28-81
CHECKED
STRESS
WEIGHT
PROJ.
CUSTOMER

Payne inc. Annapolis, Md. 21401

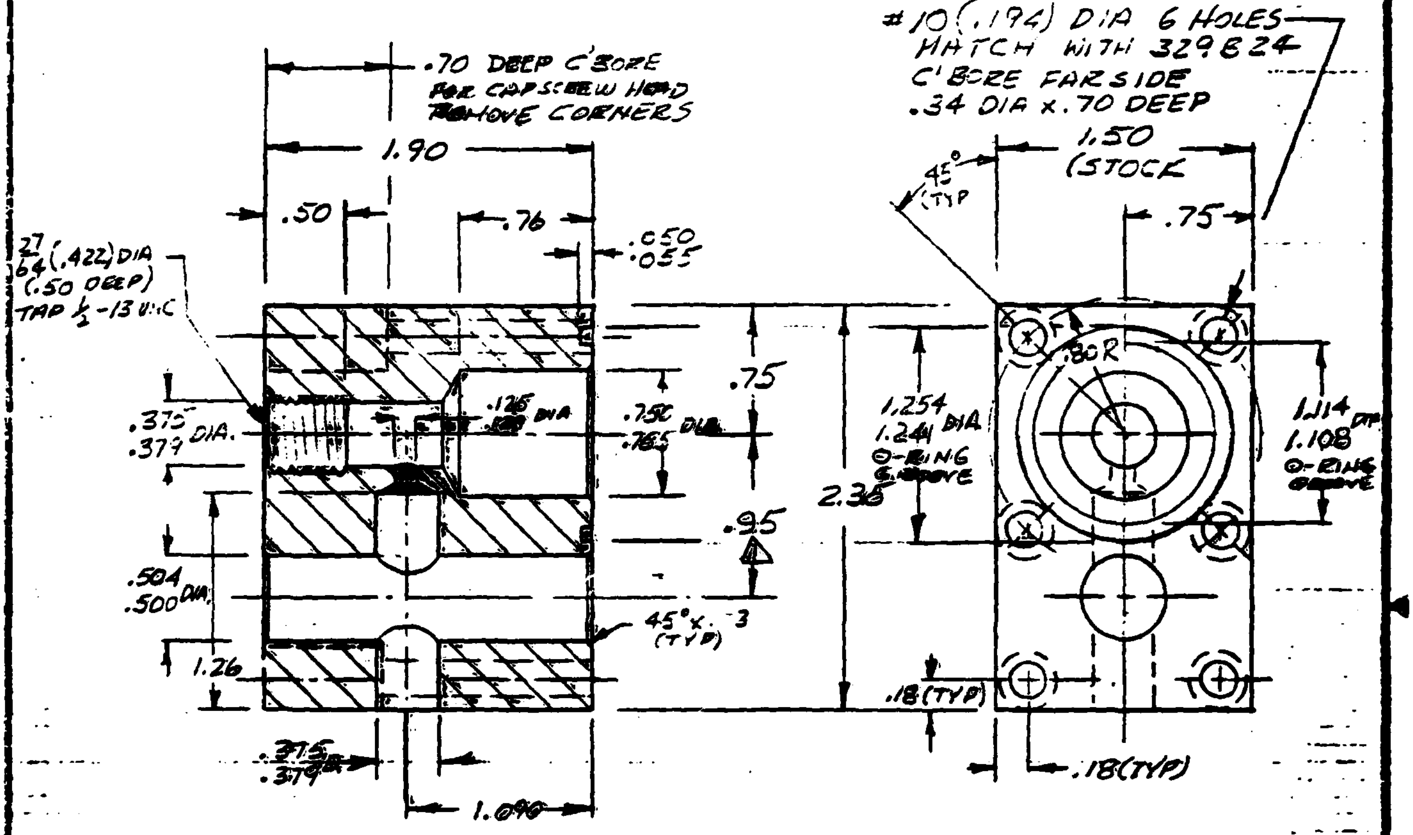
SPACER, ACCUMULATOR

SIZE	FED. CODE NO.		
A	57433	329A23	

SCALE FULL SIZE WT. EST. ACT. SHEET 1 OF 1

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

NADC 81157-30



⚠1 MATCH BORE ℄ WITH 329 B24.

NOTES:

☒		-3	HEAD	1.50 PLATE ACRYLIC	CLEAR, MIL-P-21105
	☒	-1	HEAD	1.50 PLATE CRES. STL.	TYPE 304 OR EQUIV
		PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID. NO.	UNIT WT.

329A25-1
329A25-1
(1) 3.49 F15
349 D75
NEXT ASSY
USED ON

ODD DASH NOS. SHOWN
EVEN DASH NOS. OPPOSITE
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOL. ON .XX DIM. ±
TOL. ON .XXX DIM. ±
TOL. ON ANGLES ±
MEET DIMS. BEFORE PLATING
BURR ALL EDGES
CORNER RADII OR C'BORES
& SPOTFACES
UP TO 1.25 DIA. .00
GREATER THAN 1.25 .00
63 MAX PER MIL-STD 10

CONTRACT NO.
SIGNATURES & DATE
DRAWN K 28
CHECKED
STRESS
WEIGHT
PROJ.
CUSTOMER

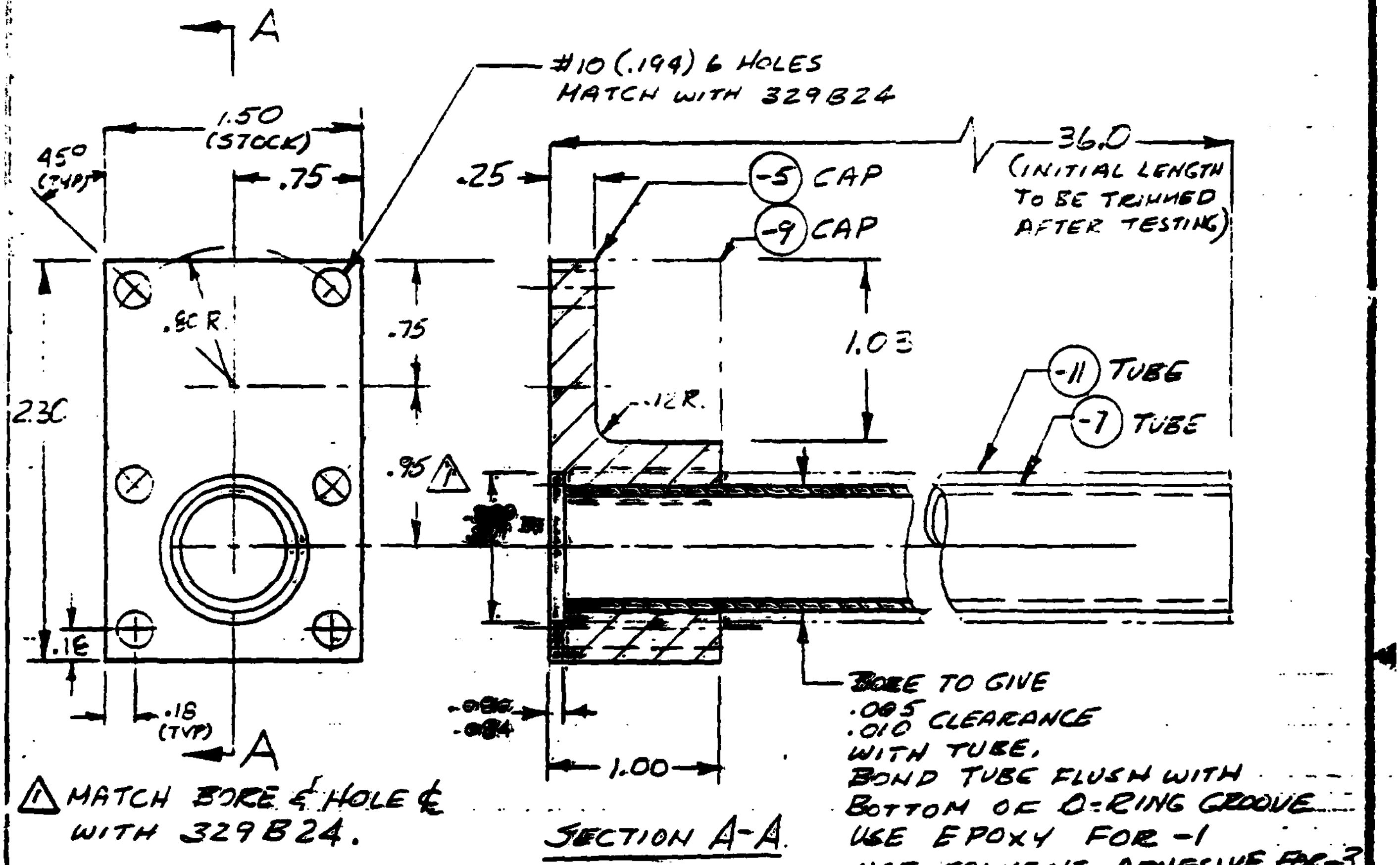
Payne inc.
Annapolis, Md.
21401

HEAD, PROPULSION UNIT

SIZE	FED. CODE NO.		CHGE LTR
A	57433	329 A 25	

SCALE Full Size | WT: EST: ACT. | SHEET 1 OF 1

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



SECTION A-A

NOTES:

1 MATCH BORE & HOLE ℄ WITH 329B24.

		PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID. NO.	UNIT WT.
1		-11	TUBE	.875 O.D. X .125 WALL TUBING	ACRYLIC MIL-P-21145	
1		-9	CAP	1.50 PLATE ACRYLIC CLEAR	MIL-P-21145	
	1	-7	TUBE	.75 O.D. X .065 WALL TUBING	CRES. STL. TYPE 304 OR EQUIV	
	1	-5	CAP	1.50 PLATE CRES. STL.	TYPE 304 OR EQUIV	
X		-3	CAP ASSY			
	X	-1	CAP ASSY			

329A26-3 329015
329A26-1 329015

ODD DASH NOS. SHOWN
EVEN DASH NOS. OPPOSITE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOL. ON .XX DIM. ± .03
TOL. ON .XXX DIM. ± .010
TOL. ON ANGLES ± ½°
MEET DIMS. BEFORE PLATING
BURR. ALL EDGES
CORNER RADII ON C'BORES & SPOTFACES:
UP TO 1.25 DIA. .005
GREATER THAN 1.25 .005
63 MAX PER MIL-STD 10

CONTRACT NO.
SIGNATURES & DATE
DRAWN 10-29-81
CHECKED
STRESS
WEIGHT
PROD.
CUSTOMER

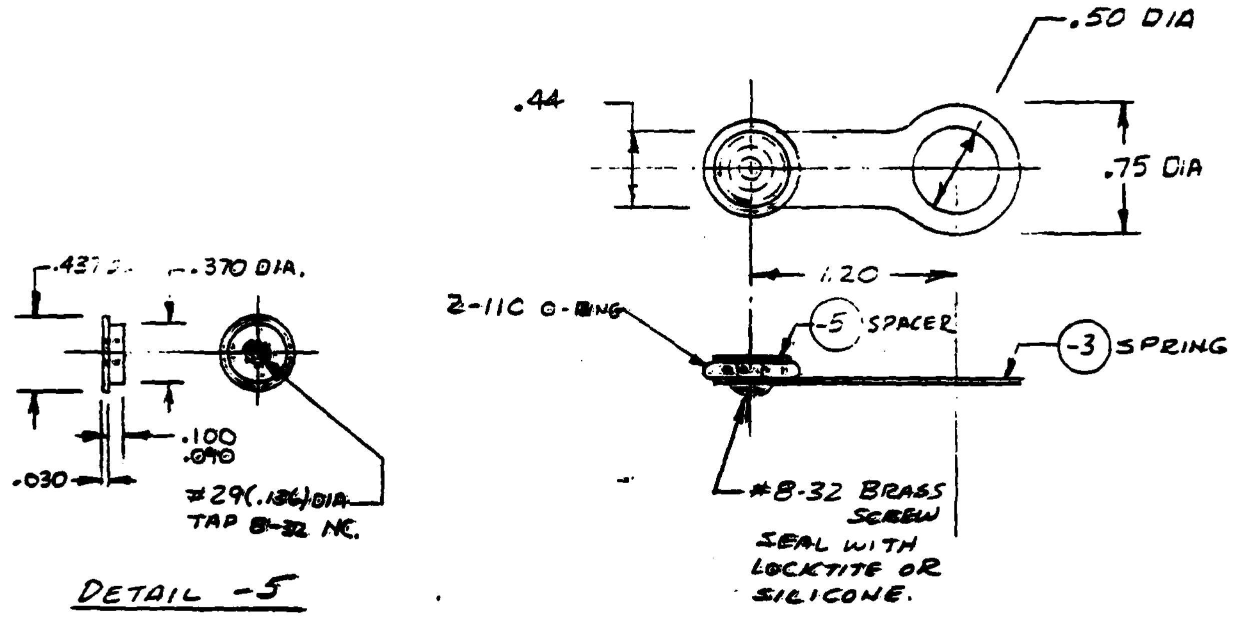
Payne inc. Annapolis, Md. 21401

CAP ASSY.,
PROPULSION UNIT

SIZE	FED. CODE NO.		CHG. LTR.
A	57433	329A26	

SCALE FULL SIZE WT: EST: ACT. SHEET 1 OF 1

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



1. REMOVE ALL SHARP EDGES.

NOTES

1	#8-32	BRASS SCREW			
1	2-110	O-RING	PARKER OR EQUIV BUNA N	SHORE A HARDNESS TO DUROMETER	
1	-5	SPACER	.50 DIA	BRASS BAR	
1	-3	SPRING	.010 SHIM STOCK	BRASS	
☒	-1	VALVE ASSY			
329A27-1	PART NUMBER	PART NAME	STOCK SIZE & MATERIAL	SPEC. OR CODE ID. NO.	UNIT WT.

ODD DASH NOS. SHOWN
EVEN DASH NOS. OPPOSITE
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOL. ON .XX DIMS. ± .03
TOL. ON .XXX DIMS. ± .010
TOL. ON ANGLES ± 1/2°
MEET DIMS. BEFORE PLATING
BURR ALL EDGES
CORNER RADII ON C'BORES
& SPOTFACES
UP TO 1.25 DIA. .005
GREATER THAN 1.25 .005
MAC PER MIL-STD 10

CONTRACT NO.
SIGNATURES & DATE
DRAWN 10-29-81
CHECKED
APPROVED
WEIGHT
PROJ.
CUSTOMER

Payne inc.
Annapolis, Md.
21401

VALVE ASSY., EXHAUST CHECK

SIZE A
FED. CODE NO. 57433
329A27
DWG. LTR.
SCALE FULL SIZE
WT. EST. ACT.
SHEET 1 OF 1