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Punch Valve Development Testing Low and High Velocity Test Results

W. C. Replogle and S. L. Brandon

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Low and High Velocity Test Results

W. C. Replogle, S. L. Brandon
Sandia National Laboratories, Livermore, CA

ABSTRACT

This is a report on the use of quasi-static tests to predict fundamental parameters for punch valve development. This report summarizes the results from low and high velocity tests performed with .63 and .38 centimeter diameter plungers, 5 centimeters long, penetrating aluminum and composite targets. The low velocity tests, .025 meters per second, were performed to understand the effects and interactions of plunger diameter, plunger tip shape, target material, and target support on penetration energy and plunger functionality. High velocity tests, 75 meters per second, were compared to low velocity results.

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Executive Summary

At Sandia we performed over 70 low velocity and 25 high velocity tests to understand the critical design parameters for developing a punch valve. The ultimate goal for the project is to design a punch valve capable of penetrating a composite target and transferring helium at 2,000 psi with a leak rate of less than 1×10^{-6} SCCS. Low velocity tests are desirable because they are simple, quick and inexpensive to perform.

We performed low velocity experiments to understand critical design variables and high velocity experiments to confirm the low velocity results. The parameters under investigation are summarized in the Table 1.

Table 1. Critical design variables for punch valve design.

Design Parameter	Style	
Plunger Tip Shape	Blunt	Sharp
Plunger Diameter	Large (.25")	Small (.125")
Target Material	Aluminum (6101, 2024)	Composite
Target Thickness	Thick (Variable)	Thin (Variable)
Backup Diameter	Large (.4")	Small (.3")

The low velocity experiments were performed on a Material Test System (MTS) 812 with velocities of .025 meters per second. The test results show that at low velocity a blunt or "cookie cutter" tip requires approximately half as much energy as a pointed tip to penetrate a target. Changing the plunger diameter from .38 to .64 centimeters required increasing the penetration energy by a factor of 2. The backup diameter has a strong effect on penetration energy for low strength materials but little effect on high strength or brittle materials. These tests confirmed theoretical calculations. Blunt plungers penetration energy scales with the square of the target thickness and the peak force scales linearly with the target thickness. The penetration mechanism, the material deformation and distance to shear, is a strong function of target material and clearance between the plunger and backup diameter. The backup diameter affects the peak force during penetration and has a significant effect on the sliding friction between the plunger and target after penetration. There are other low order effects and interactions that are discussed in the report.

High velocity tests were performed with a Sandia designed gas gun. The gas gun accelerated the 5 centimeter long plungers to velocities from 40 to 130 meters per second. This corresponds to kinetic energies between 10 and 55 joules. The usable energy from a typical actuator is 25 joules.

We calibrated the gas gun for the plungers of interest and punched targets identical to those tested in the low velocity experiments. Based on energy requirements measured in low velocity experiments for composites we were able to predict the marginal penetration energy for the gas gun within 20%.

The major conclusions for the punch valve of interest are listed below.

1. Use a concave plunger to minimize energy required for penetration energy.
2. On composites an MC 3753 actuator is marginal with a small diameter blunt plunger on thin composites and will not work with large diameter plungers.
3. Minimize the clearance between the backup diameter and the plunger diameter.
4. Minimize the plunger diameter.
5. Account for sliding friction.
6. Accommodate a "plug" of target debris on the plunger tip after penetration.

1.0 Introduction

The definition of a punch valve for this report is: A valve designed to penetrate and transfer material through a barrier. The valve is functioned by initiating an explosive, the expanding gasses accelerate a piston through the barrier and into a sealing material. After functioning, gas is transferred through a passage in the plunger.

The tests described in this report are not design specific, they are intended to investigate fundamental design parameters. The goal of the testing is to understand the energy requirements and plunger geometry effects for penetrating aluminum and composite materials. We will use the results of these tests in the design of a punch valve capable of reliably punching and delivering material through composite barriers.

We performed tests at low and high plunger velocities. The majority of tests were performed at low velocity, .025 meters per second, because of the data gathering capability of the equipment and the ease in running the experiments. Since punch valve plungers travel at high velocities, high velocity tests, 75 meters per second, were done to confirm the predictions of the low velocity experiments.

In the remainder of this report we summarize shearing mechanisms, the test hardware, test setup, experimental matrix, and test results for both low and high velocity testing. We compare the low and high velocity test results and draw design specific conclusions applicable to punch valve design.

2.0 Quasi Static Testing

In this section of the report we discuss the low velocity or quasi static shear formulas, test hardware, test setup, experimental matrix, and test results.

2.1 Shearing formulas

The two variables that are relevant to punch valves are force and energy. In this section we summarize the shear formulas used for calculating the peak force and work. We also note the equation for calculating pooled standard deviation since it is used throughout the document.

The shearing force is directly proportional to the shear stress multiplied by the area sheared¹

$$\sigma_{sy} = \frac{f}{A} = \frac{f}{(\pi \times d \times t)}$$

Where:

σ_{sy} = the shear strength

f = peak applied force

d = plug diameter

t = plug thickness

Solving for force:

$$f = \sigma_{sy} \times \pi \times d \times t$$

In practice the actual shearing force also depends on the resistance to shear " s "². So the peak required force is given by:

$$f = s \times \pi \times d \times t$$

Where s = resistance to shear in units of load per distance squared.

Since work is force multiplied by displacement, the energy to shear a plug is calculated as follows.

$$= \int_{x=0}^{x=kt} f \times dx$$

For constant force the work becomes:

$$= \sigma_{sy} \times \pi \times d \times t^2$$

But this is only for ideal cases in pure shear. In actuality the force is not constant and usually not applied throughout the thickness of the material. The assumption of constant force is not a good one, but for the purpose of this investigation it is adequate. According to Mark's Standard Handbook for Mechanical Engineers the actual shear work will be 20 to 80% less than the maximum force multiplied by the thickness, depending on the clearance and the material. Thus the work is given by:

$$= c(\sigma_{sy} \times \pi \times d \times t^2) \quad \text{Where } .2 \leq c \leq .8$$

In order to calculate the work the constant c must be determined experimentally as a function of clearance and material. In this report we will refer to clearance as the difference in the diameter of the plunger and the hole in the supporting plate.

We performed many low velocity experiments to study many aspects of punch valve design. To utilize the greatest number of tests in calculating standard deviations the method of pooling standard deviations was used. The equation for pooled standard deviations is shown here for reference³.

In general, if g sets of experimental conditions are genuinely replicated and the n_i replicate runs made at the i th set yield an estimate S_i^2 of σ^2 having $\nu_i = n_i - 1$ degrees of freedom, the pooled estimate of run variance is

$$S^2 = \frac{\nu_1 S_1^2 + \nu_2 S_2^2 + \dots + \nu_g S_g^2}{\nu_1 + \nu_2 + \dots + \nu_g}$$

With $\nu = \nu_1 + \nu_2 + \dots + \nu_g$ degrees of freedom.

2.2 Test Equipment

The Material Testing System (MTS) test equipment consists of an MTS 812 Test System, Shown in Figure 1, controlled by an MTS Test Star controller. The test system is a 20kip load frame and actuator mounted on an MTS bench-top unit with an internal hydraulic power supply. The Test Star software is run on a Compaq 3/25i Desk Pro system. Load and displacement data is provided by the MTS stroke transducer and MTS load cell. The stroke transducer is an LVDT with a range of ± 5 inches (12.7 centimeters). The load cell is a 20kip load cell.

Figure 1. Material Testing System.

A typical hardware setup is shown in Figure 2. When a test is performed the plunger is driven through the target. Force and displacement data is taken until the plunger tip is several diameters through the target. Note that the diameter of the plug sheared from the target is nearly the same as the plunger not the backup diameter.

Figure 2. Low velocity test hardware.

The carrier plate is for plunger alignment and for clamping the target to the receiver plate. The receiver plate has a larger diameter hole than the carrier plate, this diameter is referred to as the backup diameter throughout this report. The receiver plate also has a counter-bore for positioning the target. The carrier and receiver plates are 316 stainless steel. The entire assembly is fastened with six .25-20 UNC screws.

The plungers used to penetrate the targets were made from Custom 455 Stainless Steel heat treated at 950F for 4 hours and cooled in an inert environment. This solution annealed 455 has a yield strength of 230 ksi and tensile strength of 240 ksi. (Custom 455 is a trade name, the material is essentially PH 14-8 Mo age hardenable stainless steel.) Two types of plunger tips and two plunger diameters were used. The plunger shown in Figure 1 has a pointed conical tip. A convex tipped plunger or "cookie cutter" was also used in many tests. Plunger geometry details relating to the experiments are discussed in section 2.3.

2.3 Design Variables.

The goal of the testing is to quantify energy requirements as a function of plunger geometry and target material. Variables investigated include plunger tip shape, plunger diameter, target material, target thickness, and target backup diameter.

We investigated two types of plunger tips typically used in explosively actuated valves; blunt and pointed. Plungers with blunt tips are used extensively in mini

valves and pointed plungers are frequently used in punch valves. The tip shapes are shown in Figure 3.

The pointed tip has a larger included angle than most plungers. The tip angle was chosen to illustrate the difference between blunt and pointed plungers. A longer tip with a gradual taper is standard but the diameter required to avoid buckling is large and a gradual taper would result in an excessively long plunger.

The dotted lines shown in Figure 3 approximate the gas transfer path for each plunger type. These paths were not machined in the plungers for these tests. The gas outlet holes were drilled to investigate the possibility of material clogging the outlet during functioning.

Figure 3. Plunger tip geometries.

The plunger diameters were selected to cover the range of possibilities for a composite penetrating punch valve. The small diameter, .38 centimeter was selected as a minimum diameter based on material transfer and buckling. The small diameter plunger is just small enough to penetrate the composite materials without buckling or fracturing and yet not so small that the gas transfer path causes choked flow during transfer.

The large plunger diameter is limited by penetration energy. A large plunger has ample room for a gas transfer path but can require excessive energy to penetrate the materials. For these reasons and based on our experience, i.e. the inventory of plungers in Sandia designs, a large diameter of .64 centimeters was selected.

We used two types of target materials in these tests, aluminum and composites. Aluminum was used because it is a candidate material for the sealing portion of the punch valve and it is also part of the composite material. All of the aluminum targets were made from heat treated bar stock. We investigated relatively high and low strength aluminum. The high strength aluminum was 2024 with a T3 heat treatment and the low strength aluminum was 6101 with a T6 heat treatment. Tabulated

properties for these materials are shown in Table 2⁴. The thickness of aluminum investigated were .16 and .32 centimeters.

Table 2. Material properties of aluminum targets.

Aluminum Type	Tensile Strength	Yield Strength
2024	70ksi (T3)	50ksi (T3)
6101	32ksi (T6)	28ksi (T6)

The composite materials were fiberglass bonded to aluminum. Composite targets were investigated because they are typical materials found in aerospace system structures. The thin composite we called C1 was .64 centimeters thick; .53 centimeters of fiberglass and .11 centimeters of aluminum. The thick composite we called C2 was 1.0 centimeters of fiberglass and .25 centimeters of aluminum.

The final parameter related to target material is the clearance between the plunger and receiver plate. This was varied by changing the backup diameter and by changing plunger diameters. The backup diameter is illustrated in Figure 2. Ideally a backup diameter should be a few mils larger than the plunger diameter. The result of closely matched diameters is an efficient shear of the target material. The problem with this type of design is aligning the plunger and backup diameter. This problem is compounded for punch valves because the components are assembled blind. One side of the valve contains the actuator and plunger and the other side of the valve catches or receives the plunger during functioning. During the valve assembly the two halves of the valve must be aligned on opposite sides of the target. For this reason generous backup diameters of .76 and 1.04 centimeters were chosen.

The critical parameters for penetration energy are summarized in Table 3.

Table 3. Critical design variables for punch valve design.

Design Parameter	Style	
Plunger Tip Shape	Blunt	Sharp
Plunger Diameter	Large (.25")	Small (.125")
Target Material	Aluminum (6101, 2024)	Composite(.25", .50")
Target Thickness	Thick (Variable)	Thin (Variable)
Backup Diameter	Large (.4")	Small (.3")

2.4 Test Set-Up and Operation

The tests were setup with the plunger attached to the load cell. The carrier, target, and receiver assembly were attached to the actuator. The Test Star system provides both manual and software control of the test system. With the test fixtures in place the actuator was manually adjusted to find the stroke position for the plunger to penetrate the specimen but not hit the bottom of the receiver center hole. This position was determined for both diameters of the sharp tipped and concave tipped plungers and used for the software test control.

For test control a Test Star SX program was created for each type and diameter of plunger. The difference in the programs is the end level or stroke position at the end of the test. The programs are included in the appendix. The software ramps the actuator using stroke feedback for control to the predetermined stroke position. The time to reach the end level is set to 1 second to achieve the maximum stroke rate of 1 inch/second (.025 meters/second). The program also acquires data from the load cell and stroke LVDT during the test. Level crossing data is acquired for every .001 inch (.0025 centimeters) change in the stroke. The data is then stored in a data file on the disk.

2.5 Data Reduction

The data files from the programs consist of three columns of ASCII data: Displacement, Time, and Load. Microsoft Excel was used to reduce and plot the data. First a load vs. displacement curve was plotted. We numerically integrated the shear area to determine the shear work. The key to calculating the shear work was selecting the end point for the integration. The starting point is simply where the load first increases. The end point is selected based on the rate of change of the slope at the end of the shear. Most of the data had an abrupt change in slope between the shear force and the sliding friction force. This transition defined the endpoint of the shear energy.

2.6 Experiments Performed.

We performed five experiments consisting of over 70 tests on the MTS. In this section the goal for each experiment, the test matrix, and test are summarized. The experiments are reviewed in the following order:

1. Scoping experiments
2. 6101 (T6) aluminum
3. 2024 (T3) aluminum
4. C1 composite
5. C2 composite

2.6.1 Scoping Experiments

We began the testing with a set of scoping experiments. The goal of the scoping experiments was to gain a qualitative understanding of the effects of the variables and develop a repeatable procedure for testing and data reduction. Several sets of experiments were performed. The target materials included aluminum, silver, pewter, and fiberglass. There was no material specification available for the aluminum used in the scoping experiments. (Silver and pewter were included because they are candidate materials for a seal design. The seal design is beyond the scope of this report and only the results relative to penetration energy are discussed.)

We performed several small full factorial experiments with duplicate runs. The experiments met the goals stated above. The Scoping experiments showed a large first order effect from the plunger tip shape and plunger diameter. The backup hole diameter effects were small compared to the effects of the plunger geometry. The test data for silver are shown in Figure 4. The data from silver is shown because it best illustrates the trends in the testing.

Figure 4 shows the independent effects of plunger diameter and tip shape. The plunger diameter affects the peak force for penetration. The tip shape is reflected in the shape and width of the force-displacement plots. The sharp tip causes considerably more deformation of the target than the blunt tip, resulting in a longer distance to penetration and a higher total energy than a blunt tip. Tip shape and plunger diameter are dominant factors for penetration energy. These are important trends for designing a punch valve.

Figure 4. Typical force displacement data illustrating plunger geometry effects.

A sharp tip also increases the required penetration distance. The penetration distance is important because of the energy lost to sliding friction and the effect on the size of the valve. The plunger length is determined by the tip shape and material outlet location. The pointed tip deforms the target and the plunger must penetrate further for the material outlet to clear the deformed material. To avoid clogging the material outlet must be located behind the tip taper, thus the plunger must penetrate farther through the target than for a blunt plunger. Figure 5 illustrates the longer penetration distance required for a pointed plunger due to target deformation and material outlet location.

Figure 5. Effect of plunger tip on target penetration distance.

2.6.2 6101 Aluminum

The next experiment we performed was on 6101 (T6) aluminum. The goal of this experiment was to quantify the effects seen in the scoping. We also wanted to establish a database on the repeatability of our procedure. For these reasons we limited the variables to plunger diameter and tip shape and ran duplicate tests. The experiment is summarized in Table 4.

The trends from 6101 (T63) aluminum are the same as the scoping experiments but allowed us to quantify them. Figures 7 and 8 show the force displacement data taken during the experiment. Note the difference in the load scales when comparing the large and small diameter data.

Table 4. 6101 Aluminum experimental set-up and calculated energies.

Small Diameter Plunger		Large Diameter Plunger	
Run #	Energy	Run #	Energy
Blunt Tip	1 10.5 Joules	2 18.2 Joules	
	8 10.9	7 20.4	
	9 11.7	11 20.1	
	10 10.4	12 16.8	
Sharp Tip	3 24.4 Joules	4 48.8 Joules	
	6 24.0	5 47.6	
	13 22.7	15 47.6	
	14 23.1	16 47.5	

6101 Aluminum - Large Plunger

Figure 6. Tip shape effect on energy for .64 centimeter diameter plungers.

6101 Aluminum - Small Plunger

Figure 7. Plunger tip shape effect on energy for .32 centimeter plungers.

Figures 6 and 7 are typical for the data taken on 6101 aluminum. The repeatability of the tests is evident from viewing the graphs. The error in the energies is random in both the experiment and the data reduction. The pooled standard deviation for the energies is 1.1 J with 12 degrees of freedom.

Table 5. 6101 Aluminum experimental results.

Plunger Tip	Small Diameter Plunger		Large Diameter Plunger		Diameter Effect
	Average Energy	Standard Deviation	Average Energy	Standard Deviation	Increase In Punch Energy From Diameter
Blunt	10.9 J	0.6	18.9	1.7	74%
Sharp	23.6 J	0.8	47.9	.6	103%
Increase in Punch Energy From Tip Shape	117%		153%		

Table 5 summarizes the test results. For low velocities a blunt tipped plunger requires 10 to 20 joules of energy to penetrate the target and a sharp tip requires as much as 50 joules. Test data shows that increasing plunger diameter results in a 74% increase in penetration energy for a blunt tip plunger, and a 103% increase for a sharp tipped plunger. For constant diameter the increase in energy when changing from blunt to sharp tips is 117% for small diameter plungers and 153% for large diameter plungers. These energy increases are based on the difference between the average penetration energies for the respective plunger types.

The shear resistance based on blunt tipped plunger data was 19,200 psi with a pooled standard deviation of 300 psi with 6 degrees of freedom. As a point of reference the calculated peak force based on shear strength was 20% lower than the measured values. The peak forces are mainly of interest to the designer if there is a chance for buckling the plunger.

The shear constant based on the blunt tipped data was .83 with a pooled standard deviation of .06 with 6 degrees of freedom. The shear constants for the blunt tipped plungers were 1.75 and 2.14 for the small and large diameter plungers respectively. This is beyond the expected range for shearing but the pointed plungers are not acting in pure shear. In fact the pointed tip probably deforms material radially as well as axially during penetration. A large portion of the energy in penetrating with a pointed plunger is expended in deforming the target not shearing. Because of the shear mechanism the constant "c" described in section 2.1 is not applicable to pointed plungers.

2.6.3 2024 Aluminum

The next series of tests were performed on 2024 (T3) aluminum. The purpose for these tests was to understand effects of material strength on penetration energy and the effect of backup diameter on sliding friction. Since repeatability and tip shape trends were established, and to save targets for the high velocity tests, fewer tests were performed and only blunt tips were used in this experiment. The test matrix is shown in Table 6.

Table 6. 2024 Aluminum experimental set-up and calculated energies.

Large Diameter Plunger			Small Diameter Plunger		
	Run #	Punch Energy Friction Energy		Run #	Punch Energy Friction Energy
Large Backup Diameter	3	18.9 J 89.1 J/in		5	12.7 J 1.6 J/in
	4	18.7 129.		6	13.3 3.1
Small Backup Diameter	1	15.0 J 30.8 j/in		No Tests Performed	
	2	15.5 30.0			

2024 Aluminum Large Plunger

Figure 8. Backup diameter effects on 2024 aluminum.

Figure 8 illustrates the effects of backup diameter on penetration energy and sliding friction. The force-displacement data plots are wider for the larger diameter backup. The differences in the shearing mechanism are visible in the test samples. The holes in the small diameter backed samples have a coarse serrated appearance. The holes in the large diameter backed samples are smooth and shiny from the plunger sliding through. The exit diameter is also smaller for the large diameter backed sample. Sketches of the cross sections are shown in Figure 9.

Figure 9. Effect of backup diameter on hole in target material.

The evidence from the test samples suggest the backup diameter affects the shearing mechanism. A portion of the plunger's energy is used to deform the target. The large diameter backup allows more deformation of the target. The plunger deforms the target until the target fails. As a result the target is extruded into the backup diameter until it fails, then the plunger slides through the deformed material.

The smaller diameter backup supports the target and the target fails sooner than for the large diameter backup. The result is a target with a larger diameter hole and a force-displacement curve that has a higher peak and shorter distance to shear.

Figure 10 is a graph where data from 2024 aluminum is superimposed on data from 6101. The profiles are clearly different. The higher strength 2024 rises to a higher load and shears sooner than the 6101. The width of the 6101 data illustrates the energy used to deform the target. The plugs from the tests match the sketch shown in Figure 9. The high strength material shears a larger, jagged hole in the target and the hole from the 6101 is smooth from the plunger squeezing through the deformed target. The implication is that for high strength aluminum the backup diameter effects are smaller than for lower strength aluminum. In general for aluminum targets a smaller backup diameter will take less energy to penetrate and large diameter backups will provide a better sealing capability.

Figure 10. Strength of material effect on energy profiles.

The 2024 and 6101 aluminum were chosen because they span the strength of materials range anticipated for punch valve applications. We expected higher penetration energies for the high strength material but the calculated energies were similar. The average penetration energy for a large diameter blunt tip plunger in 6101 is 18.9 joules. The average energy for the same plunger in 2024 is 15.3 joules. The explanation for calculating similar energies in different strength materials is in the shape of the force displacement plots. The higher peak and shortened distance to shear for the 2024 results in a similar net energy as the short and wide profile of the 6101.

Based on the peak loads for the 2024 aluminum the average resistance to shear with a small diameter backup was 44,500 psi and for a large diameter backup was 43,200 psi. These averages were based on a total of four runs. The spread in the data for a given diameter was less than 5%.

The shear constant for the 2024 was .38 for the small diameter backup and .47 for the large diameter backup. This data also was repeated to within 5%.

The sliding friction is the friction between the plunger and the target after penetration. The energy lost to friction is characterized by the magnitude of the force after the target is sheared. In Figure 8 the data for the large backup diameter shows a load several orders of magnitude greater than that of the small backup diameter. This is because the backed up target shears a hole of increasing diameter that allows the plunger to pass nearly untouched. The large backup diameter fails in such a way that the plunger is in contact with the target throughout the target thickness. This effect is evident in the large energy losses to friction.

For 2024 aluminum the backup diameter effects on frictional energy losses were not evident for small diameter plungers. This is because the energy lost to friction is a function of the clearance between the plunger and backup diameter and with the

small plunger the clearance is always relatively large. For the large diameter plunger the clearance ranges from .13 to .38 centimeters and for the small plunger the clearance ranges from .38 to .64 centimeters.

Reviewing the data from the 6101 aluminum (note that all runs had a small backup diameter) the average energy loss to friction for large diameter blunt tipped plungers was 34 joules per inch (13.4 joules per centimeter). For 2024 aluminum, large diameter plungers lose between 30 and 130 joules of energy per inch (11.8 and 51 joules per centimeter) depending on the backup diameter. For the large plunger the frictional energy losses are significant considering the average penetration energy for these plungers is 18.9 joules. The implication to the valve designer is to minimize the backup diameter and account for frictional losses based on clearance, material strength, plunger diameter and penetration distance.

2.6.4 A1 Fiberglass Composite

Next we performed tests on fiberglass bonded to aluminum. The first set of tests was performed on .47 centimeter thick fiberglass bonded to .10 centimeter thick aluminum, see Figure 11. The goals for the tests were to see if plunger geometry trends are the same as for aluminum and to quantify the penetration energy.

Figure 11. 1A Fiberglass / aluminum composite.

We performed a 2^3 full factorial experiment with duplicate runs to investigate plunger diameter, plunger tip shape and backup diameter effects. The experimental matrix and results are summarized in Table 7.

The resistance to shear for the large diameter blunt plungers is 16 200 nsi with a
 Table 7. .64 Centimeter composite experimental set-up and calculated energies.

		Small Diameter Plunger		Large Diameter Plunger	
		Small Backup Diameter	Large Backup Diameter	Small Backup Diameter	Large Backup Diameter
		Run #	Energy	Run #	Energy
Blunt Tip		2	17.1 J	1	14.9 J
		12	16.2	16	15.5
Sharp Tip		6	28.7J	7	27.4 J
		14	31.6	10	30.0

Figure 12. Large diameter, blunt tipped data from .64 centimeter composite.

Figure 13. Large diameter, sharp tipped data from .64 centimeter composite.

Figures 12 and 13 show the large plunger force versus displacement data for the C1 composite. The data profiles resemble those from the aluminum. A blunt plunger results in a narrow truncated profile and a sharp plunger gives a wide triangular profile.

The tip shape has a profound effect on the penetration energy. In all cases for the C1 composite the sharp tipped plunger required more than twice the energy than the blunt plungers of the same diameter. The data indicates the plunger must have at least 30 to 70 joules of energy just to penetrate the C1 composite.

Quantitative analysis of blunt plunger data shows an average increase of 50% in penetration energy between the small and large plunger diameters. For all the data the backup diameter effects are minimal and appear primarily in the peak forces. The small diameter backup results in higher peak forces. The backup diameter effects are diminished because of the high strength and brittle nature of the composite. It is interesting to note that the effect of backup diameter is reversed relative to the data on aluminum. For the composite, it requires more energy (due to the increased force) to penetrate a target with a small backup diameter. The sliding friction is also reversed. For a large plunger the frictional force is greater with a small backup diameter.

It is important to note that the plug of target material carried with the plungers varied with plunger tip shape. The plug carried by the sharp tip is large and tattered. In many cases with a sharp tip the plug had strands of fiberglass that broke off at the backup diameter not the plunger diameter. The plugs with the blunt plungers were more uniform and cylindrical. The implication to punch valve design is that in the gas transfer and seal design the geometry of the plug must be accounted for.

The resistance to shear for the large diameter blunt plungers is 16,200 psi with a standard deviation of 1,460. The resistance to shear for the small diameter blunt plungers is 14,700 psi with a standard deviation of 480.

Considering all the data, a good rule of thumb for aluminum backed fiberglass is that the energy is directly proportional to the plunger diameter. Changing from a blunt to a pointed tip required twice the penetration energy. Just as with aluminum a blunt tip is the preferred design. The relative effects of the variables in this experiment are illustrated in Figure 14.

Figure 14. Scoping experiment level effects for C1 composite.

2.6.5 C2 Fiberglass Composite

The next experiment was performed on a thicker composite. The C2 composite is 1.0 centimeters thick bonded to .25 centimeter thick aluminum. The goal for this experiment was to develop a correlation for penetration energy as a function of composite thickness. The experimental matrix and calculated energies are summarized in Table 8.

Table 8. 1.27 centimeter composite experimental set-up and calculated

		Small Diameter Plunger		Large Diameter Plunger	
		Small Backup Diameter	Large Backup Diameter	Small Backup Diameter	Large Backup Diameter
		Run # Energy	Run# Energy	Run # Energy	Run# Energy
Blunt Tip	2 Plunger Failed		No Tests Performed	4 96.9 J	5 101 J
				9 104	6 96.3
Sharp Tip	3 Plunger Failed		No Tests Performed	1 168	7 167 J
				8 160	10 171

In tests 2 and 3 the plungers buckled, only dimpling the aluminum. The peak force before failure was 2,000 pounds, which agrees with buckling data taken in the scoping experiments. Assuming the penetration energy scales as it did for the C1 composite the small diameter plunger would see a peak force of approximately 3,250 pounds before shearing the C2 composite. (The average peak load for the C2 material is 6,500 pounds). Based on the large diameter results there was no chance to penetrate the thick composite with the small diameter plunger so the remainder of small plunger tests were dropped from the matrix.

Type 2B Composite

Figure 15. Blunt plunger energy profiles for C2 composite.

Type 2B Composite

Figure 16. Pointed plunger energy profiles for C2 composite.

Figures 15 and 16 show the data gathered for the C2 composite. The profiles are typical for the plunger geometry. The blunt plunger data scales well with the C1 data. The C2 composite is twice as thick and required 2.0 times as much force to penetrate. The penetration energy has increased approximately as the square of the thickness, requiring 4.3 times as much energy as the C1 composite. Based on this data the plunger geometry and penetration energy trends are predictable for blunt plungers at low velocity.

The resistance to shear for the C2 material is 16,300 psi with a standard deviation of 660 psi. This agrees well with the calculated value for the C1 material of 16,200 psi with a standard deviation of 1,460 psi. This agreement is not surprising because the resistance to shear is based on measured force which scaled well. The usefulness of the consistent value of resistance to shear for large diameter blunt plungers is in predicting future loads and energies for other similar targets.

The force and energy data from the sharp tipped plunger penetrations did not correspond with shear theory. This was not surprising since the sharp tip does not penetrate with pure shear. At this point it was determined that sharp tipped plungers are not considered a good design option.

3.0 High Velocity Testing

In this section of the report we discuss the high velocity test plan, equipment, procedure, data reduction method, and experiments performed. The goal of this testing was to see if the lessons learned from low velocity tests hold true at high velocity.

3.1 Test Equipment

We modified a Sandia designed gas gun to perform the high velocity testing. A gas gun is a device that uses compressed gas to accelerate projectiles, or in this case plungers, to high velocities. The velocity achieved depends on the projectile mass and the gas pressure. The velocity is measured at the end of the barrel of the gas gun just before the plunger strikes the target. The velocity is measured by 3 light beams that are spaced axially at 1.27 centimeter intervals at the end of the barrel. When the light beams are interrupted by the plunger an oscilloscope is triggered and saves the time-trigger data for the test. Three velocities are calculated based on the light beam data. Typically a second set of light beams are utilized to measure the velocity of the plunger after penetrating the target but due to the large diameter backup this feature was not useable.

Figure 17 is a picture of the gas gun used for these experiments. Figure 18 is a simplified sketch of the gas gun to illustrate the key features. For detailed investigation of the gas gun components the drawing numbers are included in the appendix.

Figure 17. Gas gun used for high velocity testing.

Figure 18. Key features of the gas gun.

3.2 Test Setup and Operation

The functioning of the gas gun takes place in 5 steps.

1. The gas reservoir is pressurized
2. The solenoid holding the plunger is actuated
3. The foil diaphragm separating the pressure vessel from the plunger fractures
4. The plunger is accelerated down the barrel until it passes the vents
5. The vents relieve the pressure behind the plunger and the plunger remains in free flight through the light beams into the target.

In order to achieve the desired kinetic energy the gas gun must be calibrated. The calibration is done by firing a number of plungers at different pressures and measuring the velocities. From this data, and the mass of the plunger, a calibration curve relating pressure to kinetic energy can be created.

We generated a calibration curve, a straight line, based on 25 tests with no targets. We continued to add data as actual tests with targets were performed. The final calibration plot is shown in Figure 19. The Equation for a line drawn through these points is

$$KE = .022 \times P$$

where KE is kinetic energy in joules and P is pressure in psi.

GAS GUN CALLIBRATION

Figure 19. Calibration curve for the gas gun.

3.3 Data Reduction

The data from the gas gun experiments was in the form of time and distance points recorded on the Nicolet 4175. Since the distance between the light tubes was known the data reduction consisted of gathering the time data from the Nicolet and calculating the velocities. The key to consistent data reduction was in selecting the velocity to calculate the kinetic energy. As mentioned above three velocities can be calculated based on the light beam data. The velocity between the first two tubes, between the middle and last tube and between the first and last tube. We calculated all three velocities and for all but one run the plunger was always accelerating. The difference in velocities was typically 3 or 4 %.

The velocity between the second and third light tubes was used for calculating the kinetic energy since they were the closest to the target. Since the kinetic energy is proportional to the velocity squared, the error in the velocity measurement is magnified in the calculated energy. Furthermore since the velocity is always increasing this is a systematic error and the calculated energies should be consistently lower than the actual plunger energy at the target. If the plunger has constant acceleration between the first light tube and the target the velocity should be approximately 4% greater at the target than the calculated value (the target is 1.27 centimeters from the last light tube. The result would

be an underestimate of the kinetic energy by approximately 8%. This does not account for the variability in the gas gun.

The error in the calibration curve is not relevant since the velocity is measured independent of the gas pressure.

3.4 Experiments Performed

There is a limited window for gathering useful information from the gas gun. Since we could not utilize light beams behind the target we only learn from the plungers that achieve partial penetration. Plungers that pass through the target have an unknown quantity of excess energy and only signify that we had more than enough energy. The plungers that do not penetrate the target and the plungers that remain lodged in the target offer the most information. In performing the tests we selected pressures that should result in partial penetrations based on the low velocity data. We defined the penetration distance as the distance from the back of the target to the tip of the plunger.

The backup diameter for all the high velocity experiments was 1.22 centimeters.

In this section we summarize the results from tests performed on the same materials as in the low velocity testing. We review the tests in the following order.

1. Scoping Experiments
2. 6101 (T6) Aluminum
3. 2024 (T3) Aluminum
4. C1 Composite
5. C2 Composite

3.4.1 Scoping Experiments

The goal of the scoping experiments was to identify pitfalls in the testing procedure and to see if it was possible to predict partial penetrations based on the low velocity data.

The scoping experiments consisted of two runs with large diameter plungers and 6101 aluminum targets. Only two tests were performed because the experimental procedure was well established on the calibration runs and because of the success of the scoping tests. One test was performed with a blunt tip and one with a sharp tip, both tests resulted in a partial penetration where the plunger was stuck in the target. Figure 20 shows targets from both high and low velocity testing. Three of the targets in Figure 20 show partially penetrated targets with the plunger lodged in the target.

The Scoping experiments were performed on used targets. To save samples we used targets from the low velocity testing. The targets used were from tests with small diameter plungers. The targets were positioned so the plungers punched new holes. The possibility of penetrating a work hardened area was possible.

The first test in the scoping experiment had the one and only plunger that was decelerating between the light tubes. This data point is labeled on the calibration curve in Figure 19. Assuming the deceleration was constant, the kinetic energy of the plunger at the target was 18.2 joules. The penetration energy from the low velocity tests was 18.9 joules. There are many assumptions here but the results were sufficient to move on to real tests.

Figure 20. Targets and plungers from low and high velocity testing.

3.4.2 6101 Aluminum

There were five pristine 6101 aluminum targets left after the low velocity testing. The goal of this experiment was to repeatedly lodge blunt plungers in the targets. The test results are summarized in Table 9.

Table 9. Test results for 6101 aluminum with blunt plungers.

Run	Plunger	Pressure	Velocity	Energy	Penetration
C3	Large-Blunt	1689 psi	80.3 m/s	36.7 J	.72 in.
C5	Small-Blunt	543	64.8	12.0	.47 in
C6	Large-Blunt	1630	81.0	37.6	Thru
C7	Large-Blunt	1621	80.6	37.1	Thru
C8	Large-Blunt	1550	78.0	34.8	Thru

The first run was with a large diameter plunger. The pressure was set at 1680 psi, the target pressure was 1610 psi, the same as the plunger that was decelerating in the scoping experiment. This time the plunger was still accelerating as it passed the light tubes. The kinetic energy between the last light tubes was calculated at 36.7 joules. The plunger partially penetrated the target. The penetration distance was 1.83 centimeters. This has considerably more energy than the scoping experiment but resulted in a similar penetration distance.

The second run was performed with a small blunt plunger and resulted in a partial penetration. The kinetic energy was 12.0 joules. The analogous average low velocity energy just to punch this material was 10.9 joules with a .6 standard deviation.

The last three runs were attempts to repeat the partial penetration result from the first run. The plunger penetrated completely through the target in all three tests. Since the quantity of excess energy is unknown all we can conclude is that 37 joules was sufficient energy for full penetration in these three tests. These results suggest that the C3 data was the anomaly but more tests are required to be sure. No distinguishing differences were seen on any of the plugs or targets. The holes in the target were smooth and shiny, characteristic of low strength material with a large backup diameter.

3.4.3 2024 Aluminum

The goal of the tests on 2024 aluminum was to span the range of penetration distances from not penetrating to passing completely through the target. The low velocity results had an average penetration energy of 18.8 joules with a standard deviation of .1 for large blunt plungers with a 1.0 centimeter backup diameter. Assuming the penetration energy continues to increase with the backup diameter the minimum penetration energy, neglecting friction, is 21.8 joules. The sliding friction was between 90 and 130 joules per inch (35 and 51 joules per centimeter) for the 1 centimeter backup. The sliding friction data is too sporadic to draw much of a conclusion from, except to account for some energy loss to friction. We arbitrarily decided to use a nominal energy of 35 joules, to account for some frictional energy losses, and test at, above, and below this energy level. The results are summarized in Table 10.

Table 10. Test results for 2024 aluminum with large blunt plungers.

Run	Plunger	Pressure	Velocity	Energy	Penetration
A2	Large-Blunt	2043 psi	89.4 m/s	45.6 J	Thru
A5	Large-Blunt	1541	77.3	34.0	.819 in
A6	Large-Blunt	1543	77.6	34.3	.701 in
A8	Large-Blunt	1750	82.2	38.5	Thru
A9	Large-Blunt	1242	68.9	27.1	Thru
A10	Large-Blunt	1046	62.6	22.3	Thru

The results are scattered. Judging by tests A2, A5, A6, and A8 the trends look correct. The nominal energy level of 34 joules results in partial penetrations and the higher energies pass through the target. But A9 and A10 contradict these results. These lower energy tests also pass through the targets. Inspection of the targets confirms that these targets were easier to penetrate. The holes in the targets from the first three tests are smooth and shiny from the plunger squeezing through. The inner wall of the holes in the targets from the last three tests appear jagged. These holes resemble the differences we saw in the large and small diameter backup data from the low velocity tests. We could not find an explanation for the difference in the shearing mechanism between the first and last three tests.

3.4.4 C1 Composite

The goal of the C1 composite testing was to perform tests at energies above and below the nominal penetration energy predicted by the low velocity tests. This composite was .10 centimeters of aluminum and .53 centimeters of fiberglass. We limited the variables to plunger diameter and only used blunt tips. This was done to establish a repeatability with a small set of tests.

The nominal penetration energy based on the low velocity tests is 27 joules. This energy is the average energy for a large blunt plunger penetrating C1 composite plus 3.4 joules of energy loss to friction. The energy loss to friction was derived from the average frictional loss for one inch of travel for the large blunt plungers with a large diameter backup. The test summary is shown in Table 11.

Table 11. C1 composite test results.

Run	Plunger	Pressure	Velocity	Energy	Penetration
A1	Large-Blunt	1507 psi	Unknown*	33.2 J	.91 in
A3	Large-Blunt	1541	76.7 m/s	33.5	.27
A4	Large-Blunt	1552	78.2	34.8	1.34
A11	Large-Blunt	1215	68.3	26.6	-.20
A12	Large-Blunt	1396	73.5	30.8	.05
A13	Large-Blunt	1552	76.0	32.9	.195
A15	Large-Blunt	1560	76.8	33.6	.36
A16	Small-Blunt	553	64.1	11.8	-.22
A17	Small-Blunt	1003	86.4	21.3	.145
A18	Small-Blunt	1060	89.3	22.8	.635

The C1 composite test results were much more conclusive than the aluminum results. The large blunt plunger results show a definite trend from only penetrating the aluminum, to barely penetrating the fiberglass, to .9 inches (2.29 centimeters) of penetration. The large plunger data from Table 11 is graphed in Figure 21. In reviewing the penetration results note the definition of penetration distance is the distance from the tip of the plunger to the back side of the composite. Thus a negative penetration means the plunger never came completely through the composite.

Figure 21. High velocity test results for C1 composite.

The prediction of a nominal penetration with 27 joules was low. The energy for 2.54 centimeters of penetration was close to 33 joules not 27 as predicted. This result may not be as far off as it appears. Two distinct energy regimes exist. The energy to penetrate the target has one profile and the energy loss due to friction has another. It is possible to fit the data in Figure 21 with two curves. The bend between the curves and the fact that they do not intersect at the back of the target could be attributed to coning of the target and the momentum of the plunger.

The conclusions from the large plunger data can be extended to the small plunger data. Based on the large plunger data it is plausible that the energy / penetration trend is the same. If this is the case, the data point and .145 inches of penetration are in the transition region and the -.22 and .635 inch points are in the shearing and frictional energy regimes respectively.

In the low velocity tests the average shearing energy for the small blunt plungers with a large backup diameter was 15.2 joules in the C1 composite. This is lower than the results found in the high velocity data.

Based on the high velocity trends in the C1 composite more information could have been gained for the aluminum targets by performing low energy tests. Data in the non penetrating regime give the most information. Data from plungers that do not penetrate through the target combined with data from plungers which stick in the target are most meaningful.

3.4.5 C2 Composite

The energy to penetrate the C2 composite was beyond the capacity on the gas gun. The small diameter plungers buckled on the B1 composite in the low velocity tests and large diameter results predict a minimum penetration energy of 62.1 joules. The gas gun is limited by a MAWP of 2500 psi which translates to 55 joules. We performed one test on the C2 composite with a large blunt plunger. The kinetic energy was 55.6 joules and the plunger put a .05 inch dimple in the aluminum.

IV. Conclusion

In this section we draw conclusions for the use of low and high velocity testing for predicting plunger performance and the design implications of plunger geometry and target material.

4.1 Low and High Velocity Testing

In general the low velocity testing is repeatable and effective for identifying nominal penetration energies for high velocity tests in composites. Blunt plunger data follows theoretical predictions for aluminum targets. Force-displacement profiles are informative.

High velocity tests using the gas gun are harder to interpret, especially for aluminum. There is less data and the results are sporadic. Penetration consistently required higher energy at the high velocity. Based on energy requirements measured in low velocity experiments we were able to predict the marginal penetration energy for the gas gun within 20% for composites. The implication to the designer is to add a safety factor when identifying reliable penetration energies based on low velocity data and perform high velocity testing to investigate the actual energy required. The data from all the testing is summarized in Tables 12 through 18.

4.2 Geometry and Target Material Effects

The plunger tip shape and diameter are the most important design parameters. The test results show that a blunt tip requires approximately half as much energy as a pointed tip to penetrate a target. Changing the plunger diameter from .38 to .64 centimeters increased the penetration energy by a factor of 2.

The backup diameter has a strong effect on penetration energy for low strength materials but little effect on high strength or brittle materials. The backup diameter effects the peak force during penetration and has a significant effect on the sliding friction between the plunger and target after penetration.

As theory predicts for blunt plungers the penetration energy scales with the square of the target thickness and the peak force scales linearly with the target thickness. The penetration mechanism, the material deformation and distance to shear, is a strong function of target material and clearance between the plunger and backup diameter.

Several generalities can be made from the test results.

1. Sharp tip plungers require twice as much energy for penetration.
2. Peak force is directly proportional to plunger diameter.

3. For composites energy requirements are proportional to the square of the target material thickness.
4. For aluminum, a larger backup diameter requires more penetration energy and suffers a greater energy loss to friction.
5. For composites a smaller backup diameter requires more penetration energy and suffers a greater energy loss to friction.

The major conclusions for the punch value of interest are listed below.

1. Use a concave "cookie cutter" plunger to minimize penetration energy.
2. On composites an un-boosted MC 3753 actuator is marginal with a small diameter blunt plunger on thin composites and will not work with large diameter plungers.
3. Minimize the clearance between the backup diameter and the plunger diameter in order to obtain clean plugs.
4. Minimize the plunger diameter for lower penetration energy and less energy losses to friction.
5. Account for sliding friction in calculating energy requirements.
6. Accommodate a "plug" of target debris on the plunger tip after penetration.

Table 12. Low velocity test results for 6101 (T6) aluminum.

Tip	Backup	Plunger	E avg	E stdv	F avg	F stdv	C avg	C stdv	S-Ave	S stdv
Blunt	0.3	0.25	18.9 J	1.7	1897 lb	38.6	0.84	0.08	19320 psi	393
Blunt	0.3	0.25								
Blunt	0.3	0.25								
Blunt	0.3	0.25								
Blunt	0.3	0.15	10.9	0.6	1126.8	7.9	0.81	0.04	19128	134
Blunt	0.3	0.15								
Blunt	0.3	0.15								
Blunt	0.3	0.15								
Sharp	0.3	0.15	23.6	0.8	1291.5	43.7	1.75	0.06	21925	743
Sharp	0.3	0.15								
Sharp	0.3	0.15								
Sharp	0.3	0.15								
Sharp	0.3	0.25	47.9	0.6	1925.8	34.3	2.14	0.03	19616	350

Table 13. Low velocity test results for 2024 (T3) aluminum.

Tip	Backup	Plunger	E avg	E stdev	F avg	F stdev	C avg	S- Ave
Blunt	0.3	0.25	*5.1 J		*2009 lbs		*0.512	*40927 psi
Blunt	0.3	0.25	15.3	0.4	4367.0	39.6	0.38	43830
Blunt	0.3	0.25						
Blunt	0.4	0.25	18.8	0.1	4239.0	35.4	0.47	44177
Blunt	0.4	0.25						
Blunt	0.4	0.15						47127
Blunt	0.3	0.15						

*.0625 inches thick target.

Table 14. Low velocity test results for C1 Composite.

Tip	Backup	Plunger	E[i]	E avg	E stdev	F[lbs]	F avg	F stdev	S- Ave	S stdev
Blunt	0.4	0.25	24.1	23.8	0.7	2907	2934.0	54.0	16198 psi	1458
Blunt	0.3	0.25	23.4	23.9	1.1	3452	3427.0	50.0		
Blunt	0.4	0.25	23.4			2961				
Blunt	0.3	0.25	24.5			3402				
Blunt	0.3	0.15	17.1	16.6	0.8	1801	1770.5	61.0	14659	477
Blunt	0.4	0.15	14.9	15.2	0.5	1689	1683.5	11.0		
Blunt	0.3	0.15	16.2			1740				
Blunt	0.4	0.15	15.5			1678				
Sharp	0.4	0.25	61.18	62.1	1.8	2219	2231.5	25.0	12940	1956
Sharp	0.3	0.25	72.12	71.2	1.9	3023	2850.0	346.0		
Sharp	0.4	0.25	62.98			2244				
Sharp	0.3	0.25	70.21			2677				
Sharp	0.4	0.15	29.97	28.7	2.6	1658	1656.5	3.0	14963	1058
Sharp	0.3	0.15	31.61	30.1	2.9	1896	1869.0	54.0		
Sharp	0.4	0.15	27.35			1655				
Sharp	0.3	0.15	28.67			1842				

Table 15. Low velocity test results for C2 composite.

Plunger	E[i]	E avg	E stdev	F[i]lb	F avg	F stdev	S-Ave	S stdev
0.25	96.3	98.8	5.0	6090	6245.5	311.0	16137 psi	666
0.25	103.5	100.2	6.6	6720	6609.0	222.0		
0.25	101.3			6401				
0.25	96.9			6498				
0.25	170.7	168.6	4.2	6828	6666.0	324.0	17182	823
0.25	160.2	164.1	7.6	6487	6829.0	684.0		
0.25	166.5			6504				
0.25	167.9			7171				

Table 16. High velocity test results for 6101 (T6) aluminum.

Run	Plunger	Pressure	Velocity	Energy	Penetration
C3	Large-Blunt	1689 psi	80.3 m/s	36.7 J	.72 in.
C5	Small-Blunt	543	64.8	12.0	.47 in
C6	Large-Blunt	1630	81.0	37.6	Thru
C7	Large-Blunt	1621	80.6	37.1	Thru
C8	Large-Blunt	1550	78.0	34.8	Thru

Table 17. High velocity test results for 2024 (T3) aluminum.

Run	Plunger	Pressure	Velocity	Energy	Penetration
A2	Large-Blunt	2043 psi	89.4 m/s	45.6 J	Thru
A5	Large-Blunt	1541	77.3	34.0	.819 in
A6	Large-Blunt	1543	77.6	34.3	.701 in
A8	Large-Blunt	1750	82.2	38.5	Thru
A9	Large-Blunt	1242	68.9	27.1	Thru
A10	Large-Blunt	1046	62.6	22.3	Thru

Table 18. High velocity test results for C1 composite.

Run	Plunger	Pressure	Velocity	Energy	Penetration
A1	Large-Blunt	1507 psi	Unknown*	33.2 J	.91 in
A3	Large-Blunt	1541	76.7 m/s	33.5	.27
A4	Large-Blunt	1552	78.2	34.8	1.34
A11	Large-Blunt	1215	68.3	26.6	-.20
A12	Large-Blunt	1396	73.5	30.8	.05
A13	Large-Blunt	1552	76.0	32.9	.195
A15	Large-Blunt	1560	76.8	33.6	.36
A16	Small-Blunt	553	64.1	11.8	-.22
A17	Small-Blunt	1003	86.4	21.3	.145
A18	Small-Blunt	1060	89.3	22.8	.635

APPENDIX A
Punch Valve Hardware Drawings

1. GENERAL REQUIREMENTS AND DRAWING INTERPRETATIONS ARE DEFINED IN 9900000.
2. MATERIAL: CUSTOM 455 SOL ANL GRD.
SPECIFICATION: AMS-5617F (7/1/88); MIL-S-83311 (2/11/71).
3. HEAT TREAT AFTER MACHINING; 950°F 4 HRS, COOL IN AN INERT ENVIRONMENT.
4. MARK DRAWING NUMBER AND ISSUE ON BAG OR ON A TAG TIED TO THE PART.

DESIGN AGENCY
PART NUMBER

XXXXXX-000

REVISIONS

ISS	SHEET ZONE	PREPARED BY	DESCRIPTION	DATE	CHKR	APVD
A		S.BUNN, 8414 B.REPLOGLE, 8412

DETAIL B
SCALE 4.000

SEE DETAIL B

R.030±.010
R.005 MAX

TURNING CENTER OK

SHEET	1	2	3	4	5	6	TITLE
ISSUE	A						Nail .149 Diameter Sharp
PART CLASSIFICATION UNCLASSIFIED							
DRAWING CLASSIFICATION UNCLASSIFIED							
SIZE B							DRAWING NUMBER A61199
STATUS SL-REL-11-May-95							CAGEC14214 SCALE 2.000 SHEET 1 OF 1
ORIGIN SL-PRO-R13.0							

GEOMETRIC PRECISION = XX.XXX XXX XX

SCALE 1.000

SECTION A-A
SCALE 2.000

1. GENERAL REQUIREMENTS AND DRAWING INTERPRETATIONS ARE DEFINED IN 9900000.
2. MATERIAL: CUSTOM 455 SOL ANL GRD.
SPECIFICATION: AMS-5617F (7/1/88); MIL-S-83311 (2/11/71).
3. HEAT TREAT AFTER MACHINING; 950°F, 4 HRS, COOL IN AN INERT ENVIRONMENT.
4. MARK DRAWING NUMBER AND ISSUE ON BAG OR ON A TAG TIED TO THE PART.

DESIGN AGENCY
PART NUMBER

XXXXXX-000

REVISIONS

ISS	SHEET ZONE	PREPARED BY	DESCRIPTION	DATE	CHKD	APVD
A		S.BUNN, 8414 B.REPLOGLE, 8412

DETAIL B
SCALE 4.000

GEOMETRIC PRECISION = KX XXX XX

SHEET	1	2	3	4	5	6	TITLE	
ISSUE	A						Nail .149 Diameter Concave	
PART CLASSIFICATION UNCLASSIFIED								
DRAWING CLASSIFICATION UNCLASSIFIED								
SIZE							DRAWING NUMBER	
B							A61200	
			CASEC14214			SCALE 2.000		SHEET 1 OF 1
STATUS			SL-REL-11-May-95			ORIGIN SL-PRO-R11.0		

SECTION A-A
SCALE 2.000

1. GENERAL REQUIREMENTS AND DRAWING INTERPRETATIONS ARE DEFINED IN 9900000.
2. MATERIAL: CUSTOM 455 SOL ANL GRD.
SPECIFICATION: AMS-5617F (7/1/88); MIL-S-83311 (2/11/71).
3. HEAT TREAT AFTER MACHINING; 950°F, 4 HRS, COOL IN AN INERT ENVIRONMENT.
3. MARK DRAWING NUMBER AND ISSUE ON BAG OR ON A TAG TIED TO THE PART.

DESIGN AGENCY
PART NUMBER

XXXXXX-000

REVISIONS

ISS	SHEET ZONE	PREPARED BY	DESCRIPTION	DATE	CHKR	APVD
A		S.BUNN, 8414 B.REPLOGLE, 8412

DETAIL B
SCALE 4.000

SCALE 1.000

GEOMETRIC PRECISION = XX.XXX XXX XX

SHEET	1	2	3	4	5	6	TITLE	
ISSUE	A						Nail .248 Diameter Concave	
PART CLASSIFICATION UNCLASSIFIED								
DRAWING CLASSIFICATION UNCLASSIFIED							SIZE B	DRAWING NUMBER A61202
				CAGEC14214		SCALE 2.000		SHEET 1 OF 1
STATUS SL-REL-11-May-95							ORIGIN SL-PRO-R11.0	

SECTION A-A

1. GENERAL REQUIREMENTS AND DRAWING INTERPRETATIONS ARE DEFINED IN 9900000.
2. MATERIAL: CUSTOM 455 SOL ANL GRD.
SPECIFICATION: AMS-5617F (7/1/88); MIL-S-83311 (2/11/71).
3. HEAT TREAT AFTER MACHINING; 950°F, 4 HRS, COOL IN AN INERT ENVIRONMENT.
4. MARK DRAWING NUMBER AND ISSUE ON BAG OR ON A TAG TIED TO THE PART.

DESIGN AGENCY
PART NUMBER

XXXXXX-000

REVISIONS

ISS	SHEET	ZONE	PREPARED BY	DESCRIPTION	DATE	CHRR	APVD
A			S.BUNN, 8414 B.REPLOGLE, 8412

DETAIL B
SCALE 4.000

SHEET	1	2	3	4	5	6	TITLE
ISSUE	A						Nail .248 Diameter Sharp
PART CLASSIFICATION UNCLASSIFIED							
DRAWING CLASSIFICATION UNCLASSIFIED							SIZE B DRAWING NUMBER A61201
STATUS SL-REL-11-May-95							CASEC14214 SCALE 2.000 SHEET 1 OF 1 ORIGIN SL-PRO-R11.0

GEOMETRIC PRECISION SCALE 1.000 XXX XXX XX

SECTION A-A

1. GENERAL REQUIREMENTS AND DRAWING INTERPRETATIONS ARE DEFINED IN 9900000.
2. MATERIAL: 316 STAINLESS STEEL.
3. MARK DRAWING NUMBER AND ISSUE ON BAG OR ON A TAG TIED TO THE PART.

DESIGN AGENCY
PART NUMBER

XXXXXX-000

REVISIONS

ISS	SHEET ZONE	PREPARED BY	DESCRIPTION	DATE	CHKR	APVD
A		S.M. BUNN, 8414 B. REPLOGLE, 8412

6X, $\varnothing .406 \pm .010$

6X, $\varnothing .280 \pm .010$ EQ SP
ON A $\varnothing 2.400 \pm .010$ B.C.

SECTION A-A

SHEET	1	2	3	4	5	6	TITLE Carrier Plate 1.5		
ISSUE	A								
PART CLASSIFICATION UNCLASSIFIED							DRAWING NUMBER A61207		
DRAWING CLASSIFICATION UNCLASSIFIED									
				CAGEC14214		SCALE 1.000		SHEET 1 OF 1	
STATUS SL-REL-11-May-95						ORIGIN SL-PRO-R11.0			

GEOMETRIC PRECISION = XX.XXX XXX XX

1. GENERAL REQUIREMENTS AND DRAWING INTERPRETATIONS ARE DEFINED IN 9900000.

2. MATERIAL: 316 STAINLESS STEEL.

3. MARK DRAWING NUMBER AND ISSUE ON BAG OR ON A TAG TIED TO THE PART.

DESIGN AGENCY
PART NUMBER

XXXXXX-000

REVISIONS

ISS	SHEET ZONE	PREPARED BY	DESCRIPTION	DATE	CHKR	APVD
A		S.M.BUNN, 8414 B.REPLOGLE, 8412

SECTION A-A

SHEET	1	2	3	4	5	6	TITLE		
ISSUE	A								
PART CLASSIFICATION							Carrier Plate 2.5		
UNCLASSIFIED									
DRAWING CLASSIFICATION							SIZE	DRAWING NUMBER	
UNCLASSIFIED							B	A61208	
						CAGEC14214		SCALE 1.000	SHEET 1 OF 1
STATUS SL-REL-11-May-95							ORIGIN SL-PRO-R11.0		

GEOMETRIC PRECISION = XX.XXX XXX XX

1. GENERAL REQUIREMENTS AND DRAWING INTERPRETATIONS ARE DEFINED IN 9900000.
2. MATERIAL: 316 STAINLESS STEEL.
3. MARK DRAWING NUMBER AND ISSUE ON BAG OR ON A TAG TIED TO THE PART.

DESIGN AGENCY
PART NUMBER

XXXXXX-000

REVISIONS

ISS	SHEET ZONE	PREPARED BY	DESCRIPTION	DATE	CHRR	APVD
A		S.M.BUNN, 8414 B.REPLOGLE, 8412

SHEET	1	2	3	4	5	6	TITLE	
ISSUE	A							
PART CLASSIFICATION UNCLASSIFIED							Receiver Plate 3	
DRAWING CLASSIFICATION UNCLASSIFIED								
SIZE							DRAWING NUMBER	
B							A61209	
					CASEC14214		SCALE 1.000	SHEET 1 OF 1
STATUS SL-REL-11-May-95					ORIGIN SL-PRO-R11.0			

GEOMETRIC PRECISION = XX.XXX XXX XX

- A

GEOMETRIC PRECISION = XX.XXX XXX XX

Base Plate

PART CLASSIFICATION
UNCLASSIFIED

DRAWING CLASSIFICATION
UNCLASSIFIED

SIZE	DRAWING NUMBER
B	A61211

		CASEE14214	SCALE 1 000	SHEET 1 OF 1
--	--	------------	-------------	--------------

STATUS SL-REL-11-May-95

ORIGIN SI - PRO-BILL 0

1. GENERAL REQUIREMENTS AND DRAWING INTERPRETATIONS ARE DEFINED IN 9900000.
2. MATERIAL: SEE P.O. #XXXXX.
3. PART THICKNESS "0A" TBD ON P.O. #XXXXX.
4. MARK DRAWING NUMBER AND ISSUE ON BAG CONTAINING THE PART.

DESIGN AGENCY
PART NUMBER

XXXXXX-000

REVISIONS

ISS	SHEET ZONE	PREPARED BY	DESCRIPTION	DATE	CHKR	APVD
A		S.M. BUNN, 8414 B. REPLOGLE, 8412

SHEET	1	2	3	4	5	6	TITLE
ISSUE	A						Sample
PART CLASSIFICATION							
UNCLASSIFIED							
DRAWING CLASSIFICATION							SIZE
UNCLASSIFIED							B
							DRAWING NUMBER
							A61212
CASEC14214							SCALE 2.000
STATUS SL-REL-11-May-95							SHEET 1 OF 1
ORIGIN SL-PRO-R11.0							

GEOMETRIC PRECISION = XX.XXX XXX XX

1. GENERAL REQUIREMENTS AND DRAWING INTERPRETATIONS ARE DEFINED IN 9900000.

2. MATERIAL: 316 STAINLESS STEEL.

3. MARK DRAWING NUMBER AND ISSUE ON BAG OR ON A TAG TIED TO THE PART.

DESIGN AGENCY
PART NUMBER

XXXXXX-000

REVISIONS

ISS	SHEET ZONE	PREPARED BY	DESCRIPTION	DATE	CHKR	APVD
A		S.M.BUNN, 8414 B.REPLOGLE, 8412

SHEET	1	2	3	4	5	6	TITLE
ISSUE	A						Receiver Plate 4
PART CLASSIFICATION	UNCLASSIFIED						
DRAWING CLASSIFICATION	UNCLASSIFIED						
SIZE	B						DRAWING NUMBER A61210
STATUS SL-REL-11-May-95						CAGEC14214 SCALE 1.000 SHEET 1 OF 1	
						ORIGIN SL-PRO-R11.0	

GEOMETRIC PRECISION = XX.XXX XXX XX

1. GENERAL REQUIREMENTS AND DRAWING INTERPRETATIONS ARE DEFINED IN 9900000.
2. MATERIAL: 4340 RC 40.
3. MARK DRAWING NUMBER AND ISSUE ON BAG OR ON A TAG TIED TO THE PART.

DESIGN AGENCY
PART NUMBER

XXXXXX-000

REVISIONS

ISS	SHEET ZONE	PREPARED BY	DESCRIPTION	DATE	CHRR	APVD
A		S.BUNN, 8414 B.REPLOGLE, 8412

SHEET	1	2	3	4	5	6	TITLE	
ISSUE	A						Extension Adapter 3 Inch	
PART CLASSIFICATION UNCLASSIFIED							DRAWING CLASSIFICATION UNCLASSIFIED	
DRAWING CLASSIFICATION UNCLASSIFIED								
SIZE							DRAWING NUMBER A61204	
CAGEC14214							SCALE 2.000	
SHEET 1 OF 1								
STATUS SL-REL-11-May-95							ORIGIN SL-PRO-R11.0	

GEOMETRIC PRECISION = XX.XXX XXX XX

1. GENERAL REQUIREMENTS AND DRAWING INTERPRETATIONS ARE DEFINED IN 9900000.

2. MATERIAL: 4340 RC 40.

3. MARK DRAWING NUMBER AND ISSUE ON BAG OR ON A TAG TIED TO THE PART.

DESIGN AGENCY
PART NUMBER

XXXXXX-000

REVISIONS

ISS	SHEET ZONE	PREPARED BY	DESCRIPTION	DATE	CHKR	APVD
A		S.BUNN, 8414 B.REPLOGLE, 8412

SCALE 0.500

SHEET	1	2	3	4	5	6	TITLE	
ISSUE	A						Extension Adapter 4.75 Inch	
PART CLASSIFICATION UNCLASSIFIED								
DRAWING CLASSIFICATION UNCLASSIFIED							SIZE	DRAWING NUMBER B A61206
							CAGEC14214	SCALE 2.000 SHEET 1 OF 1
STATUS SL-REL-11-May-95							ORIGIN SL-PRO-R11.0	

GEOMETRIC PRECISION = XX.XXX XXX XX

SECTION A-A
SCALE 2.000

1. GENERAL REQUIREMENTS AND DRAWING INTERPRETATIONS ARE DEFINED IN 9900000.
2. MATERIAL: 4340 RC 40.
3. MARK DRAWING NUMBER AND ISSUE ON BAG OR ON A TAG TIED TO THE PART.

DESIGN AGENCY
PART NUMBER

XXXXXX-000

REVISIONS

ISS	SHEET ZONE	PREPARED BY	DESCRIPTION	DATE	CHKR	APVD
A		S.BUNN, 8414 B.REPLOGLE, 8412

SECTION A-A
SCALE 2.000

SHEET	1	2	3	4	5	6	TITLE
ISSUE	A						Extension Adapter 6 Inch
PART CLASSIFICATION UNCLASSIFIED							
DRAWING CLASSIFICATION UNCLASSIFIED							
SIZE B							DRAWING NUMBER A61205
CAREC14214							SCALE 2.000
STATUS SL-REL-11-May-95							SHEET 1 OF 1
ORIGIN SL-PRO-R11.0							

GEOMETRIC PRECISION = XX.XXX XXX XX

APPENDIX B
Test Star Programs

Procedure Name = POINTED Default Procedure
File Specification = C:\TS\TWSX\POINTED.000

Data File Options

File Format = Excel Text File
Log Events = Yes
Include Procedure Description = No

Recovery Options

Autosave disabled.

S1 : Step

Step Done Trigger 1 = DATA

STEP : Monotonic Command

Start Trigger = Step Start
End Trigger = <none>
Segment Shape = Step
Time = 1 (Sec)
Axial
Control Mode = Length A SG
Endlevel = -1.2 (in)

DATA : Data Acquisition

Start Trigger = Step Start
End Trigger = <none>
Mode = Level Crossing
Buffer Type = Single
Master Channel = Length 1
Slave Channel 1 = Time
Slave Channel 2 = Force 1
Data Header =
Level Increment = 0.001 (in)
Buffer Size = 4000

Procedure Name = POINTEDB Default Procedure
File Specification = C:\TS\TWSX\POINTEDB.000

Data File Options

File Format = Excel Text File
Log Events = Yes
Include Procedure Description = No

Recovery Options

Autosave disabled.

S1 : Step

Step Done Trigger 1 = DATA

STEP : Monotonic Command

Start Trigger = Step Start
End Trigger = <none>
Segment Shape = Step
Time = 1 (Sec)
Axial
Control Mode = Length A SG
Endlevel = -3.67 (in)

DATA : Data Acquisition

Start Trigger = Step Start
End Trigger = <none>
Mode = Level Crossing
Buffer Type = Single
Master Channel = Length 1
Slave Channel 1 = Time
Slave Channel 2 = Force 1
Data Header =
Level Increment = 0.001 (in)
Buffer Size = 4000

Procedure Name = BLUNT Default Procedure
File Specification = C:\TS\TWSX\BLUNT.000

Data File Options

File Format = Excel Text File
Log Events = Yes
Include Procedure Description = No

Recovery Options

Autosave disabled.

S1 : Step

Step Done Trigger 1 = DATA

STEP : Monotonic Command

Start Trigger = Step Start
End Trigger = <none>
Segment Shape = Ramp
Time = 1 (Sec)
Axial
Control Mode = Length A SG
Endlevel = -1.1 (in)

DATA : Data Acquisition

Start Trigger = Step Start
End Trigger = <none>
Mode = Level Crossing
Buffer Type = Single
Master Channel = Length 1
Slave Channel 1 = Time
Slave Channel 2 = Force 1
Data Header =
Level Increment = 0.001 (in)
Buffer Size = 4000

Procedure Name = BLUNTB Default Procedure
File Specification = C:\TS\TWSX\BLUNTB.000

Data File Options

File Format = Excel Text File
Log Events = Yes
Include Procedure Description = No

Recovery Options

Autosave disabled.

1 : Step

Step Done Trigger 1 = DATA

STEP : Monotonic Command

Start Trigger = Step Start
End Trigger = <none>
Segment Shape = Ramp
Time = 1 (Sec)
Axial
Control Mode = Length A SG
Endlevel = -3.558 (in)

DATA : Data Acquisition

Start Trigger = Step Start
End Trigger = <none>
Mode = Level Crossing
Buffer Type = Single
Master Channel = Length 1
Slave Channel 1 = Time
Slave Channel 2 = Force 1
Data Header =
Level Increment = 0.001 (in)
Buffer Size = 4000

APPENDIX C

Detailed Data

Thickness	Tip	Backup di	Plung dia	Material	.577 Yeild	test	E(in-lb)	E(j)	Aluminum Material			R to Shea	S- Ave	S sdev	C avg	C stdev	E avg	E stdev	F avg	F stdev
0.125	Blunt	0.3	0.25	6101	16156	2	161.3	18.2	1896	0.1165	0.81	19313	19320	393	0.84	0.08	18.9	1.7	1896.8	38.6
0.125	Blunt	0.3	0.25	6101	16156	12	148.7	16.8	1847	0.1	0.75	18813								
0.125	Blunt	0.3	0.25	6101	16156	7	180.6	20.4	1941	0.1159	0.91	19771								
0.125	Blunt	0.3	0.25	6101	16156	11	177.6	20.1	1903	0.1109	0.90	19384								
0.125	Blunt	0.3	0.15	6101	16156	10	92.3	10.4	1126	0.11	0.78	19116	19128	134	0.81	0.04	10.9	0.6	1126.8	7.9
0.125	Blunt	0.3	0.15	6101	16156	1	93.3	10.5	1131	0.11	0.78	19200								
0.125	Blunt	0.3	0.15	6101	16156	8	96.6	10.9	1116	0.112	0.81	18946								
0.125	Blunt	0.3	0.15	6101	16156	9	103.3	11.7	1134	0.114	0.87	19251								
0.125	Sharp	0.3	0.15	6101	16156	13	201.3	22.7	1242	0.276	1.7	21085	21925	743	1.75	0.06	23.6	0.8	1291.5	43.7
0.125	Sharp	0.3	0.15	6101	16156	14	204.3	23.1	1268	0.279	1.7	21526								
0.125	Sharp	0.3	0.15	6101	16156	3	215.7	24.4	1334	0.282	1.8	22647								
0.125	Sharp	0.3	0.15	6101	16156	6	212.4	24.0	1322	0.268	1.8	22443								
0.125	Sharp	0.3	0.25	6101	16156	4	431.9	48.8	1888	0.402	2.2	19231	19616	350	2.14	0.03	47.9	0.6	1925.8	34.3
0.125	Sharp	0.3	0.25	6101	16156	5	421.2	47.6	1968	0.375	2.1	20046								
0.125	Sharp	0.3	0.25	6101	16156	15	420.8	47.6	1936	0.383	2.1	19720								
0.125	Sharp	0.3	0.25	6101	16156	16	420.5	47.5	1911	0.376	2.1	19465								
Thickness	Tip	Backup di	Plung dia	Material	.577 Yeild	test	E(in-lb)	E(j)	F(lbs)	x(in)	c	R to Shea	S- Ave	S sdev	C avg	C stdev	E avg	E stdev	F avg	F stdev
0.0625	Blunt	0.3	0.25	2024	28850	01A1	45.3	5.1	2009		0.51	40927	40927		0.51					
0.125	Blunt	0.3	0.25	2024	28850	1	132.6	15.0	4339		0.37	44197	43830	815	0.38	0.01	15.3	0.4	4367.0	39.6
0.125	Blunt	0.3	0.25	2024	28850	2	137.4	15.5	4395	0.0482	0.39	44767								
0.125	Blunt	0.4	0.25	2024	28850	3	167.4	18.9	4264		0.47	43433			0.47	0.00	18.8	0.1	4239.0	35.4
0.125	Blunt	0.4	0.25	2024	28850	4	165.9	18.7	4214	0.0582	0.47	42923								
0.125	Blunt	0.4	0.15	2024	28850	41	112	12.7	2720	0.0600	0.53	46176	47127	1901						
0.125	Blunt	0.3	0.15	2024	28850	42	117.3	13.3	2832	0.0627	0.55	48078								

COMPOSITE MATERIALS																				
Thickness	Tip	Backup di	Plung dia	Material	Run	test	E[in-lb]	E[j]	F[lbs]	x[in]	c x Yelid	R to Shea	S- Ave	S sdev	C avg	C stdev	E avg	E stdev	F avg	F stdev
0.25	Blunt	0.4	0.25	A1	9	1ablla24	213.4	24.1	2907	0.1333	4347	14805	16198	1458	4301.41	95.83	23.8	0.7	2934.0	54.0
0.25	Blunt	0.3	0.25	A1	11	1ablla23	206.7	23.4	3452	0.1027	4211	17581					23.9	1.1	3427.0	50.0
0.25	Blunt	0.4	0.25	A1	3	1ablla14	207.8	23.4	2961	0.1337	4233	15080								
0.25	Blunt	0.3	0.25	A1	4	1ablla13	216.7	24.5	3402	0.111	4414	17326								
0.25	Blunt	0.3	0.15	A1	2	1abls13	151.0	17.1	1801	0.1405	5126	15287	14659	477	4782.73	280.11	16.6	0.8	1770.5	61.0
0.25	Blunt	0.4	0.15	A1	1	1abls14	132.0	14.9	1689	0.1378	4483	14337					15.2	0.5	1683.5	11.0
0.25	Blunt	0.3	0.15	A1	12	1abls13	143.6	16.2	1740	0.1443	4877	14770								
0.25	Blunt	0.4	0.15	A1	16	1abls14	136.8	15.5	1678	0.1488	4645	14243								
0.25	Sharp	0.4	0.25	A1	13	1ashla24	541.4	61.18	2219	0.4462	11030	11301	12940	1956	12010.83	965.15	62.1	1.8	2231.5	25.0
0.25	Sharp	0.3	0.25	A1	15	1ashla23	638.2	72.12	3023	0.431	13002	15396					71.2	1.9	2850.0	346.0
0.25	Sharp	0.4	0.25	A1	8	1ashla14	557.3	62.98	2244	0.4351	11354	11429								
0.25	Sharp	0.3	0.25	A1	5	1ashla13	621.3	70.21	2677	0.4362	12658	13634								
0.25	Sharp	0.4	0.15	A1	10	1ashsm24	265.2	29.97	1658	0.3015	9005	14074	14963	1058	8833.81	547.05	28.7	2.6	1656.5	3.0
0.25	Sharp	0.3	0.15	A1	14	1ashsm23	279.7	31.61	1896	0.2788	9498	16094					30.1	2.9	1869.0	54.0
0.25	Sharp	0.4	0.15	A1	7	1ashsm14	242.0	27.35	1655	0.2757	8218	14048								
0.25	Sharp	0.3	0.15	A1	6	1ashsm13	253.7	28.67	1842	0.2705	8614	15635								
Thickness	Tip	Backup di	Plung dia	Material	Run	test	E[in-lb]	E[j]	F[lbs]	x[in]	c x Yelid	R to Shea	S- Ave	S sdev	C avg	C stdev	E avg	E stdev	F avg	F stdev
0.5	Blunt	0.4	0.25	B2	6	2bblla24	851.87	96.3	6090	0.21	4339	15508	16367	666	4483.22	156.11	98.8	5.0	6245.5	311.0
0.5	Blunt	0.3	0.25	B2	9	2bblla23	915.57	103.5	6720	0.2188	4663	17112					100.2	6.6	6609.0	222.0
0.5	Blunt	0.4	0.25	B2	5	2bblla14	896.1	101.3	6401	0.1933	4564	16300								
0.5	Blunt	0.3	0.25	B2	4	2bblla13	857.57	96.9	6498	0.1871	4368	16547								
0.5	Sharp	0.4	0.25	B2	10	2bshla24	1510.9	170.7	6828	0.4417	7695	17387	17182	823	7496.83	199.49	168.6	4.2	6666.0	324.0
0.5	Sharp	0.3	0.25	B2	8	2bshla23	1418.09	160.2	6487	0.43	7222	16519					164.1	7.6	6829.0	684.0
0.5	Sharp	0.4	0.25	B2	7	2bshla14	1473.55	166.5	6504	0.4306	7505	16562								
0.5	Sharp	0.3	0.25	B2	1	2bshla13	1485.45	167.9	7171	0.4118	7565	18261								

APPENDIX D
Gas Gun Drawing Numbers

Gas Gun Drawing Numbers

Name	Number
PRIMARY BARREL	A41125
SOLENOID BARREL	A41126
TEST BLOCK	A41127
PRESSURE CHAMBER	A41128
CAP NUT	A41129
NUT GLAND	A41130
HOLDER	A41131
SOLENOID ASSEMBLY	A41132
BRACKET	A41133
CATCHER	A41134
CASE SUPPORT	A41135
PLUG	A41136
ADJUSTMENT SCREW	A41137
PISTON ASSEMBLY	A41138
END CAP	A41139

REFERENCES

1. Mechanical Engineering Design, Shigley and Mischke, Fifth Edition, McGraw Hill, New York, 1989.
2. Mark's Standard Handbook for Mechanical Engineers, Eighth Edition, McGraw Hill.
3. Statistics For Experimenters, George E.P. Box, William G. Hunter, J. Stuart Hunter, John Wiley and Sons Inc. 1978.
4. Materials Engineering, Materials Selector 1987, Penton Publishing, Cleveland Ohio.

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