PNNL-13281

Pacific Northwest National Laboratory
Operated by Battelle for the
U.S. Department of Energy

Comparison of Nozzles and Flow Straighteners for Tank Waste Sluicing Applications

O. D. Mullen
D. R. Jackson

September 2000

Prepared for
The U.S. Department of Energy
Under Contract DE-AC06-76RLO 1830

This work is funded by the Office of Science and Technology within the U.S. Department of Energy's Office of Environmental Management under the Tanks Focus Area Program

PACIFIC NORTHWEST NATIONAL LABORATORY

operated by

BATTELLE

for the

UNITED STATES DEPARTMENT OF ENERGY

under Contract DE-ACO6-76RLO1830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, V A 22161
ph: (800) 553-6847
fax: (703) 605-6900
email: orders@ntis.fedworld.gov
online ordering: http:llwww.ntis.gov/ordering.htm

@ This document was printed on recycled paper.

(8/00)

PNNL-13281

Comparison of Nozzles and Flow Straighteners for Tank Waste Sluicing Applications

O. D. Mullen
D. R. Jackson

September 2000

Prepared for
The U.S. Department of Energy
Under Contract DE-AC06-76RLO 1830

This work is funded by the Office of Science and Technology within the U.S. Department of Energy's Office of Environmental Management under the Tanks Focus Area Program

Summary

The purpose of these tests was to provide quantitative and qualitative comparisons for several different sluice nozzle/flow straightener combinations to support past qualitative reviews and observations and to provide information that may be useful for future deployment of in-tank sluicing systems on the Hanford site. The specific tests were designed to assess the relative coherence of water streams produced by each different nozzle and flow straightener combination. The assessments presumed applicability for sluicing waste from underground storage tanks. The criteria for comparison were impact force produced by the stream impinging on a target plate at various distances from the nozzle and coherence of the streams demonstrated by the variation of force on two different size targets.

As a result of these tests, it was determined that the standard Hanford flow straightener is measurably less effective than a commercial fire fighting flow straightener at producing a coherent stream when used with the standard Hanford nozzle and that a lighter and more compact fire fighting deluge nozzle will deliver a stream of equal coherence to that from the Hanford nozzle when either nozzle is used with the commercial flow straightener.

In conclusion, the data contained in this report supports a recommendation to update the Hanford sluicing nozzle and flow straightener components to utilize commercially developed and proven designs.

Contents

Figures

1.0 Introduction

1.1 Background

The baseline method for retrieval of nuclear materials processing wastes from the underground storage tanks on the U.S. Department of Energy sites is sluicing or "past-practice sluicing" (Figure 1.1). This process utilizes one or more nozzles inserted through tank access risers in the dome. The nozzles are mounted to a hanging sluicing monitor, which has essentially two degrees of freedom, tilt from the vertical and rotation about the vertical axis of the riser. The sluicing medium is typically recycled supernate from the tank farm, supplied to the nozzles at up to 1.03 Mpa (150 psi) and 1.3 m^3/min (350 gpm). The sluicing jet is directed at the waste surface in a methodical pattern to dislodge and mix the waste into a pumpable slurry and carve drainage channels from the working area to the retrieval pump. The slurry is pumped to the transfer pipe loop using a submersible pump deployed through another access riser. The nozzles are typically 25 mm (1 inch) in diameter and of a Leach & Walker style having a low angle tapered entry section and a straight throat about three diameters in length.

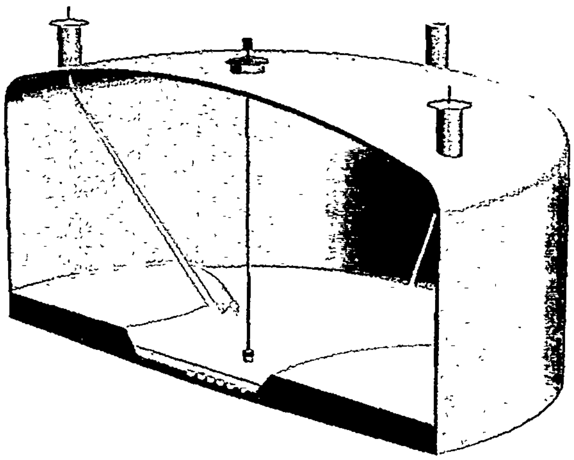


Figure 1.1 Sluicing concept - two sluicers are shown in opposing risers, and a single slurry pump is in the central riser. A single sluicer may be used with the slurry pump in the opposite side riser.

1.2 Objective

The purpose of these tests was to provide a simple comparison between four different sluice nozzle/flow straightener configurations and the nozzles with no flow straightener. The results were based on sluice stream contact force and continuity.

Sluice stream contact force was a quantitative measurement of the normal force generated by impingement of a sluicing jet on a target at various known distances. Stream continuity was assessed by comparison of force data from targets of two different diameters supplemented with visual data and subjective observation. The underlying assumption motivating this test is that a more coherent stream will provide more efficient and effective sluicing of tank wastes than will a stream that is relatively diffuse. While other testing experience and intuition may support this assumption, it is not the intent of these tests to do so.

The results of this test are intended to identify enhancements to the sluicing method of tank waste retrieval.

1.3 Scope of the Testing

The scope of this test program is to determine the force generated by impingement of water jets on normal targets at various distances for each of the nozzle/flow straightener combinations being tested. Two target sizes were used to assess the stream coherence as a function of distance. Still photographs were also used as qualitative information on stream coherence at each distance.

2.0 Procedure

2.1 Apparatus

2.1.1 Nozzles

Two nozzles were tested:

One nozzle was the standard Hanford nozzle, which is the baseline device currently in use at the Hanford site (Figure 2.1). It features a 2-1/2 inch[1] Female National Pipe Thread (FNPT) connection and a 25-mm (1-inch) throat diameter. The test specimen used had a somewhat rough bore in the small end of the converging section. The Hanford nozzle is a decidedly robust piece of equipment at 5.1 kg (11.3 lb).

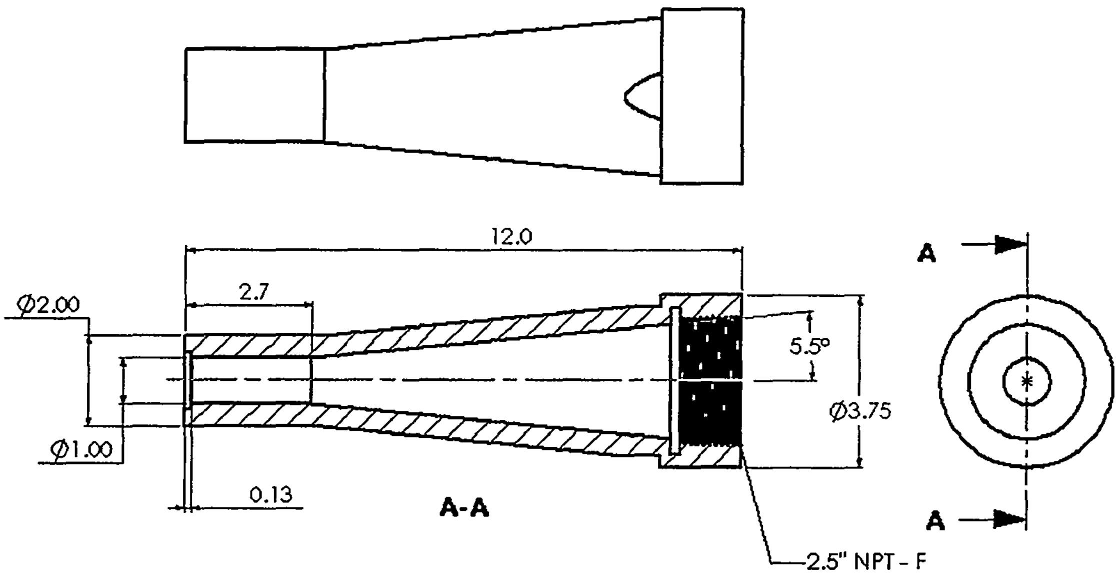


Figure 2.1 Hanford Nozzle (dimensions in inches).

The other nozzle used was an Elkhart Brass Mfg. Co. #181 Brass Deluge Tip (Figure 2.2), which was specifically procured for comparison purposes. The #181 nozzle includes a larger angle converging section and a smoother finish in the bore than the Hanford nozzle, and is much more compact and lighter weight. The brass material would be unsuitable for tank retrieval work; however, the geometry could easily be reproduced in a stainless steel. The #181 nozzle features a 2-1/2 inch Female National Hose Thread (FNHT) inlet, which requires a gasket ring but provides a smooth internal wall through the connection.

---

[1] English units will be applied when they refer to a standard specification such as NPT pipe fittings, pipe side, etc., or where instruments actually read-out in specific English units or are specifically calibrated to an English unit. English units are also used within charts and figures.

It was originally intended that a third nozzle would also be included in the testing. A Marconaflo sluicing nozzle was intended to be included in the tests; however, budget and schedule constraints prevented that from occurring. In lieu of actual testing, a manufacturer's test report and subsequent test data for the Marconaflo system has been appended for reference.

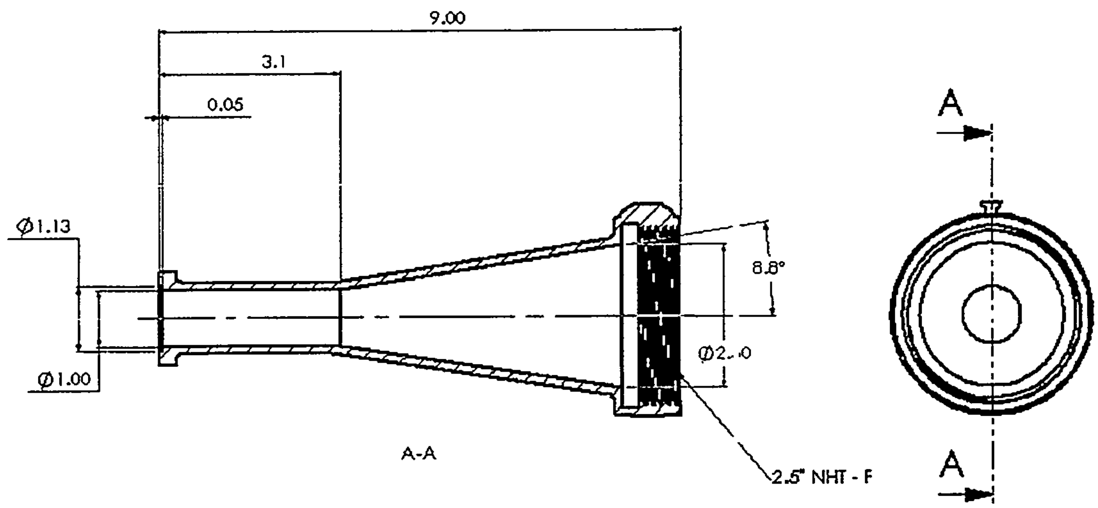


Figure 2.2 Elkhart #181 Brass Deluge Tip.

2.1.2 Flow Straighteners

A flow straightener is designed to reduce or eliminate localized turbulence in flow streams flowing through cylindrical conduits. They typically accomplish this by inserting straightening vanes in the flow stream to prevent swirling of the flow stream as it progresses along the conduit. There are many types and designs of straightening devices in use in industry and these tests were limited in scope to include only two specific designs.

The first one was the standard Hanford flow straightener (Figure 2.3), which is the baseline device. It is essentially a 0.6 meter (2 ft) length of 2-1/2 inch Schedule 40 steel pipe with Male National Pipe Thread (MNPT) ends that has four long straight vanes welded to the interior wall of the pipe and extending about 6 mm (1/4 inch) toward the center. The vanes are welded to the pipe with single welds of about 25 mm (1 inch) at each end and stand off the wall about 4 mm (5/32 inch) except at the welds. The remaining length of the vanes is completely unsupported. The device weighs 4.5 kg (10 lb).

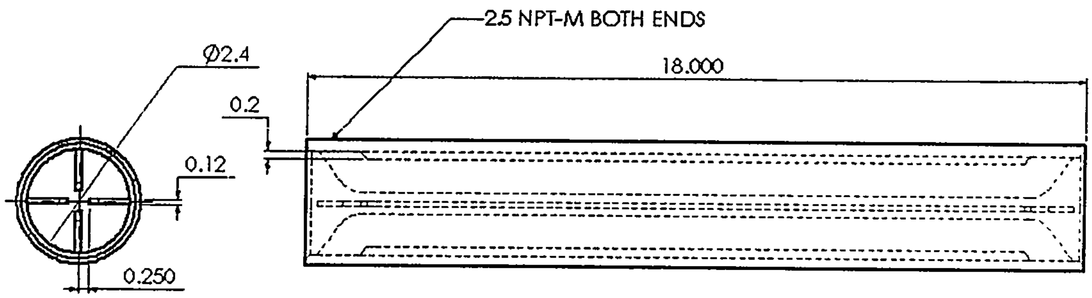


Figure 2.3 Hanford Flow Straightener.

The second device was an Elkhart #282A Stream Shaper (Figure 2.4), which has an acetal plastic "honeycomb" piece mounted in a lightweight alloy housing with 2-1/2 inch FNHT inlet and a 2-1/2 inch MNHT outlet. It weighs 0.7 kg (1.5 lbs.).

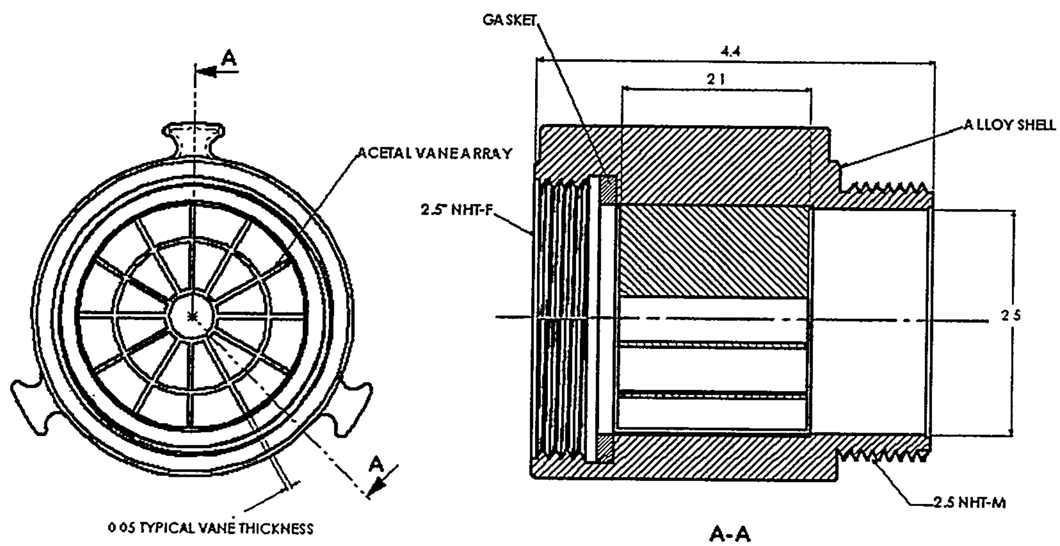


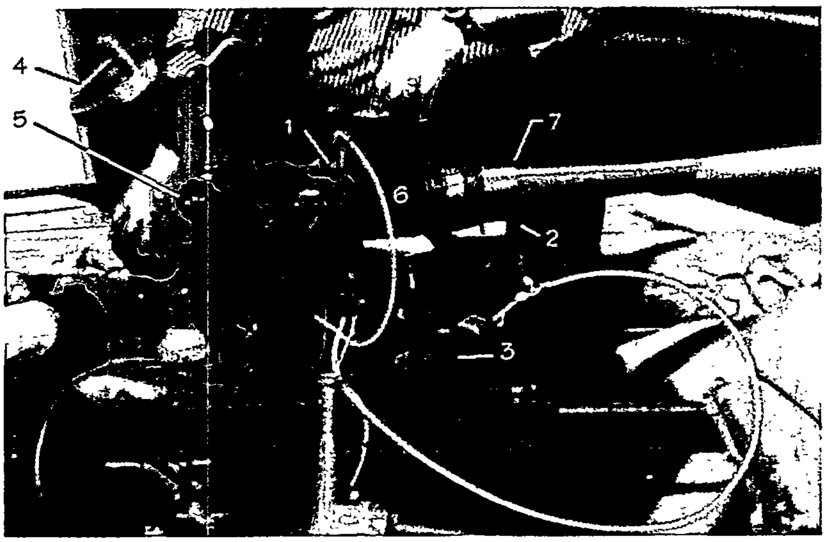
Figure 2.4 Elkhart Stream Shaper.

2.1.3 Combinations Tested

The following combinations of flow straightener and nozzle were tested:

- Elkhart nozzle, no flow straightener,
- Hanford nozzle, no flow straightener,
- Elkhart nozzle, Elkhart Stream Shaper,
- Hanford nozzle, Hanford flow straightener, and
- Hanford nozzle, Elkhart Stream Shaper.

2.1.4 Monitor



1. DIFFERENTIAL PRESSURE (dP) TAP AT MONITOR
2. Dp AND PRESSURE TAP AT NOZZLE ENTRY
3. dP TRANSDUCER
4. ELEVATION CONTROL HANDWHEEL
5. ROTATION LOCK
6. FLOW STRAIGHTENER (ELKHART)
7. NOZZLE (HANFORD)

Figure 2.5 The monitor installation.

The nozzles and flow straighteners were mounted to a fire fighting deck-mount monitor (Elkhart Brass Mfg. Co. Model 8297-99 Stingray Deck Gun), which provided rotary and tilt motion (Figure 2.5). An operator controlled lateral rotation of the nozzle by pushing the nozzle back and forth while the vertical angle was adjusted using a hand-wheel. All the tests were performed with a nearly horizontal jet.

The monitor was bolted to a steel skid, which was secured in place by butting it against a fire hydrant bollard and staking the other end to the pavement. In addition, about 200 kg (441 lb) of sandbags were piled onto the staked end of the skid.

2.1.5 Water Supply

The water source was a municipal fire hydrant, which provided water at about 410-kPa (60 psi) fed to a 9 m^3 (2400 gallon) buffer tank through a totalizing flow meter and hose.

The tank was vented and provided up to 1 m (3.3 ft) of suction head to the pump. The flow rate to the buffer tank was manually controlled using a simple gate valve.

A rented diesel pump (Power Prime model HH-125, 6 inch x 4 inch) was in turn used to supply the water to the nozzles by means of two 8-m (25-ft) lengths of 62-mm (2.5-inch) fire hose in series with a coriolis flow meter (see Section 3.1.7 Instrumentation).

The pump proved inadequate to achieve the desired 1.03 MPa (150 psi) at the nozzle due to inlet losses and pressure drop across the delivery hoses, monitor, and flow meter. As a result the tests were conducted at approximately 0.83 Mpa (120 psi).

2.1.6 Targets

The targets were circular flat steel discs. One was 27 cm (10.5 inch) in diameter and the other one was 54 cm (21.0 inch) in diameter. The sizes were chosen to be the same as those used in the Marconaflo tests [2] performed by the manufacturer. The targets were attached to a sensor that measured the force moments imparted to the target by the jet. The larger target was designed to easily attach over the top of the smaller target to reduce setup time (Figure 2.6).

The target mount had provisions for adjusting range, elevation, elevation angle, and bearing to the target. The target, item (3) in Figure 2.7, and force-moment sensor (1) were bolted to an existing bracket (2) and to a machinist's rotary cross-slide indexing table (7). The table was then mounted to a plate (6) mounted with threaded rod (16) and nuts (17) to provide pitch adjustment and to provide a method of clamping itself to a set of forklift forks. The forklift was driven to range location +/- 25 mm (1 inch) and roughly aligned by steering the forklift into position. Then the target alignment to the jet was fine-tuned with the indexing table. It was not known exactly how precisely the monitor could be aimed; therefore, some features of the target mounting were intended to support precise positioning and alignment of the target to the water jet. The forklift tilt mechanism proved to be controllable enough to present the target normal to the measured vertical jet angle within a few tenths of a degree, so the threaded rod pitch adjustment was not used. One bar of the target mount was extended to the side to provide a rough aiming target to minimize dwell time of the jet on the target, reducing risk of damage to the force-moment sensor. The monitor proved relatively easy to aim, so target alignment to the jet was easier than anticipated. The rotary table also proved very useful for quick bearing alignment.

---

[2] 'Letter Report: Marconaflo™ 1977 Test Program, Interoffice Correspondence J.F. Ogg to W.N Sims. See Appendix

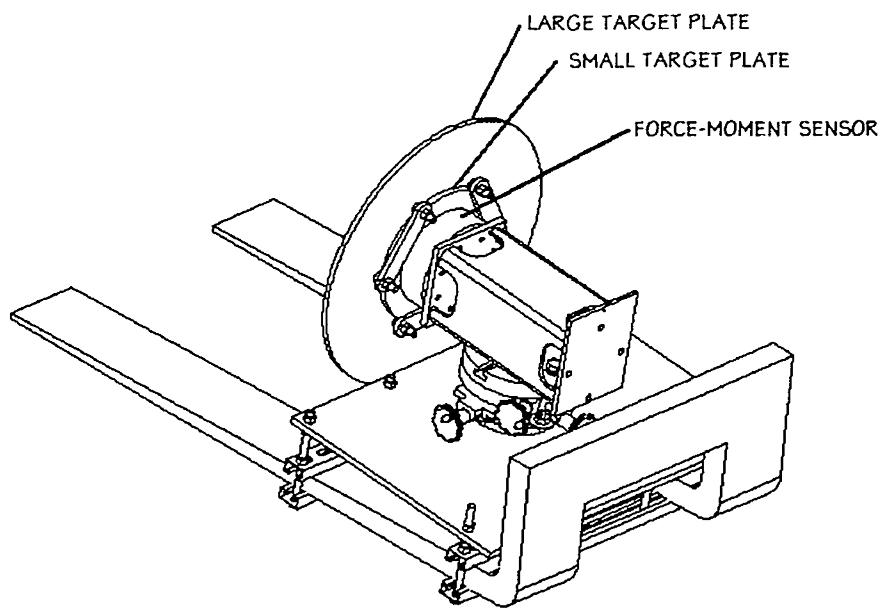


Figure 2.6 Rear view of target with 54-cm (21-inch) plate attached.

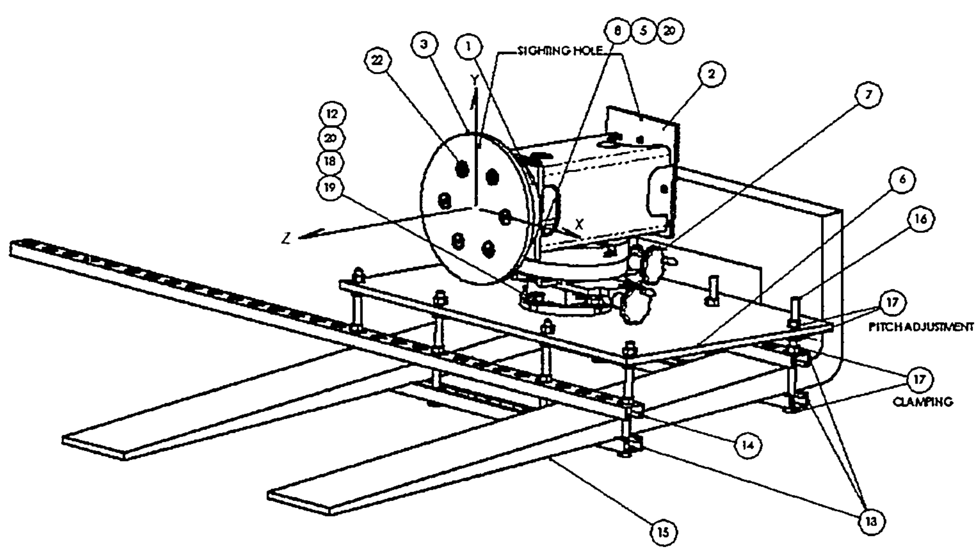


Figure 2.7 Front oblique view of target with 27-cm (10.5-inch) plate only. Axes (X, Y, Z) of the force-torque sensor reference frame are shown.

2.1.7 Instrumentation

2.1.7.1 Force Measurement

The force and moment resulting from impingement of the sluice jet on the target plate was measured with an Assurance Technologies Inc. (now ATI Industrial Automation) flow temperature (F/T) Sensor Omega 600/7000, Serial Number (S/N) 3369. The device was calibrated by the vendor just prior to the testing. The Fx (force aligned with X-axis), Tx (Moment about the X-axis), Ty and Tz axes exhibited non-linear error of slightly greater than 1%. Fz force (axial force) output, the force of primary interest, was well within the 1% tolerance.

Output from the F/T sensor is processed by a multiplexor (Mux) box and controller (same S/N number) and supplied to the data acquisition system as a matrix of values updated at a user-controllable interval.

2.1.7.2 Flow Measurement

Water flow rate was measured with a Micro Motion Coriolis flow sensor Model DS3005155SU, S/N 162827 and transmitted to the data acquisition system by a transmitter Model RTF9739, S/N 1511597. The data acquisition system (DAS) was scaled so a 0-400 gpm flow (see Footnote 1 on page 2.1) corresponded to the 4-20 mA sensor output. The Micro Motion device also sensed water temperature, where the DAS was scaled from 10-40°C to correspond with a second 4-20 mA signal.

2.1.7.3 Pressure

Gage pressure at the entrance to the nozzles was measured with an Ametek pressure transducer, Model 88F005A20CSSM, S/N 40173-1-18, calibrated to 0-300 psi, with an accuracy of +/- 0.25%. The unit was calibrated by AMETEK on January 4, 1995, with NIST trace number 45F-2-00290.

2.1.7.4 Differential Pressure

The differential pressure (dP) across the flow straightener was measured with a Rosemount differential pressure transducer/transmitter unit, model number 115 1DP4E22 B2, S/N 266332, with a range of 0 - 150 inches water (see footnote on page 2.1) and an accuracy of +/- 0.1%.

2.1.7.5 Data Acquisition

Signal outputs from the various sensors/transmitters were recorded using a portable computer with a real-time graphical data display, which facilitated rapid aiming and real-time data review. The software used was National Instruments Labview "Virtual Instrument" developed on a Labview system and downloaded to the portable as an executable program.

Analog data from the flow and pressure instruments was converted from the current signal to a voltage signal using precision 249Ω resistors and then to a digital signal with a National Instruments DAQcard-700S/N A14EE5.

Calibration factors for the pressure instruments were determined by linear regression of the calibration data. The sensing range of the initial dP instrument set up on the system proved to be insufficient for our test pressures. A second, un-calibrated, unit was brought out to the field and field calibrated over its normal sensing range and installed onto our test setup. The field calibration was performed using a static water column and showed the replacement instrument to have a nominal accuracy within 2% of full-scale.

The flow instrument was a MicroMotion D300 sensor coupled with an RFT Model 9739 transmitter. The reported range and accuracy for this system was 0 to 7000 lbs/minute and +/ - 0.2% of the rate, respectively.

2.1.7.6 Geometry

The distance between the nozzle and target was measured using a steel tape measure, where the accuracy of the measurement was estimated to be +/- 25 mm (1 inch) based on the measuring device and the rough method of measurement used. Test range point elevations were measured using a surveyor's transit and measuring rod. The manufacturer's stated accuracy for the transit was +/- 1/16 inch at 100 ft distance (see Footnote 1 on page 2.1).

Jet exit and incident contact angles were measured with a hand-held digital inclinometer. Incident angle readings were made visually. The incident contact angles were measured by a student intern, who was positioned at an arbitrary distance away from the jet stream and who sighted the approximate stream angle along the top or bottom edge of the inclinometer and recorded the resultant angle reading. The device has a "hold" button to lock in the reading at any point and save it until manually cleared. This allowed the intern to sight the angle and press the hold button without trying to read the LCD readout while attempting to hold the device in position. The alignment of the inclinometer with the incident stream was necessarily subjective due to the diffuse stream and the visual alignment technique employed. As a result, the nominal 0.1° accuracy of the device proved to be an insignificant magnitude.

The jet exit angle for the Hanford Nozzle was measured by placing the inclinometer on top of the straight exit section of the nozzle and reading the resultant angle. A visual technique was again used for the Elkhart nozzle because its exit nozzle shape was not straight.

Target plate angles were also measured using the inclinometer where one edge of the inclinometer was place against the target face and the forklift tilt was adjusted until the desired angle was achieved.

2.2 Procedure

2.2.1 Setup

The monitor and target were prepared as previously described and the range was laid out with target placement marks spray-painted on the pavement. The forklift with the mounted target assembly was positioned on the range at one of the target placement marks with a plywood spray shield and tarp installed to protect it.

The pump was set up near the buffer tank discharge and the instrumentation and hoses laid out to safely and efficiently feed the monitor and nozzle assembly. A pre-job discussion of the test procedures and applicable safety issues was held before attempting a few trial runs. The purpose of the trial runs was to shake down operations and instrumentation and to fine tune our test procedure. It was during the initial trial run that the first dP instrument was determined to have an inadequate range - 750 mm (30 inch) H_2O to measure the dP across the Elkhart flow straightener. Before the next trial run the unit was replaced with the 3.75 m (150 inch) H_2O unit, which was field calibrated immediately preceding its installation. The next trial run proved that the setup was ready to begin testing.

It was also discovered that water was able to penetrate along the small target mounting bolts and enter the sensor internal areas. This caused the sensor to malfunction. The unit was allowed to dry out, after which the sensor operated normally. The small target plate was reattached using silicone grease along the bolts and filling the space behind the plate with epoxy. As an added precaution the next trial runs used the larger target plate, which did not have any direct pathways for water to migrate to the sensor. The system checked out as fully functional after these modifications were completed.

2.2.2 Testing

2.2.2.1 Target Alignment

The initial test series were run with the large target plate as this reduced the risk of an early force/moment sensor failure from sensor contact with water. The target assembly was positioned at the desired distance mark on the ground and roughly aligned to the nozzle. A string line was pulled taught along the nozzle centerline and over the target and the target was rotated with the index table to align the target plate normal to the string. A pair of alignment marks on the target mount were used to sight against the string. A stream of water, at test pressure, was then shot at or just to the side of the target and the exit and incident angles measured. The water was shut off and the target vertical tilt was set normal to the incident jet +/- 0.5° using the forklift tilt control and measuring the angle with the inclinometer.

A full series of tests using the small target were performed after all the large target tests were completed. The sensor operated normally throughout these tests as well, indicating that the modifications applied to the small target solved the water leakage problem seen during the trial runs. During the small target tests, the incident angle was not measured. The same target tilt angle used for the large target tests were used for the small target tests.

2.2.2.2 Test Runs

All tests were conducted with the pump operating at the governed engine maximum speed of 2200 rpm. Pressure measured at the nozzle was between 783 kPa and 814 kPa (115 and 118 psi) for all tests, and the measured flow rates were between 19.9 L/sec and 20.3L/sec (315 and 321 gpm). Water temperature varied between 19.4°C and 22.2°C.

Initially, the jet was swept slowly across the target plate several times while incrementally changing the elevation for each pass. The data sample was taken starting with the jet off-target to get a baseline then the jet was slowly swept over the target. The intent was to post-process the data, selecting only force data corresponding to moments within a limited range of magnitude. This would select force data from a jet impinging on the center of the target. During the first several test runs, it was discovered that the jet could be aimed at the target accurately enough using the force and moment feedback rather than executing the sweeping action employed earlier. The jet was centered on the target and then held stationary for approximately 30 seconds. The result was that a larger sample of data was able to be collected with the jet centered and stationary than could be selected from data captured using the sweeping method. The remaining test runs were performed using this static-mode method.

Subsequent static-mode test runs were conducted by aiming the jet using instrument feedback, then moving the jet laterally off the target a couple of feet. With the jet off-target, the data sample (100 sec at approximately 10 Hz) was started. After a few seconds, the jet was redirected back at the target and brought to center, where it was held for approximately 30 sec. It was then slowly played back and forth a few times, taking it completely off the target at various intervals. This method captured a large number of data points with the jet on-target and, also, several distinct no-load force readings for detecting and compensating for drift in the force sensor (discussed in Section 3.3 Analysis).

2.3 Data Analysis

2.3.1 Data Quality

Pressure, temperature, and flow data were of secondary importance compared to stream coherence and impingement force. They were also mostly a function of the pump and water distribution system configuration than any test configurations. In all test runs, the pressure, temperature, and flow remained reasonably steady and consistent with no anomalies observed.

The force/moment sensor data was characterized by considerable variance, with σ ranging from 5% of the mean for short-range tests to >40% at the maximum range. The sensor also exhibited significant drift during several of the tests.

Initially, the force/moment sensor drift was ascribed to stress induced in the strain gage spider in the device resulting from imperfect mating of the mounting surfaces and bolt pattern. Imperfect surface mating is known to cause drift in this type of devices. To rectify the drift, the small target was re-mounted with epoxy putty between the mounting plate and the target plate. The screws were drawn finger tight until the epoxy set, then tightened an additional quarter-turn.

The large plate was installed over the small plate for the first series of tests to minimize risk of early sensor damage. Immediately after this process, the drift was reduced by 80% and within an hour, the drift had substantially disappeared. No significant drift was observed in the data taken with the large target plate bolted to the small plate.

When the large target plate was removed, drift in the Fz readings, manifest by the offset in Fz when the jet was directed away from the target plate at the end of a run, was observed. The drift appeared to be fairly linear over the 100 sec of a run. The procedure of ordering a sensor bias reset (zeroing the force/torque readings) before starting the run was adopted. The revised procedure was to reset the sensor bias, then move the jet off target and start collecting data for approximately 10 seconds. Next, the jet was moved to center on the target and data was collected for approximately 30 seconds before beginning slow sweeps across the target or, in later tests, simply directing the jet off the target again. This resulted in clean (low-noise) Fz readings at each end of the data run, which could be used to estimate the sensor drift and compensate for it.

On one test (H25) a 100-sec data run was started and an unusually high drift was observed. This test run was aborted and the restarted after the first data set was saved. The repeat data set was appended to the first. Later, after testing was concluded and during analysis of the data, it was observed that the drift had reversed and vanished during the first abortive test and was not evident in the second test run (Figure 2.8). Unfortunately, this wasn't detected during the test period so most of the small-target data includes Fz drift as fast as 0.3 lbf/sec. For low-drift-rates, a linear approximation is a reasonable compensation; however, it may undercorrect for higher rates of drift, where it appears that the rate of drift decays with time.

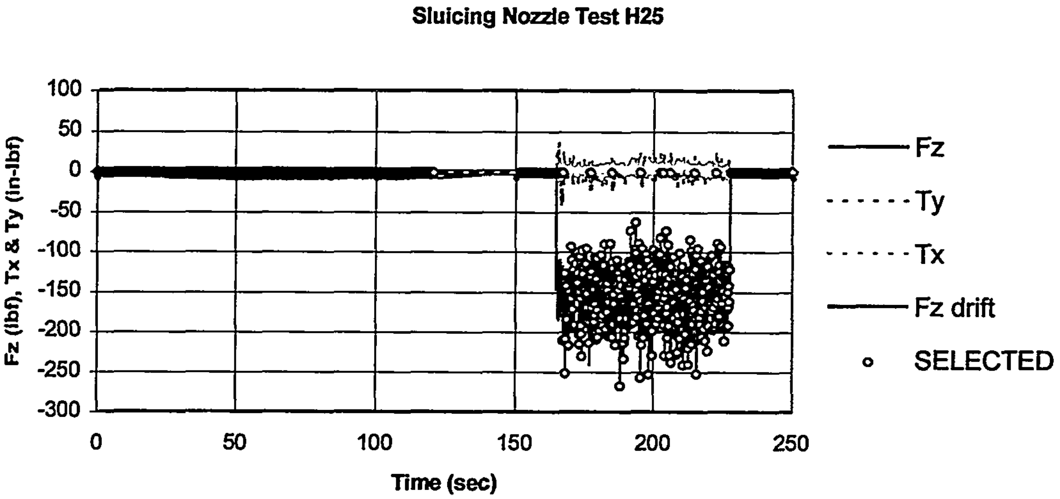


Figure 2.8 Data plot for Test H25 showing non-linear drift in Fz.

2.4 Data Reduction

The following selection and averaging techniques were used to arrive at the force values reported in Section 4, Conclusions.

2.4.1 Data Filtering

Fz (force component parallel to the Z-axis data (see Figure 2.7) was filtered using the following criterion:

a. The magnitude of Fz is greater than a threshold value, ensuring that the jet was impacting the target.

b. The magnitude of Tx and Ty (torque about the respective axes) at the same time was less than a threshold value, ensuring that the jet was near the center of the plate.

2.4.1.1. Data Selection

The filtered data was selected by applying the criteria that any data point used had to be contiguous in the discrete time domain with four other data points passing the filter. The non-zero selected data were used to compute the average and standard deviation values reported.

2.4.1.2 Selection Criteria

The Fz criteria were determined by plotting the average Fz for both filtered and filtered/selected data as a function of the Fz limit. The limit was set at a value where the slope of the resulting curve was nearly zero. For a typical data set, some of the data was recorded when the jet was not centered on the plate, which resulted in the measured force being low and the moments either low or relatively high. A low Fz filter will include a lot of off-center data since the low force will result in a low moment as well, allowing the data to pass the Tx, Ty filter. This will reduce the average Fz magnitude markedly, as can be seen in Figure 2.9.

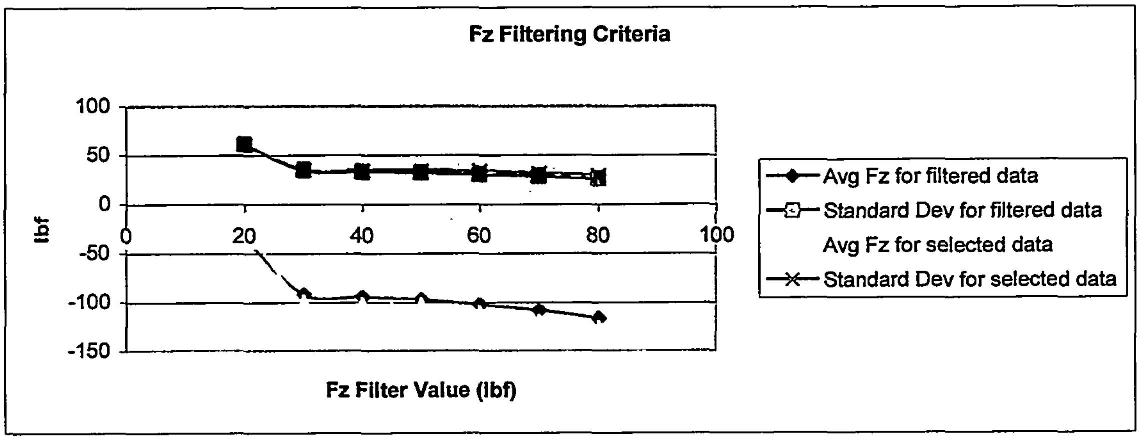


Figure 2.9 Typical filter value selection plot.

If the Fz filter value is set too high, it starts to bias the average by deleting data in the -3σ band. In cases where the force varied slowly through the filter value, the filter again introduced a bias in the same manner. In those cases, the data in the transitional periods were manually changed to a zero value to ensure that it would be filtered without biasing the selected data.

2.4.2 Other Factors

The most significant influence on the data quality was probably the wind. The tests were conducted outdoors in varying winds. The wind conditions for the 48-hour period in which the tests were performed are plotted in Figure 2.10. The time period of actual testing was about 0.3 – 0.6 day and 1.3 – 1.6 day. Most of the time the average wind velocity was less than 4.5 m/sec (10 mph), and the direction was southerly (the range was aligned roughly south north, with the jet traveling north). During those conditions the wind had little effect on stream properties. After noon on the first day of testing the wind picked up to an average over 6.7 m/sec (15 mph) and shifted to westerly, which had a much greater influence on the coherence of the stream. By about 2:30 P.M. that day, the direction was NW and the wind speeds had increased enough to suspend further testing that day. The tests that were run that day were for the Hanford nozzle, which was being tested at increasing range using both flow straighteners at each target distance. While the wind degraded the coherence of the respective streams, it did so randomly and without bias with regard to which flow straightener was being used. Essentially, the flow straighteners were tested against each other under reasonably similar conditions.

On the second day of testing, the wind was lighter and less steady in the morning. The test sequence was to change nozzle and flow straightener combinations at each given distance, so the combinations were tested under similar conditions at each target distance. The absolute performance data taken during the afternoons when the wind tended to pick up is somewhat suspect, but the comparisons between the various equipment combinations tested should remain valid

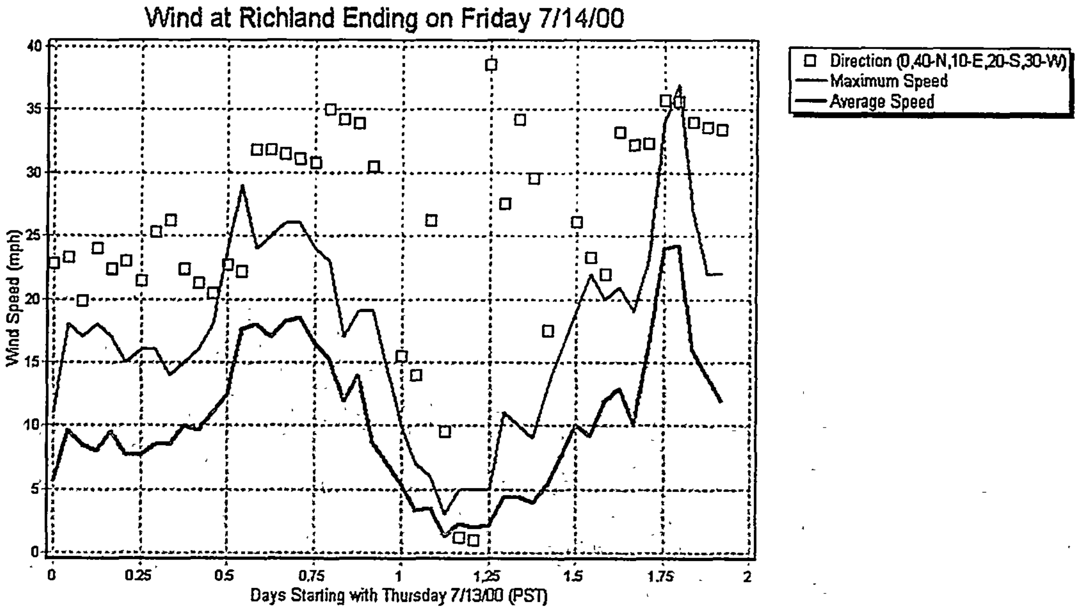


Figure 2.10 Plot of wind speed and direction during the testing. (Courtesy http://www.pnl.gov/waconia/Weather/Rosy_combo.ASP)

2.4.3 Empirical Observations

Photographs were taken of the sluice streams to visually compare the stream coherence. Selected photos are presented in the following Figures 2.11 through 2.15.

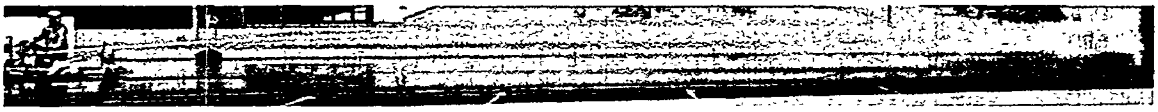


Figure 2.11 Test H17 - Elkhart nozzle with Elkhart Stream Shaper, 19.2 m (63 ft).

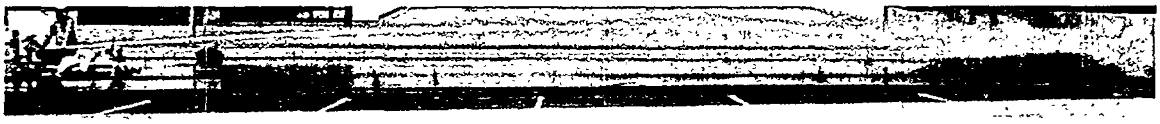


Figure 2.12 Test H18 - Hanford Standard nozzle with Elkhart Stream Shaper, 19.2 m (63 ft).

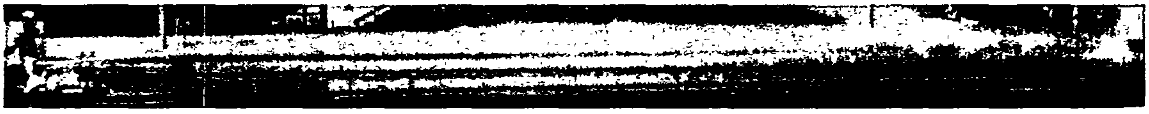


Figure 2.13 Test H19A - Hanford Nozzle with Hanford Flow Straightener, 18.59 m 61 ft).

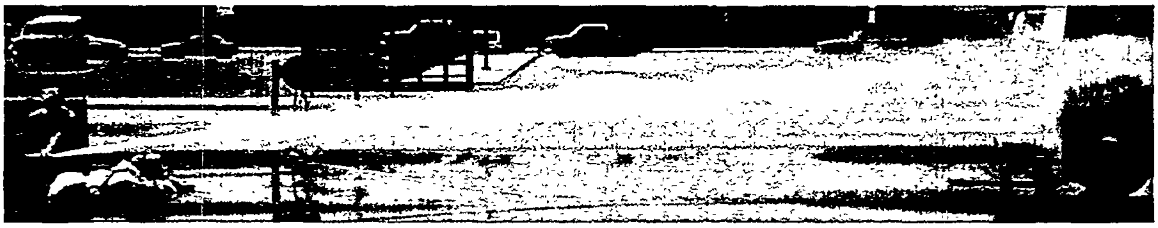


Figure 2.14 Test 29 - Hanford Nozzle with no flow straightener, 10.06 m (33 ft).

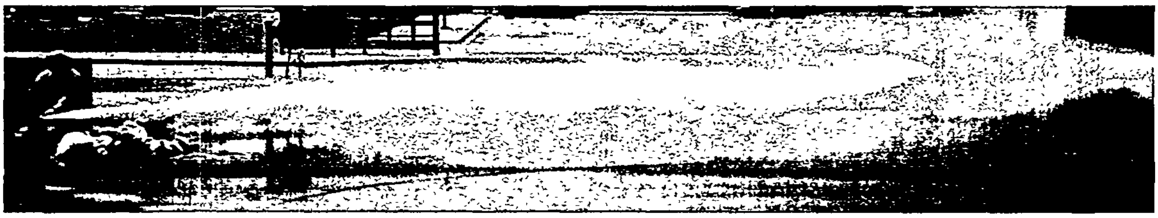


Figure 2.15 Test 30 - Elkhart Nozzle with no flow straightener.

2.5 Comparison to Theory

The flow rates measured were found to correspond to a Cd value of .958 for both of the test nozzles. If all the momentum of a stream at the discharge rates observed were cancelled at the target, the theoretical reaction would be 791N (178 lbf). Three of the averaged Fz data for short-range tests exceeded this value by no more than 2.9%. This is considered insignificant compared to the variance of the data; one standard deviation for the most consistent data set was approximately 7% of the mean value.

3.0 Conclusions

3.1 Stream Coherence

Two significant conclusions can be drawn from the numerical data:

1. The use of a flow straightener is absolutely necessary to maximize stream coherence and useful sluicing performance.
2. Tests using the larger target did demonstrate a clear distinction between the various nozzle/flow straightener combinations as evidenced by data plotted in Figure 3.1; however, Figure 3.2 shows that the Elkhart Stream Shaper provided measurably better stream coherence during testing with the smaller target plate. Note that the reaction force at close range for the small target tests agrees well (within 3%) with the theoretical value maximum. The theoretical values are plotted in Figure 3.3. The data in all three figures was plotted after selection and filtering processes were complete.

3.2 Pressure Loss – Flow Straighteners

There is a significant difference in pressure drop in the nozzle when used without a flow straightener and when used with a flow straightener. However, the difference in pressure drop between the different combinations that used a flow straightener was insignificant. The pressure drop data for the various nozzle/flow straightener combinations are presented in Figure 3.1. Note that the ESS combination (Elkhart nozzle on Elkhart Stream Shaper) required no adapters while the HSS combination (Hanford nozzle on Elkhart Stream Shaper) required a 2-1/2 inch FNHT x 2-1/2 MNPT adapter between the flow straightener and the nozzle and the HSTD (Hanford nozzle on Hanford flow straightener) combination required a 2-1/2 inch FNHT x 2-1/2 inch FNPT adapter between the monitor and the flow straightener. The adapter fittings, which could be omitted from a sluicing monitor, add some degree of pressure drop to the applicable configurations. The differential pressure across the flow straighteners amounts to about 3% of the pressure at the nozzle and the difference between flow straighteners is only about 0.6% of the nozzle pressure.

3.3 Limitations

The following limitations regarding the comparison of streams produced by the nozzles without flow straighteners must also be identified. The raw data indicate that the Elkhart nozzle alone produces a more coherent jet than the Hanford nozzle; however, mounting the Hanford nozzle to the monitor required a FNHT x MNPT adapter. The adapter interface may have introduced a step in the wall at the pipe thread joint, exacerbating the turbulence. In addition, the jets from both nozzles, when used without flow straighteners, were very incoherent so accurate aiming was impossible, and it is by no means certain that the data is representative of the best possible performance of either nozzle. The slow and diffuse jets produced were certainly influenced more by the wind than were the tighter jets produced using the flow straighteners. The force/moment data plot was of no use for aiming the jets in these two tests, as the traces were so erratic that visual averaging was impossible. The data and photographs from the nozzle-only tests should only be used to support the first conclusion above.

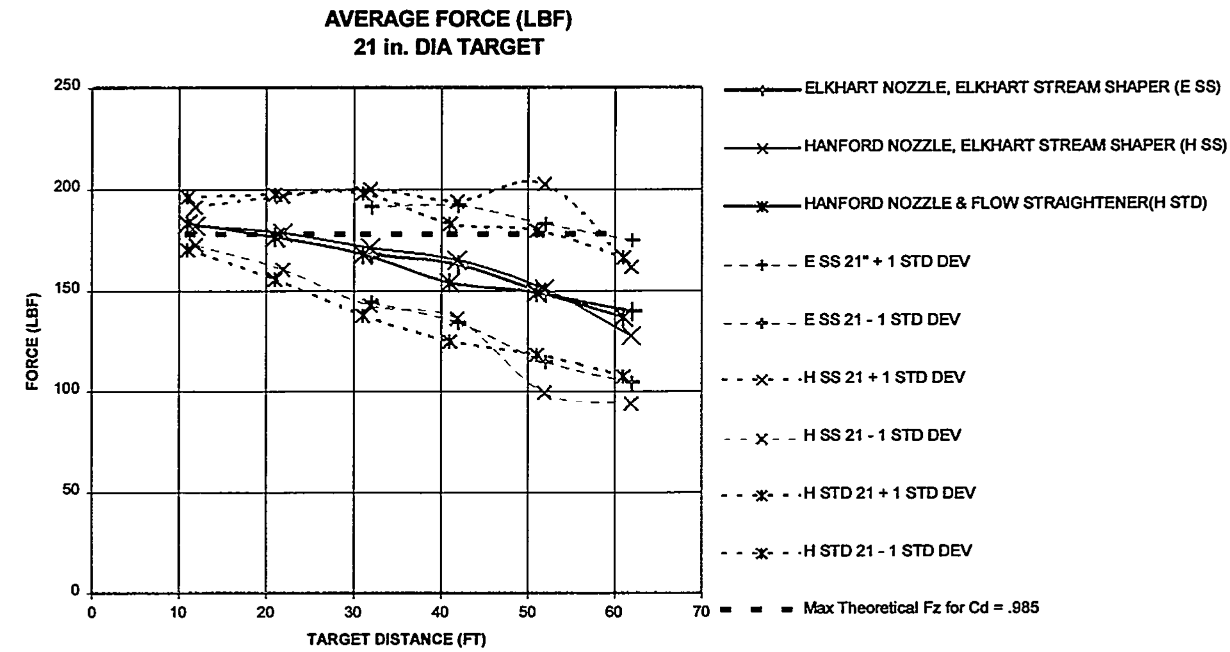


Figure 3.1 Stream force on 54-cm (21-inch) diameter target. The large variance of the data is indicated by the 1-σ bands plotted for each configuration.

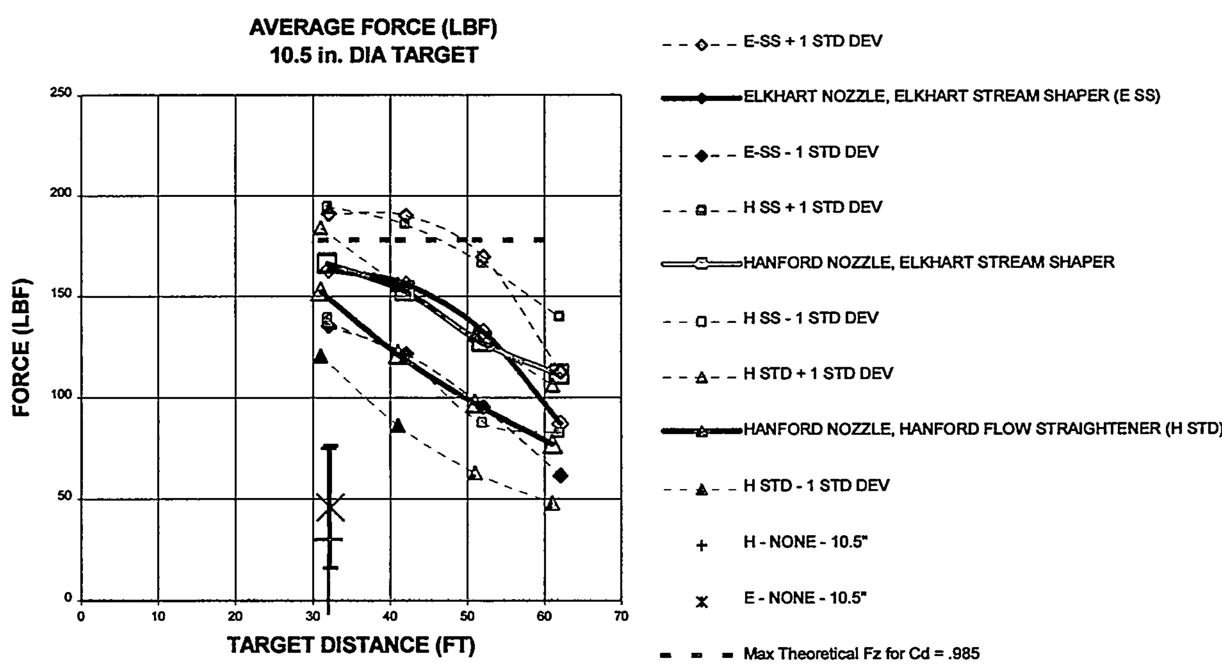


Figure 3.2 Stream force on 27-cm (10.5-inch) diameter target. H-NONE and E-None are shown with error bars of 1-σ.

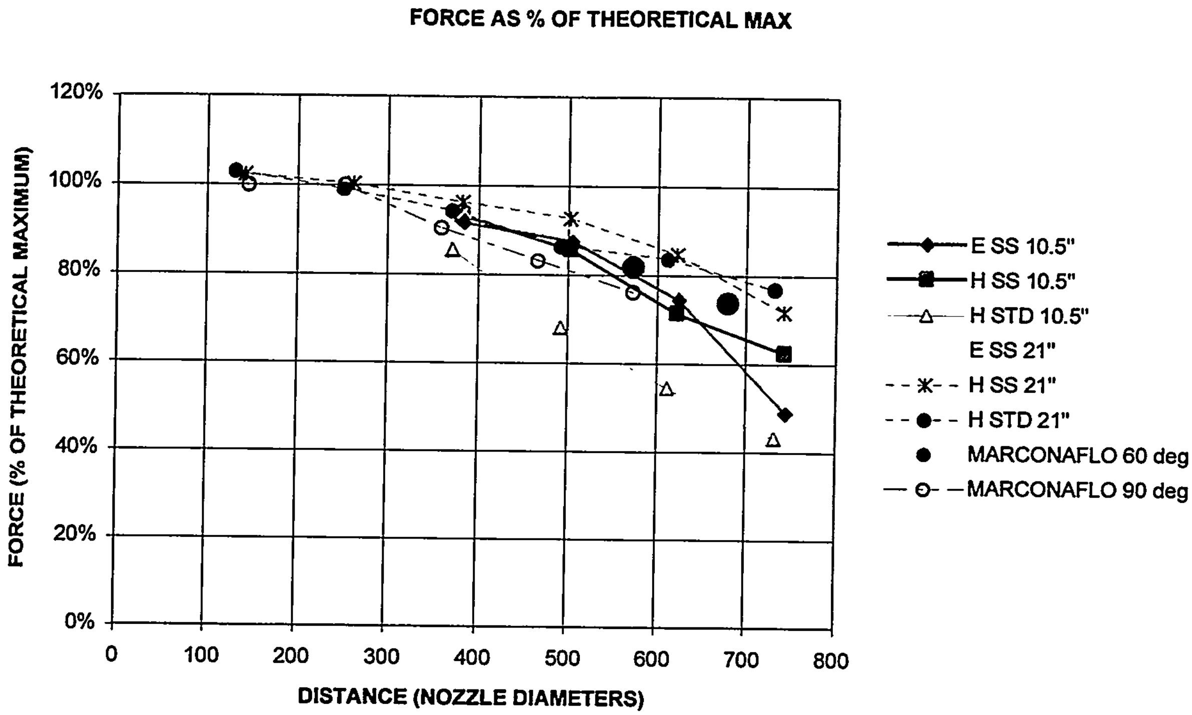


Figure 3.3 Jet force as percent of maximum theoretically possible, distance to target scaled to nozzle diameters. The Marconaflo data is for a 28.58-mm (1.125-inch) nozzle at 360 psi on a 27-cm (10.5-inch) target (1).

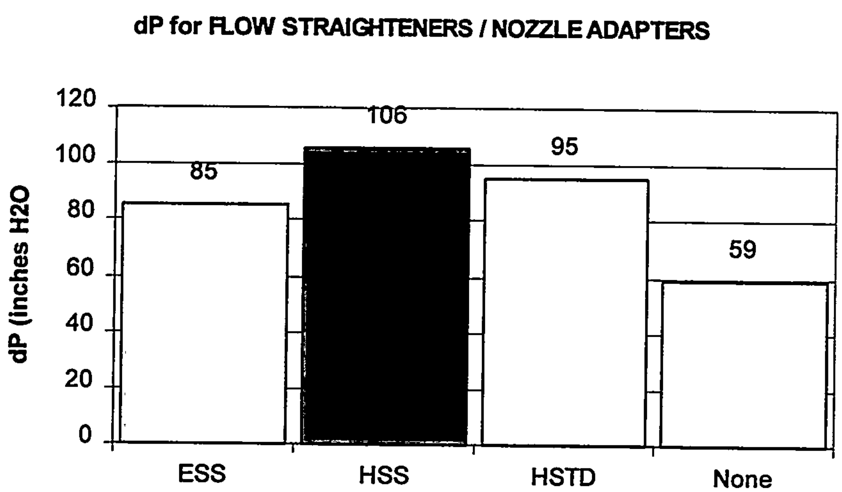


Figure 3.4 dP Comparison for flow straighteners with nozzles and adapters.

4.0 Recommendations

The Hanford flow straightener should be replaced with a more effective design unless there are other compelling reasons to continue using it. One such reason might be that the Hanford design, having larger "cell" cross-section dimensions and a single passage, would be more tolerant of any large objects/solids in the sluicing liquid. The smaller "cells" of the Elkhart design could act as a strainer with larger particles and be prone to clogging unless the fluid is filtered upstream.

Also, the Hanford nozzle is unnecessarily heavy for the common pressures used for sluicing and could easily be reduced in mass without jeopardizing its longevity or performance. A cursory analysis indicated that at 2 Mpa (300 psi) the current Hanford nozzle design has a safety factor of about 20. It must also be considered that there may be no cost benefit to redesigning it solely to reduce the mass as long as it is not too heavy for normal handling and installation activities. Since the nozzle is machined from solid stock, it would typically require additional machine time to remove weight, which adds cost to the fabrication. Ultimately it would be more expensive to fabricate a lighter version of the current design.

If the nozzle were redesigned to also incorporate a smaller and more efficient flow straightener, similar to the Elkhart streamshaper (Figure 4.1), the cost benefit might be realized by improved performance. In addition, the incorporation could eliminate the extra bulk, torque, and mechanical connections associated with the existing nozzle/flow straightener design. Using National Hose Thread and fire apparatus wrench dogs would also allow a smooth bore through the connection to the monitor and use of simple hook spanners for installation instead of heavy pipe wrenches.

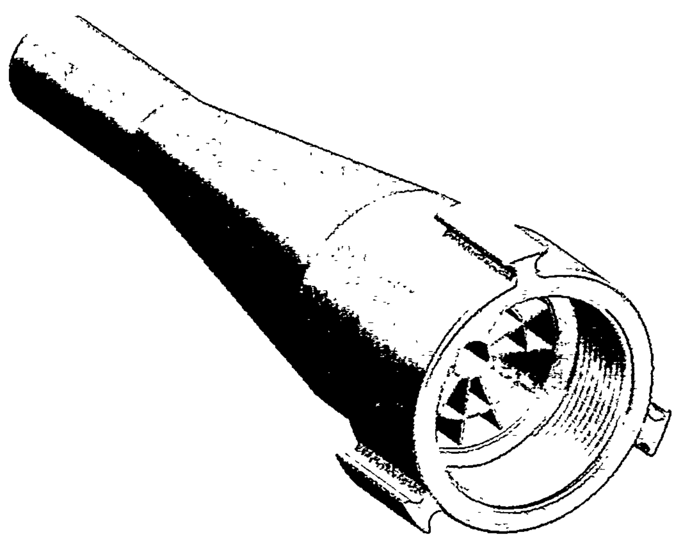


Figure 4.1 Proposed improved sluicing nozzle with integral removable flow straightener and spanner dogs.

Careful attention should also be paid to the surface finish on the nozzle bore. It is unknown whether the manufacturing quality of this nozzle is representative of the nozzles used in the field, but the Hanford nozzle used in these tests had significant machine tool marks (several thousandths of an inch deep) in the narrow end of the converging section, which may have degraded its performance. For example, for the Reynolds number of about 9000 obtained at the test flow rate, the friction factor for 0.1 mm (.004 inch) roughness in a 25-mm (1-inch) bore will be .038 versus .032 for a smooth bore, an increase of 19% in shear at the wall.

Appendix

Marconaflo System

The Marconaflo sluicing system uses a nozzle set at a fixed angle to the vertical supply pipe, which is rotated about its axis, so the jet sweeps a roughly conical pattern. The slurried waste then drains to the apex of the cone where it is retrieved by a slurry pump.

It appears from that data available that the Marconaflo system has a very effective nozzle and flow straightener, especially considering that the flow straightener is incorporated into the nozzle assembly. The Marconaflo nozzle assembly is comprised of an acutely angled and compact elbow, cast as a single piece, a flow straightener, and a short nozzle attached to the end. It is questionable whether the Marconaflo retrieval strategy is useful for complete cleaning of the large DOE tanks with relatively flat bottoms; however, it does appear to have merit and should be considered for any new storage facilities.

INTER-OFFICE CORRESPONDENCE

TO: W. N. Sims

DATE: February 3, 1978

FROM: J. F. Ogg

COPIES TO:
J. R. Collier
A. K. Andersen
J. T. Watson
N. G. Jouk
M. O. Rosenheimer

SUBJECT: Report: 1977 Nozzle Test Program

REFERENCE:

The attached report is submitted for your review.

The report concludes that the present 8-inch MARCONAJET design is close to optimum with the exception of the plastic orifice vanes. At 63 feet, the use of two metal orifice vanes increased impact on a 10.5-inch target from 74.2% to 85.5%.

The report suggests that any future tests be directed toward improving the performance of smaller nozzles and developing an effective but rugged orifice vane design.

J. F. Ogg

JFO:mu

Attachment

ACKNOWLEDGMENTS

Mr. A. K. Andersen, Manager, MARCONAFLO Research Center, was most cooperative in providing test facilities and scheduling operating personnel for the test series.

Mr. J. C. Arze and Mr. J. R. Goodpaster operated the test loop and assisted in the data collection.

Mr. W. P. Wood, former Marcona employee, provided verbal history and technical perspective on testing done in 1969-1972.

1977 NOZZLE TEST PROGRAM

I. FOREWORD

This report presents the results of the 1977 nozzle testing program. The last formal test program was conducted in 1971.

II. OBJECTIVES OF TEST PROGRAM

A. Select Optimum Nozzle Design

The basic objective was to select the optimum gooseneck orifice and straightening vane combination for the DYNAJET 3000 to be furnished to Southern California Edison.

The SCE application required that the jet stream be effective at distances up to 210 feet. Normal operating distances are less than 100 feet. Previous test distances did not exceed 50 feet.

B. Identify and Evaluate Design Features Which Affect Performance

The basic objective was to determine the effect of changes in design details on jet stream performance. The key design parameters are gooseneck geometry, straightening vane design, orifice geometry and the effect of manufacturing errors.

C. Obtain Benchmark Test Data

The basic objective was to obtain a matrix of accurate test data. This test data can be used to compare present nozzle performance with the performance of past and future nozzle designs.

In conjunction with data collection, the test results were compared with predicted results based on established analytical techniques. This permitted normalizing test values as a decimal fraction of theoretical values. The interpretations of analytical techniques with test results also permitted adjusting test data for small changes in pressure and orifice diameter.

An assessment of the experimental error was made to establish limitations on the accuracy of test data.

III. SCOPE OF TEST PROGRAM

A. General

During the period from June 6 to July 14, 1977, 55 major data points were taken representing specific design and test configurations. Some 180 supplemental data points were also obtained which provide support to the major data points.

B. Design Evaluation

The following design configurations were evaluated:

1. Four gooseneck designs (90°, 60°, 38° and 30°)
2. Three orifice sizes (1-1/8, 1-3/16, 1-1/2)
3. Four orifice vane designs (plastic, copper grid, steel cross, none)
4. Orifice extension section (with provision for vane)
5. Miscellaneous experimental vane designs

C. Test Parameters

The following test parameters were utilized.

1. Seven target distances (6'-6" to 63'-8")
2. Two target sizes (10.5" dia. and 21" dia.)
3. Pressures up to 360 PSIG (50, 100, 150, 250, 360)
4. Underwater tests at short range

IV. TEST PROCEDURE

A. Test Constraints

The large number of design and test configurations made it impractical to test all possible combinations. Therefore, the testing was conducted in a manner which converged on an optimum design configuration.

Other test constaints included a limited water allocation due to the drought, a limited availability of the pump and the generally poor condition of the test equipment. In particular, the HP water pump was overdue for a major overhaul and could only be operated for short periods between repackings.

B. Baseline Concept

An initial baseline design was established and tested. Other design configurations were then tested at selected points and the results compared to the baseline.

C. Design Optimization

An improved design configuration was then established, incorporating design features which appeared to provide the best performance. The new design configuration was tested sufficiently to establish a new, improved baseline.

Using the improved baseline design, key design features were selected to determine the optimum design.

V. SUMMARY OF TEST RESULTS

A. Calibration Tests

The test equipment and orifice discharge coefficient were calibrated prior to formal testing.

1. Target Force System Calibration

The pressure gauges and target were calibrated using known forces and pressures. The elevation difference in pressure gauge location and target was applied as a correction to all readings (1.5 PSI). Duplicate pressure gauges for nozzle supply and target pressure were used to identify gauge malfunctions.

2. Orifice Discharge Coefficient Calibration

The orifice discharge coefficient was calibrated at the 13'-8" range. At this close range, the actual jet impact is 100% of theoretical because there is no loss of momentum in the jet stream. E.g., there is no loss of mass or loss of velocity from orifice to target. Verification of 100% impact was obtained when the impact at the 23'-9" remained the same. At the 13'-6" range, the impact vs. pressure relationship remained linear over the 50 fo 350 PSI range.

Knowing the 100% impact, the orifice diameter and the supply pressure, the orifice discharge coefficient was calculated (.913). Knowing the discharge coefficient, it was then possible to determine the flow as a function of supply pressure.

Therefore, the calibration tests determined the orifice discharge coefficient and permitted calculating the flow within one to two percent.

B. Baseline Design Results

1. Baseline configuration

The baseline configuration included the following:

Gooseneck = $90^\circ/5^\circ$

Orifice = 1.125 dia., 30° straight taper

Orifice Vane = Plastic

2. Impact vs. Range with 10" Target

Data plot 3 shows the target impact for 6 target distances (13' to 63') and 3 pressures (150, 250, 360 PSIG); also shown is the calculated impact.

The target impact at 360 PSIG for the 6 target distances is:

	Lbs.	
13'-8"	655	100
23'-8"	655	100
33'-8"	592	90.5
43'-8"	545	83.3
53'-8"	498	76.2
63'-8"	447	68.2

Note: All impact data have been connected to 360 PSIG, some were obtsined at 355 and 350 PSIG.

Data plot 4 shows impact vs. distance. Note bi-linear data distribution. Up to 23 feet impact is 100%. From 23 feet to 63 feet, impact is inversely proportional to distance. Assuming the linear relationship continues, the impact would be 41% at 100 feet.

3. Impact vs. Change in Elevation

Data plot No. 5 shows the effect of raising and lowering the jet stream on target impact. The elevation adjusting screw was adjusted one and two turns above and below the centered position. (See data plot 21 for geometry of elevation adjusting screw.)

Data plot shows the impact dropping off very rapidly as the jet stream reaches the edge of the target indicating that the jet stream is still highly concentrated.

4. Tests with 21-Inch Target

Tests were conducted using a 21-inch target (which has four times the area of the standard 10.5-inch target. Data plot 6 shows the results for the 90° gooseneck. Data plots 7, 8, 9, 12 and 13 show 21-inch target impact data for the 30, 38 and 60 degree gooseneck designs.

Data for the 21-inch and 10.5-inch targets are shown below. Note that impact is a function of velocity as well as mass. Therefore, an infinitely large target would not give 100% impact at distances where air resistance becomes sufficient to reduce jet stream velocity:

Target Dia.	10.5	21
Impact	447	523
% of Max. (655 lbs.)	68.2	79.8
% Increase		11.65

C. Design Optimization

After establishing the performance of the baseline design, various design features were tested to select an optimum configuration. The three basic design features were gooseneck re-entrant angle, orifice design and straightening vane design.

1. Effect of Gooseneck Re-entrant Angle

Four goosenecks were tested which were identical except for the re-entrant angle measured from vertical. The angles were 90 (baseline), 60, 30 and 38 degrees. The 38 degree design incorporated a different method of laying out the re-entrant geometry.

(a) Tests with 10-Inch Target

Data plot sheets 10 and 11 show the effect of gooseneck angle on target impact. The table below lists the performance in descending rank:

10.5-Inch Target Data						
Gooseneck Angle	53'-8" Lbs.	53'-8" % 655 Lbs.	53'-8" Rating	63'-8" Lbs.	63'-8" % 655 Lbs.	63'-8" Rating
60	537	82.0	1.000	486	.742	1.000
30	523	79.9	.974	468	.715	.963
38	516	78.9	.961	447	.682	.920
90	498	76.0	.927	447	.682	.920
Diff. 60/90	39	6.0	.073	39	6.0	.080
Diff. 60/30	14	2.10	.026	18	.027	.037

(b) Tests with 21-Inch Target

Data plot sheets 12 and 13 show the effect of gooseneck angle on impact on a 21-inch target. Ranking of performance is shows below:

21-Inch Target Data						
Gooseneck Angle	53'-8"			63'-8"		
	Lbs.	% 655 Lbs.	Rating	Lbs	% 655 Lbs.	Rating
60	608	92.8	1.000	554	84.6	1.000
38 (30)	592	90.4	.974	523	79.8	.944
90 (90)	580	88.5	.954	523	79.8	.944
30 (38)	579	88.4	.952	520	79.4	.939
Diff. 60/30 (38)	29	4.4	.048	34	5.20	.061
Diff. 60/38 (30)	16	2.4	.025	31	4.8	.056

(c) Selection of Optimum Design

The results show that the 60 degree design is measurably superior to other designs for the two distances and two target sizes. The measurable differences are reasonably consistent ranging from 4.8 to 8% above the worst design to 2.5% to 5.6% above the second best design. However, if each reading is considered to have a tolerance of only ± 2%, the differences become trivial in many cases. From the above, it was concluded that the 60% gooseneck appeared to be the best performing design. It was selected for the SCE installation, and the remaining tests were conducted with this gooseneck.

(d) Identification of Manufacturing Errors

Due to the closeness of the results, the effect of manufacturing errors on performance was considered. All four goosenecks were set in a line, and the match between the orifice and gooseneck casting was checked. The 38 degree gooseneck had a nearly perfect match. The 90, 60 and 30 degree designs all had locations where the gooseneck casting had a larger radius than the machined orifice bore. The 60 degree design had the worst mismatch, showing an error of about .180 inches.

At this point, it was not known if the superiority of the 60 degree gooseneck over the 38 degree gooseneck was due to the manufacturing error or in spite of the error.

A comparison conducted on July 7 and 13, showed no measurable difference for identical orifice and vane configurations (545 lbs. vs. 545 lbs. on a 10.5 inch target at 63 feet with extender and two galvanized vanes). 176 lbs. were also obtained in each case with this configuration.

2. Orifice Design

An orifice with a radiused converging section was tested to compare its performance with the straight taper orifice.

The radiused orifice shown on Drawing 1016-104-C-17 was proportioned in accordance with the recommendations of the Iowa Institute of Hydraulic Research (ASCE paper 2529-1952 ASCE transactions). This design has a lower discharge coefficient

(.825 vs. .913) than the straight orifice shown on Drawing 1016-101-JO-18. This is due to the difference in final convergence angle (30° vs 15°). To provide comparable data, the orifice diameter was increased to 1.185 inches. The net result was equal predicted performance (equal flow, velocity, impact).

$$\left(\frac{1.185}{1.125}\right)^2 \times \left(\frac{.825}{.913}\right) = 1.003$$

The test results showed little or no difference in performance. Data sheet 18 shows 560 lbs. vs 544 lbs. at 63.8 feet on a 21-inch target. However, data sheet 21 shows 482 lbs. for both designs at 63.8 feet on a 10.5-inch target (sleeve/extender/plastic vane).

The straight orifice is by far the easiest to machine. From a practical standpoint, there is no cause to consider other convergence proportions, since the straight taper is equal in performance to the best design tested at Iowa.

Orifices with parallel exit extensions (2D, 3D) were not available in the 1.125-inch size for the 8-inch goosenecks. This configuration may have merit.

3. Orifice Vane Experiments

Tests conducted during the 1970-1972 period showd that stem and orifice vanes were necessary to produce good jet streams at distances in excess of 40 feet.

For the tests with the 8-inch nozzles, the stem vane was tack-welded in place to facilitate changing goosenecks. Therefore, no tests were made to determine the effect of the stem vane.

Various tests were made to determine the effect of changes in orifice vane design and arrangement. A summary of results follows:

(a) Plastic Vanes

Plastic vanes manufactured by STANG HYDRONICS were used, identical to Drawing 101-J0-09 except for a length of 1.938 inches. The vanes were placed with the thick end upstream. All of the baseline and gooseneck tests were conducted with the plastic vanes. The leading edge of the vanes were battered in a few minutes' testing due to residual particles in the test water. This battering caused the effective width to increase, much the same as a well used chisel head or tent stake. The plastic vanes were replaced several times with new vanes to obtain optimum target impact.

(b) Metal Orifice Vanes

Two metal vanes were tested:

(1) Two Partition Cross (Dwg. 104-C-18)

The objective of this design was to provide a simple, rugged metal vane. Data sheet 21 shows that the cross was not nearly as effective as the plastic vane 387 lbs. vs. 482 lbs. at 63.8 feet on a 10.5-inch target

(2) Galvanized Grid

This vane was found in the Test Center and apparently is commercially available for fire monitors. It consists of a .375 square grid made of brass which has been galvanized. The vanes were cleaned with dilute HCL acid to remove corrosion products.

The galvanized was measurably superior to the plastic vane.

	Plastic	Galv.	Comparison
53.8' - 10.5" target	537	598	1.11
63.8' - 10.5" target	482	516	1.07

(c) Orifice Extender

A 2D parallel extender was made (Dwg. 104-C-19) to serve two purposes. The first purpose was to determine if a parallel section between the gooseneck outlet and orifice inlet would be beneficial. The second purpose was to experiment with orifice vane designs and combinations since the extender could contain a vane or a sleeve. The sleeve simply filled the space that would have held the sleeve cylinder to provide smooth flow. The table below lists the results. See also data plot 15 of 21.

Case	Range	Target	Data Sheet	Exterior Vane	Orifice Vane	Impact	% 655
1	53.8	10.5	19	Plastic	None	591	90.2
2	"	"	20	Plastic	Plastic	529	80.8
3	"	"	20	None	Plastic	482	73.6
4	"	"	21	Galv.	Cross	608	92.8
5	"	"	22	Galv.	Galv.	598	91.3
6	"	"	22	No Extender	Galv.	598	91.3
7	"	"	17	No Extender	Plastic	537	82.0
8	63.8	10.5	21	Plastic	None	482	73.6
9	"	"	-	None	Plastic	No Test	
10	"	"	21	Cross	None	387	59.1
11	"	"	22	Galv.	Cross	560	85.5
12	"	"	22	Galv.	Galv.	560	85.5
13	"	"	22	No Extender	Galv.	516	78.8
14	"	"	14	No Extender	Plastic	486	74.2

The extender/vane tests tended to show that the extender was of no benefit at 53 feet and of measurable benefit at 63 feet. The galvanized vanes were measurably superior to the plastic vanes.

(d) Miscellaneous Tests

At the conclusion of the test program, various tests were performed of an experimental nature. In brief, these were:

(1) Separan

Dow Chemicals "Separan" was injected in various quantities (sheet 22) at the pump inlet while using a 10.5

inch target at 63 feet. The chemical did not increase the peak impact, it did, however, make the peak reading occur more frequently and for longer periods of time. It was concluded that Separan could be beneficial at longer distances if injected in the proper proportions at the right locations. The jet stream was noticeably clearer and more coherent.

(2) Reversed Plastic Vane

The plastic orifice vane was reversed to place the thick edge down stream. The impact remained high, but the jet stream was milky (cavitation?).

(3) Center Inserts

Various wires and rods were inserted in the center of the vanes. The wire appeared to make no difference. The .500-inch plastic rod caused a significant reduction in impact. In fairness, the plastic rod setup was very crude. More refined and systematic tests of solid inserts might show considerably better results.

D. Optimum Design

The test data indicated that the optimum design consisted of the following components:

Gooseneck design	60 degrees
Orifice design	30 degree incl. angle
Orifice vanes	Galvanized grid
Extender	Possibly at longer ranges

E. Underwater Tests

1. Foreword

The opportunity was taken to determine the effect of flooding on the jet stream impact. Partial or complete submergence of the jet stream may occur during DYNAJET operation.

2. Experiment at 4'-6" Range

The flowback tank was raised so that the orifice and target centerlines were on the same horizontal elevation.

The water was allowed to rise in the tank with the supply pressure at 360 psig. Impact was measured for various water levels. Figure 2-B shows a plot of the target impact. Note that the impact force drops sharply as the water level reaches the nozzle centerline. At 15 inches submergence, the impact force stabilizes at approximately one-fourth that of open air impact.

3. Experiments at the 13'-8" Range

Two experiments were conducted at twice the distance. For the first experiment, the flowback tank was tilted to level the orifice and target centerlines. As the jet became submerged, the impact dropped to nearly zero (about 30 lbs.)

The flowback range was then leveled, which placed the orifice 8 inches above the target centerline. As the water level reached the target centerline, the impact force dropped from 620 to 540 lbs., even though nearly all of the stream was clear of the water. Tests were terminated at this time due to water inventory limitations. (The flowback tank requires approximately 5,200 gallons of water per foot of depth when level.)

4. General Impressions

Although the impact force drops dramatically with submergence, the jet stream has a powerful effect on causing countercurrents and turbulence in the tank. This effect is significant even at the 13'-8" distance.

It should be noted that these underwater tests do not duplicate underwater reclaim operations since the geometry of the working face is not duplicated.

A considerably different test configuration would be required to adequately evaluate nozzle performance for underwater reclaim operations. Underwater reclaim tests should duplicate the working face geometry so that countercurrent and turbulence effects could be measured.

F. Comparison With Previous Tests

1. Comparison of 8" and 6" Gooseneck Designs

In late 1971 four cast gooseneck designs in the 6" size range were tested (see IOC's WPW to WNS dated 13 Jan. 1972). The tests were made with a 1.125 inch orifice but without orifice vanes. Data taken at 50 feet on a 10-inch target are listed below:

	With 24" Stem Vanes		No Stem Vanes	Vane Effect
90	420	1.000	320	1.31
60	330	.786	290	1.14
45	305	.726	270	1.13
30	275	.655	260	1.06
AVG	322		285	1.13

The above data showed a significant advantage for the 90-degree gooseneck. This advantage is maintained at the 40-foot range. These results disagree significantly with the results of the tests for the 8-inch goosenecks. Because of the consistency of the data in both test programs, there is no apparent cause to fault the validity of the data. There are significant differences in the flow conditions in the goosenecks and these differences are not likely to be the reason for the differences in the findings. The significant differences are:

	6"	8"
Water Pressure	400	360
Flow Rate - GPM	690	654
Velocity in Stem (FPS)	7.66	4.16
Length of Stem Vanes	24	42
Gooseneck Outlet Diameter	2	2.5
Gooseneck Outlet Velocity	68.9	42.70
Reynolds No. at Gooseneck Inlet	355,000	258,000
Reynolds No. in Stem Vanes	74,000	48,400
Reynolds No. in Orifice Vane	1,068,000 (2" dia.)	173,400 .500 Grid

In addition to the above differences, the actual gooseneck shapes are somewhat different. E.g., the six-inch 90-degree gooseneck does not have the same proportions as the eight-inch gooseneck. The velocities and Reynolds numbers in the 8-inch design are much less. However, the Reynolds numbers are well into the fully turbulent region in all cases - laminar flow does not occur at values above 2,000 to 4,000. Therefore, the significant difference in Reynolds does not explain the significant difference in performance.

The main effect of reduced flow velocities, stem vane length and orifice vanes in the 8-inch design may be in reducing the intensity of secondary flow currents in the stem, gooseneck and orifice entrance. With kinetic energy proportional to the velocity squared, the energy ratio in the 8-inch gooseneck would be .30 at entrance and .38 at the gooseneck outlet.

With completely effective stem and orifice straightening vanes, the effect of gooseneck re-entrant angle should be trivial. This was the actual case for the tests with the 8-inch design; the deficiencies were so small as to be within the limits of experimental error.

It is likely that the tests with the 6-inch gooseneck at 400 PSI were more suitable for evaluating the effect of gooseneck angle on performance than were the 8-inch tests.

However, the tests with the 1.125-inch orifice on two gooseneck sizes were significant in showing the effect of reduced secondary flows on jet stream performance. The 8-inch gooseneck design was more effective even at lower pressures and a somewhat greater distance.

To provide a direct comparison, the test results for the 6-inch design have been corrected to 360 PSI supply pressure and a distance of 53.8 feet. The distance correction was obtained by extending the line connecting the 40 foot and 50-foot data points.

	6-Inch (IOC 13 Jan 72)		8-Inch (Baseline)		Ratio 8"/6"
Pressure (PSI)	Corrected to 360 PSI		360		1.00
Stem Vane Length	24		42		1.75
Orifice Vane Length	None		2		-
Target Distance	Projected to 53.8		53.8		1.00
Gooseneck Rank	Angle	Lbs.	Angle	Lbs.	
No. 1	90	351	60	537	1.53
No. 2	60	256	30	523	2.04
No. 3	45	220	38	516	2.35
No. 4	30	184	90	498	2.71
AVG.		252		518	2.05

In all cases, the performance of the baseline 8-inch designs was significantly above the performance of the 6-inch desings. Comparing the performance of the best 6-inch design (90 degree gooseneck) with the optimum 8-inch design (60 degree gooseneck with .375 galvanized grid orifice vanes) gives a ratio of 1.73 (608 lbs. vs. 351 lbs.).

2. <u>Effect of Orifice Vane (EXPORTER Gooseneck)</u>

Tests conducted on 3-8-71 using a 1.125 orifice on a 6-inch gooseneck showed the effect of orifice vanes on impact. Data corrected to 360 psi is listed below.

Data 3-8-71 6" Gooseneck 1-1/8 Orifice-360 psig (corr)	Target Diameter 10.5" 40'-0"	 50'-0"	 53'-8" (Proj.)
No Orifice Vane	469	385	354
With Orifice Vane	611	551	529
Improvement Lbs.	142	166	175
Ratio	1.30	1.43	1.49
8" Ref. Data	-	-	591
Ratio 591/529	-	-	1.12
Ratio 591/354	-	-	1.67

These testsresults show that the orifice vanes are the key design difference.

3. Comparison - Summary

The key design factors are listed below with an estimate of their effect on target impact:

Orifice vanes	1.30 - 1.50
Gooseneck angle	1.08 - 1.37
Stem vanes	1.06 - 1.31
Reduced internal velocities	1.00 - 1.12
Overall effect (591/285 x .96)	2.16

VI. CONCLUSIONS

A. Overall Performance

The jet streams produced by the 8-inch nozzles were very good in nearly all cases. The optimum design produced an impact of 85 percent of maximum on a 10-inch target at 63 feet. The included angle is only .786 degrees. It is concluded that the 8-inch nozzle design is close to optimum.

B. Comparisons to Previous Results

For the same orifice size pressure and flow, the 8-inch nozzle produces approximately twice the impact at 53 feet as did the 6-inch nozzle design. The three design features that appeared to make the difference were:

1. Lower internal velocities
2. Orifice vanes
3. Larger stem vanes

C. Critical Design Features

The following design features are considered to be important:

1. Gooseneck with Re-Entrant Angle

The exact angle of the gooseneck does not appear to be as significant as is the general concept of a re-entrant angle.

2. Flow Straightening Vanes

Both stem and orifice vanes are necessary for optimum performance. The vanes should be of thin metal with small grid dimensions for best performance with clean water. For dirty water, a huskier design should be substituted or a strainer should be located well upstream of the nozzle.

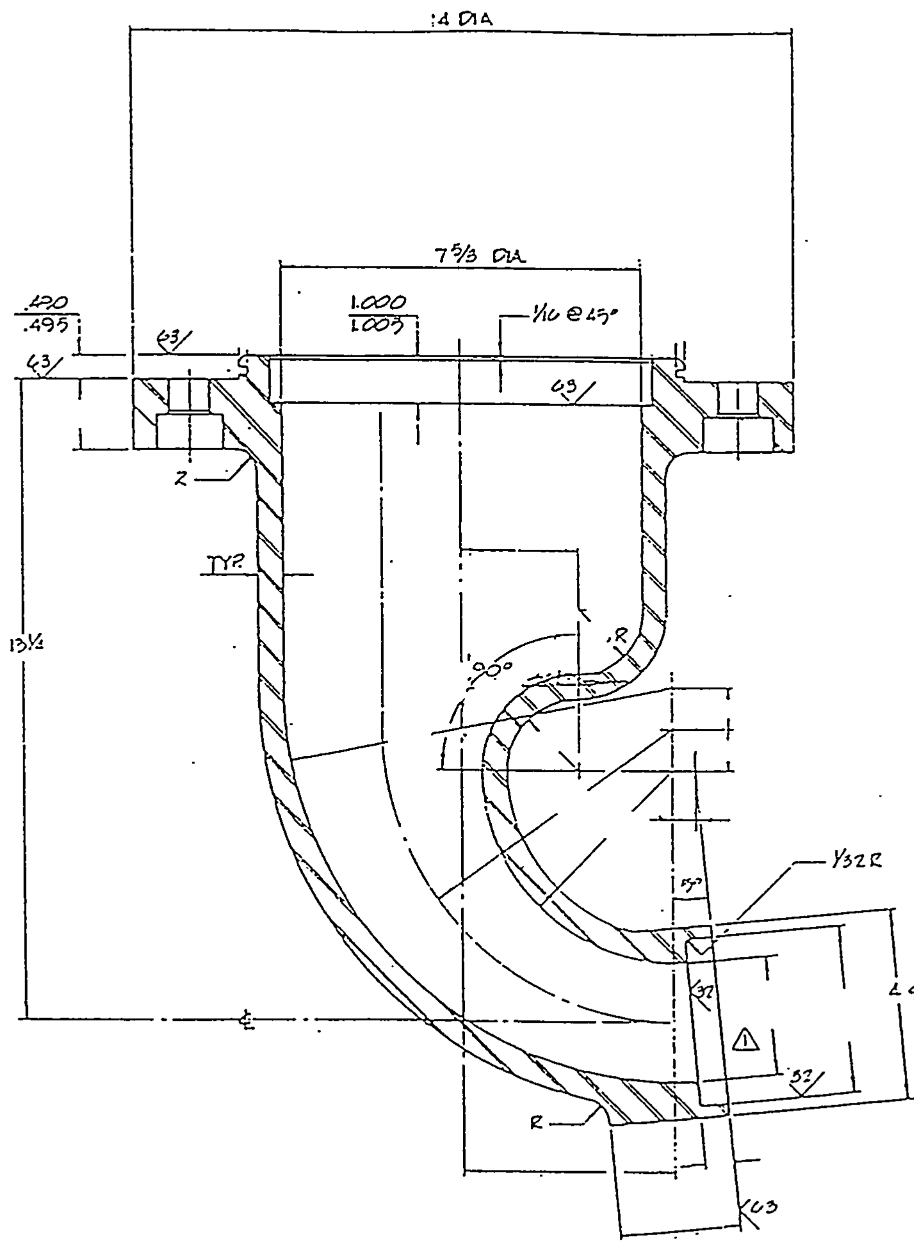
3. Low Internal Velocities

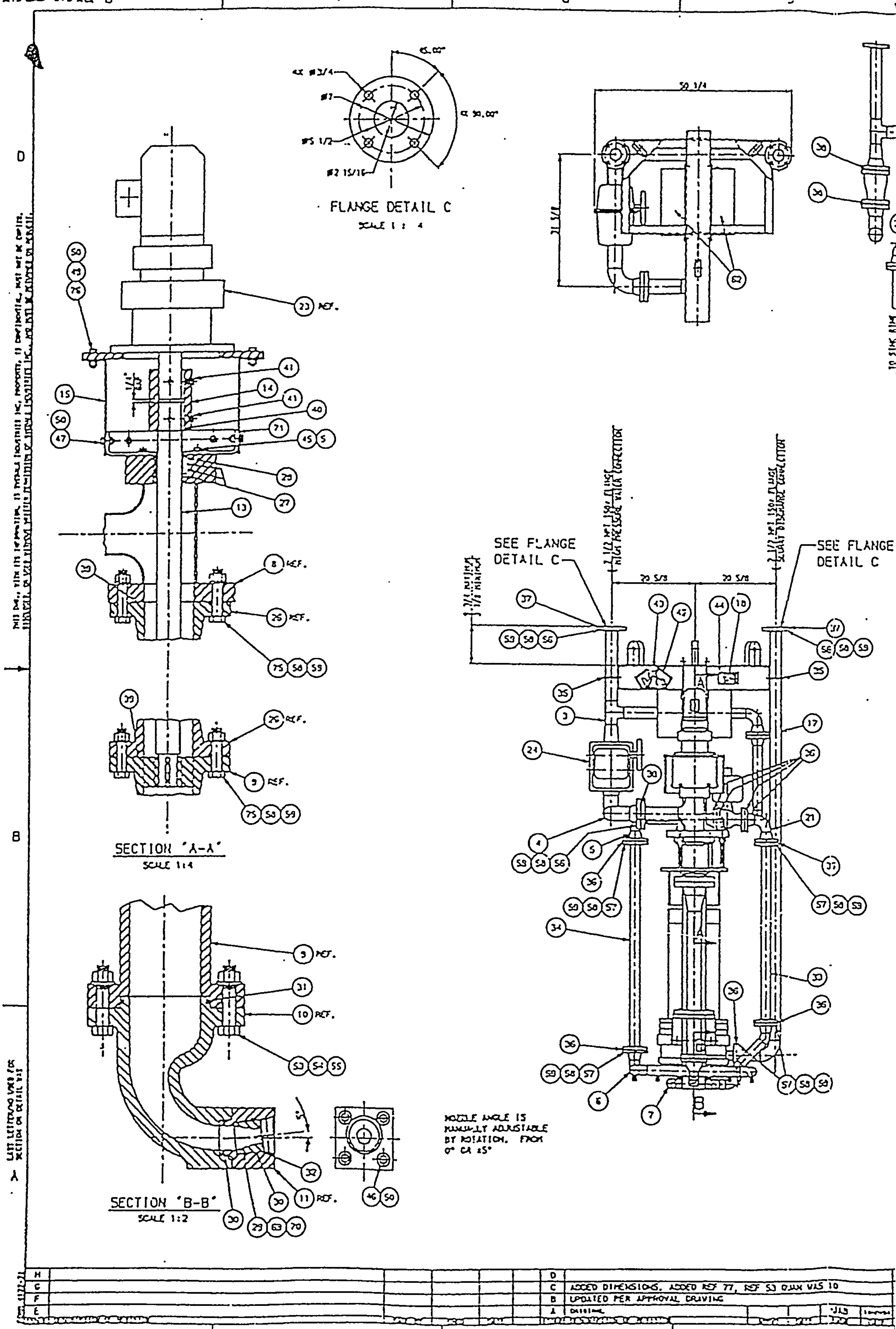
For any given orifice size, the gooseneck and stem should be as large as practical to minimize internal velocities in the stem and gooseneck.

VII. RECOMMENDATIONS

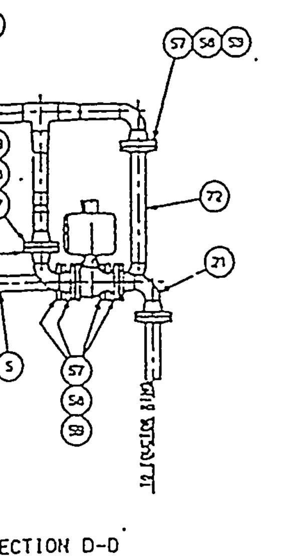
In general, the performance of the 8-inch nozzle design is so near to the maximum, it is recommended that any future test work be concentrated on smaller nozzle designs.

Tests of the small nozzles could concentrate on commercially available orifices and straightening vanes to obtain cost/performance data. A key parameter would be to determine the range of practical stem to orifice diameter ratios. It may be that there is a minimum practical stem size, say 4-inch.

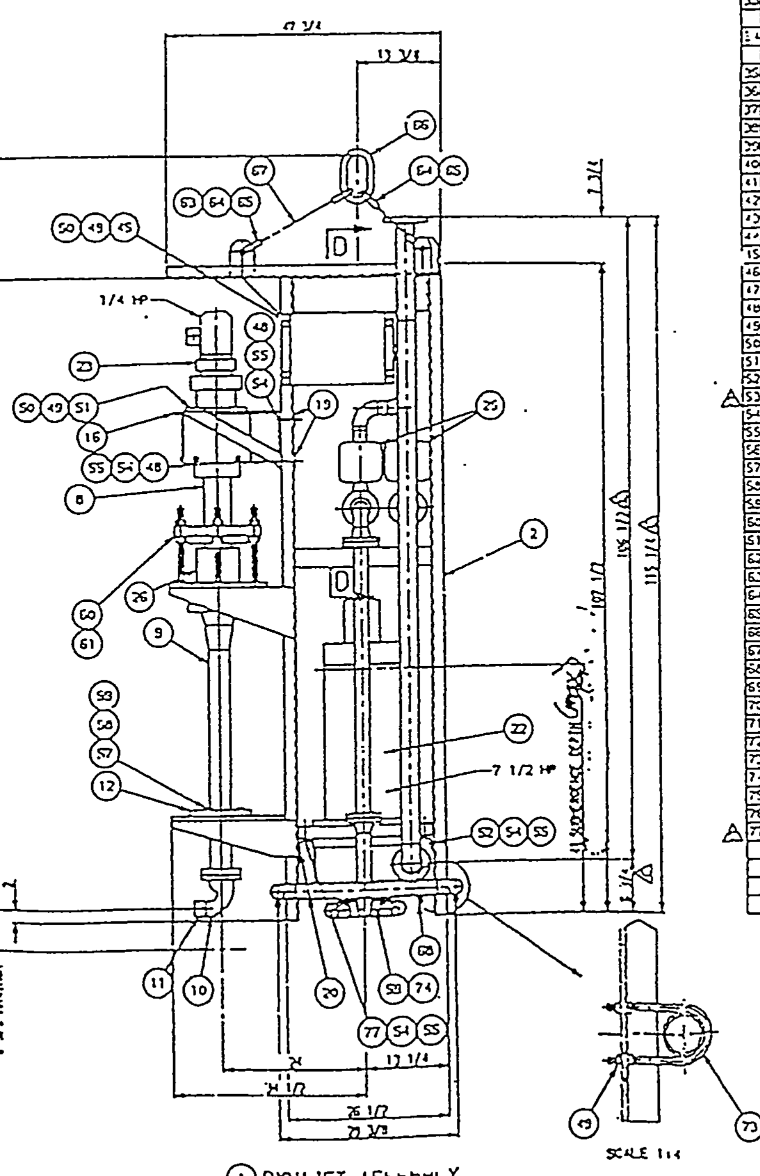

14 DIA
7 5/8 DIA
.470
.495
1.000
1.003
1/16 @ 45°
63
63
63
2
TYP
13 1/2
R
90°
1/32 R
4 SQ
32
32
R
63


FLANGE DETAIL C
SCALE 1 : 4
4X Ø3/4
Ø7
Ø5 1/2
Ø2 15/16
50 3/4
SEE FLANGE DETAIL C
SEE FLANGE DETAIL C
20 5/8
20 5/8
SECTION 'A-A'
SCALE 1:4
SECTION 'B-B'
SCALE 1:2
NOZZLE ANGLE IS MANUALLY ADJUSTABLE BY ROTATION. FROM 0° CA ±5°
ADDED DIMENSIONS. ADDED REF 77, REF 53 QUAN WAS 10
UPDATED PER APPROVAL DRAWING

NOTES:
1. APPROXIMATE ASSEMBLED WEIGHT OF PART 9-69167-1 = 2060 POUNDS.
2. HYDROSTATIC TEST ALL HIGH PRESSURE WATER PIPING TO 300 PSI.
3. JET STEM CAN BE RAISED/LOWERED MANUALLY (0 TO 6 3/8 RANGE).



ITEM	QTY	DESCRIPTION	PATTERN NO	MAT'L	PART NO / SPEC NO
1	1	GENERAL ASSEMBLY MODEL DJ02SS1 DYNAJET			9-69167-1
2	1	FRAME WELDMENT			9-69253-1
3	1	HIGH PRESSURE WATER INLET PIPE			7-69254-1
4	1	HIGH PRESSURE WATER MANIFOLD			5-69255-1
5	1	SINK RING SECONDARY ELBOW WELDMENT			3-69372-1
6	1	SINK RING WELDMENT			7-69257-1
7	1	EDUCTOR RING WELDMENT			5-69258-1
8	1	DRIVE HOUSING WELDMENT			7-69306-1
9	1	JET STEM WELDMENT			7-69305-1
10	1	NOZZLE MACHINING			5-46574-1
11	1	ORIFICE HOLDER			5-63620-1
12	1	BEARING DETAIL			5-46552-1
13	1	DRIVE SHAFT ASSEMBLY			7-69304-1
14	1	SHAFT COUPLING			3-69307-1
15	4	SHAFT EXTENSION COVER			3-69316-1
16	1	DRIVE MOUNTING WELDMENT			7-69311-1
17	1	ABRASION RESISTANT PIPE WELDMENT			5-69306-1
18	1	INFORMATION NAMEPLATE			3-69375-1
19	2	CLAMP BAR			7-69311-2
20	2	MOTOR SUPPORT CLIP			5-69253-2
21	2	ELBOW WELDMENT			3-69303-1
22	1	8" PUMP WITH 7 1/2 HP MOTOR [illegible]			
23	1	DOUBLE WORM GEAR SPEED REDUCER [illegible]			
24	1	FLANGED BALL VALVE 3"-150 LB			
		WITH ELECTRIC ACTUATOR 1/60HZ/115V			
25	2	FLANGED BALL VALVE 2-150 LB			
		WITH ELECTRIC ACTUATOR 1/60HZ/115V			
26	1	SWIVEL 4-150 LB FLANGED END CONNECTIONS			
27	3	PACKING RING 2 3/4 OD X 2 ID X 1/2 THK		[illegible]	
28	1	BACK-UP RING 2 3/4 OD X 2 ID X 3/8 THK		[illegible]	
29	1	ORIFICE 1/2 REGULAR			
30	2	O-RING 1 5/16 ID X 1 9/16 OD X			
		1/8" CROSS SECTION			
31	1	O-RING 3 3/8 ID X 3 3/4 OD X			
		3/16 CROSS SECTION			
32		SNAP RING			
33	1	3 ID WATER HOSE ASSY. X 4'-0 LG. OVERALL			
		300 PSI WORKING PRESSURE W/2-150 LB FLGS			
34	1	3 ID WATER HOSE ASSY. X 5'-0 LG. OVERALL			
		300 PSI WORKING PRESSURE W/2-150 LB FLGS			
35	2	U-BOLT 1 1/2 X 2 1/2 W/(4) HEX NUTS EA.		STL	
36	9	3-150 LB RING GASKET X 1/8 THICK			
37	2	2 1/2-150 LB RING GASKET X 1/8 THICK			
38	3	3-150 LB RING GASKET X 1/8 THICK			
39	2	4-150 LB RING GASKET X 1/8 THICK			
40	1	KEY 1/2 X 1/2 X 2 3/8 LG. ROUND END			
41	4	SET SCREW 1/2-13UNC X 3/4 LG-HEX SOC. FL. PT.			
42	1	KVS INSIGNIA			5-50495-1
43	5	DRIVE SCREW NO 10 X 3/8 LG TYPE U		STL	
44	4	DRIVE SCREW NO 4 X 1/4 LG TYPE U		STL	
45	12	BOLT, HEX HD 3/8-16UNC-2A X 1 LG.			
46	4	BOLT, HEX SOC. HD. 3/8-16UNC-2A X 2 1/2 LG.			
47	8	BOLT, HEX HD. 3/8-16UNC-2A X 3/4 LG.			
48	4	BOLT, HEX HD 1/2-13UNC-2A X 4 LG.			
49	30	NUT, HEX 3/8-16UNC-2B			
50	30	WASHER LOCK 3/8 DIA.			
51	6	BOLT, HEX HD 3/8-16UNC-2A X 1 3/4 LG.			
52	6	BOLT, HEX HD 1/2-13UNC-2A X 1 3/4 LG.			
53	6	BOLT, HEX HD 1/2-13UNC-2A X 2 3/4 LG.			
54	20	NUT HEX 1/2-13UNC-2B			
55	20	WASHER, LOCK 1/2 DIA.			
56	20	BOLT HEX HD 5/8-11UNC-2A X 3 LG.			
57	48	BOLT, HEX HD 5/8-11UNC-2A X 2 3/4 LG.			
58	64	NUT, HEX 5/8-11UNC-2B			
59	87	WASHER LOCK 5/8 DIA.			
60	6	NUT, HEX 1-8UNC-2B			
61	6	WASHER, PLAIN 1 TYPE B			
62	2	ELECTRICAL BOX (SEE UNIT BOX)			
63	3	ANCHOR SHACKLE WITH PIN SIZE 1 1/8			
64	6	WIRE ROPE THIMBLE-7/8 DIA. WIRE ROPE			
65	24	U-BOLT WIRE ROPE CLIP-7/8 DIA. WIRE ROPE			
66	1	WELDED GRADING LINK 1 STOCK SIZE			
67	1	HOISTING WIRE ROPE 7/8 DIA. (CUT TO SIZE)			
68	16	SPRAY NOZZLE			
69	1	SPARE ORIFICE 7/16 REGULAR			
70	1	SPARE ORIFICE 9/16 REGULAR			
71	1	PACKING RETAINER			3-69374-1
72	1	SINK RING PRIMARY ELBOW WELDMENT			3-69376-1
73	2	U-BOLT			3-69317-1
74	3	BOLT, HEX HD. 5/8-11UNC-2A X 1 LG.			
75	16	BOLT, HEX HD. 5/8-11UNC-2A X 3 1/2 LG.			
76	8	BOLT, HEX HD. 3/8-16UNC-2A X 1 1/4 LG.			
77	4	BOLT, HEX HD. 1/2-13UNC-2A X 3 1/4 LG.			



MARCONAFLO DYNA-JET
SLURRY PUMP

B-1

TITLE	GENERAL ASSEMBLY MODEL DJ02SS1 DYNAJET
CUST.	TEXACO
	03-2026-CJ02SBS1-5812-94
SALES ORDER NO	1675-102
DRAWING NO	9-69167 C

KENNEDY VAN SAUN
Svedala Industries, Inc.

Distribution

No. of Copies		
OFFSITE		
7	**DOE/Office of Scientific & Technical Information & Information Release**	
1	**D. W. Geiser, EM-50** US Department of Energy Tanks Focus Area Cloverleaf Building 19901 Germantown Road Germantown, MD 20874-1290	
2	**Westinghouse Savannah River Co.** Bruce Martin and Eloy Saldivar 742-4G Building, Room 1 Aiken, SC 29801-802	
ONSITE		
1	**DOE Tanks Focus Area Field Lead**	
	T. P. Pietrok	K8-50
8	**Tanks Focus Area Technical Team**	
	B. J. Williams	K9-69
2	**Numatec Hanford Corp/Retrieval**	
	P. W. Gibbons	K9-91
	E. A. Pacquet	R3-73
2	**Lockheed Martin Hanford Co.**	
	C. Defigh-Price	T4-08
	W. T. Thompson	R3-73

No. of Copies		
14	**Pacific Northwest National Laboratory**	
	K. M. Airhart	K5-22
	J. A. Bamberger	K7-15
	E. J. Berglin	H3-26
	J. L. Buelt	K2-14
	F. F. Erian	K7-15
	B. K. Hatchell (3)	K5-22
	D. R. Jackson (3)	K5-22
	O. D. Mullen (2)	K5-22
	M. W. Rinker	K5-22