# NASA Technical Memorandum

NASA TM-103576

P.26

## SPACE STATION *FREEDOM* DELTA PRESSURE LEAKAGE RATE COMPARISON TEST DATA ANALYSIS REPORT

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February 1992



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TECHNICAL MEMORANDUM

# SPACE STATION *FREEDOM* DELTA PRESSURE LEAKAGE RATE COMPARISON TEST DATA ANALYSIS REPORT

## 1.0 INTRODUCTION

Seal verification for Space Station *Freedom* (S.S. *Freedom*) is required to prove the ability of each seal to perform as designed prior to launch. In order to test the seal, gas leakage across the seal must be determined with a pressure differential of one atmosphere. Two methods of testing present the most logical way of verifying S.S. *Freedom* seals. One method would test the seal under conditions similar to those experienced during normal operation (i.e., one atmosphere internal—vacuum external). The other method would create the necessary pressure differential across the seal, but would not require the vacuum environment on the exterior side of the seal (i.e., two atmospheres internal—one external). For simplicity, these tests are referred to as 1/0 and 2/1. Two questions need to be answered:

What is the relationship between the two leakage rates?

Does the relationship always hold true?

## 2.0 CONCLUSIONS

Results of the testing performed agreed very closely with theoretical analyses relating leakage rates at different pressure ratios. The leakage rates experienced during 2/1 testing were always higher than the counterpart test performed under 1/0 conditions. Typical ratios of 2/1-to-1/0 leakage rates were near 3. When tested under 2/1 conditions, seal behavior under 1/0 conditions could be estimated with small uncertainties. When gas permeation was the major contributor to leakage, or the flaw created a long tortuous path, actual flow ratios agreed with the calculations. As the flaw configuration changed to that of an abrupt exit (orifice plate), ratios between 2/1 and 1/0 became even more conservative. The orifice type leak created a 2/1-to-1/0 ratio of 6.

## 3.0 RECOMMENDATIONS

Testing performed indicates that verifying the seals under 2/1 conditions is always conservative. Test 1/0 leakage rates can be extrapolated from 2/1 conditions quite accurately; however, this is not recommended. The reduced leakage that would occur once in orbit should be taken as an increased margin of safety, and to provide for some long-term seal degradation. Since leakage rates are conservative under the 2/1 pressure conditions, and testing a complete module in a vacuum chamber would be costly and might introduce scheduling conflicts, it is recommended that S.S. *Freedom* modules be tested using the 2/1 approach when possible.

## 4.0 DISCUSSION

### 4.1 Test Configuration

The test setup consisted of a regulated gaseous nitrogen source, connecting lines, isolation valve, pressure transducers, temperature sensors, O-ring fixture, and bell jar/vacuum pump as shown in figure 1.

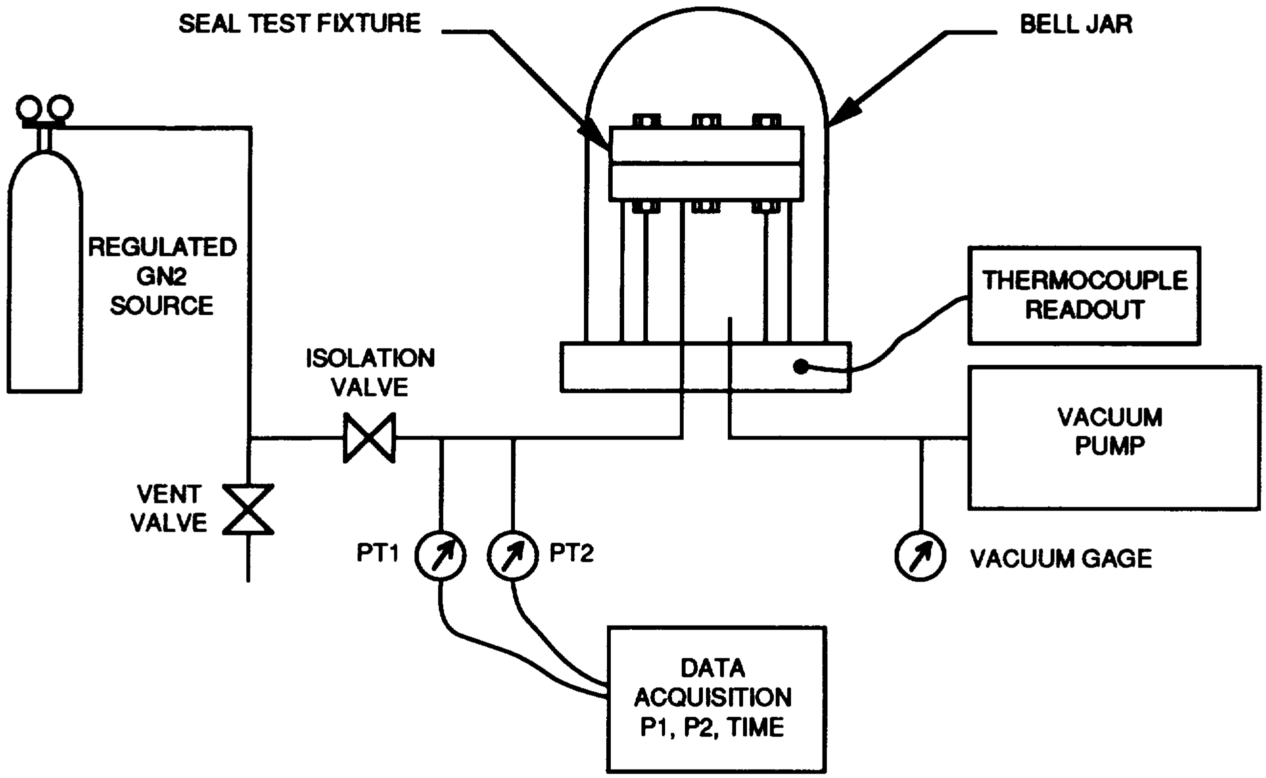



Figure 1. General test arrangement.

The fluorocarbon (V747 Viton) O-rings used had a 5.19-in outside diameter and a 0.281-in cross-sectional diameter. Groove dimensions for the fixture are shown in figure 2. Shims placed between the plates of the test fixture created a 17-percent squeeze on the O-ring. No lubrication was used on the O-rings to help eliminate a very "hard-to-control" variable. When tested under vacuum conditions, the bell jar was pumped below 1-torr absolute pressure. Pressure data was collected with a desktop computer. Temperature was manually recorded in the data file for each test. The flaws were created by laying a wire or fiber radially across the sealing surface of the O-ring.

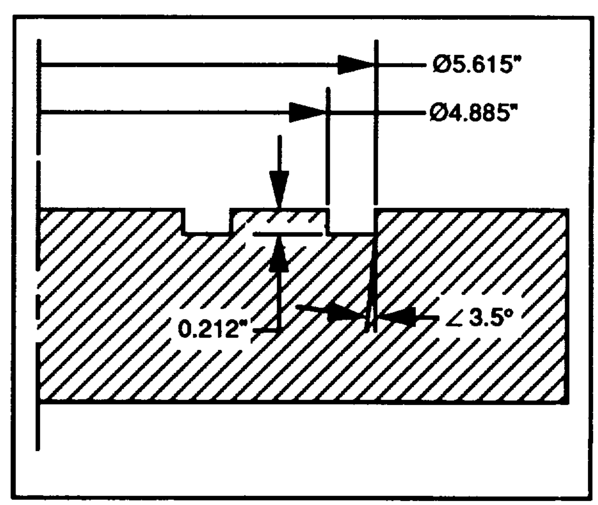



Figure 2. Fixture groove dimensions.

## 4.2 Approach

Leakage rates were calculated using the mass point analysis approach, calculating the mass of nitrogen in the fixture using the ideal gas law:

$$M_i = \frac{P_i \cdot V}{R \cdot T_i} .$$

Conversion from units mass measurement to standard volume units is accomplished by multiplying the mass by the specific volume at standard conditions of 14.696 psia and 60 °F:

$$Q_i = M_i \cdot v \qquad v = \frac{R \cdot T_{std}}{P_{std}} ,$$

$\therefore$

$$Q_i = \frac{P_i \cdot V}{R \cdot T_i} \cdot \frac{R \cdot T_{std}}{P_{std}} = \frac{P_i \cdot V \cdot T_{std}}{T_i \cdot P_{std}} . \tag{1}$$

In equation (1), $Q_i$ is the volume of gas in standard cubic centimeters, $P_i$ and $T_i$ are the system pressure and temperature at time $t_i$ in psia (or kPa) and °R (or K), respectively. $V$ is the system volume in cubic centimeters, $T_{std}$ is the standard temperature in °R (or K), and $P_{std}$ is the standard pressure in psia (or kPa).

Leakage rates are then calculated using a least squares fit of $Q_i$ versus time, with time in seconds. The resulting slope from the fit is the leakage rate in standard cubic centimeters per second (sccs). The $y$ intercept is the initial mass of the system in standard cubic centimeters (scc). A typical plot of this data is shown in figure 3.

The data used to calculate the leakage rate was chosen using barometric pressure during that test series as the ideal one atmosphere. For example, if $P_{atm}$ was 14.5 psia, 29.0 would be used for a 2/1 test. Pressure in the fixture would start out higher than 29.0 and decay through that number. The slope of the line was calculated with the ideal pressure in the center of the data, and a small range above and below the ideal as shown in figure 4.

Every flaw was tested three times at each pressure level with the results averaged to obtain the final leakage for that test condition.

Poiseuille's law for viscous flow through a cylindrical tube[1] defines the relationship between leakage and pressure as:

$$Q = \frac{\pi \cdot d^4}{256 \cdot 1 \cdot \mu} \cdot (P_e^2 - P_i^2) . \tag{2}$$

In equation (2), $Q$ is leakage, $d$ and $l$ are the average diameter and length, respectively, of the leak hole, and $\mu$ is the gas viscosity. $P_e$ and $P_i$ are the external and internal pressures, respectively.

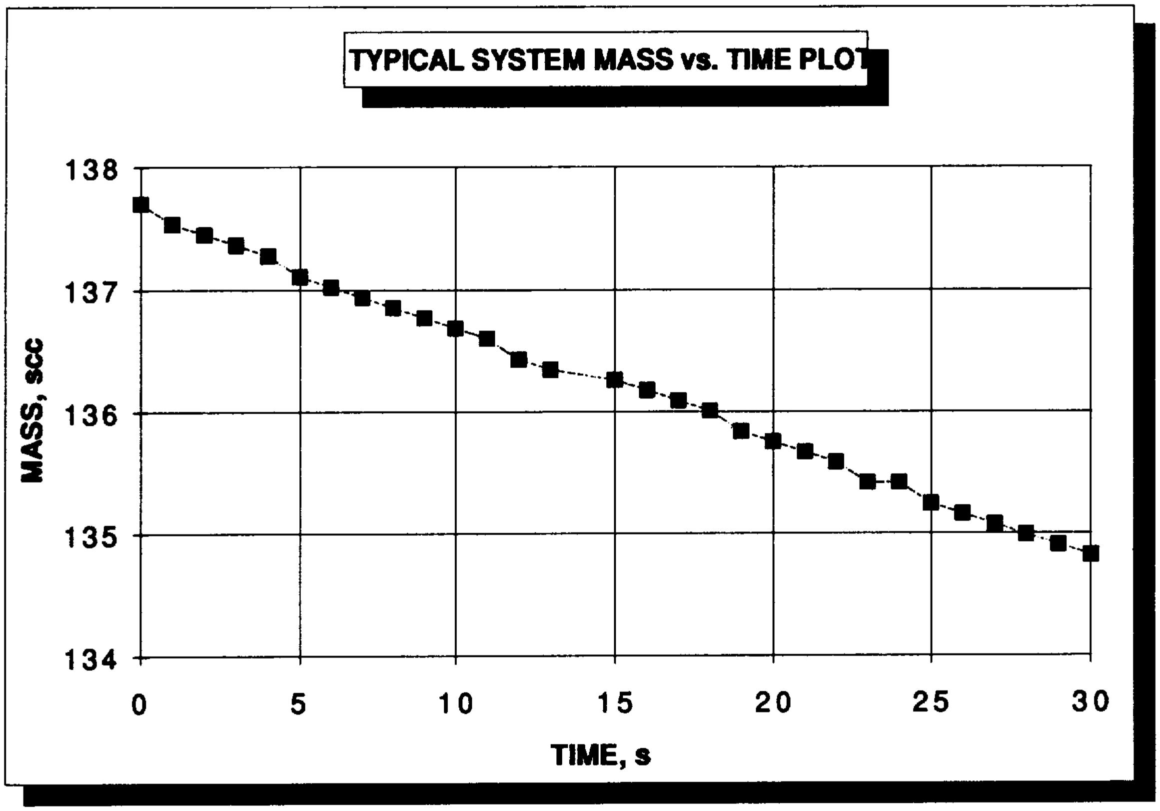



Figure 3. System mass versus time plot.

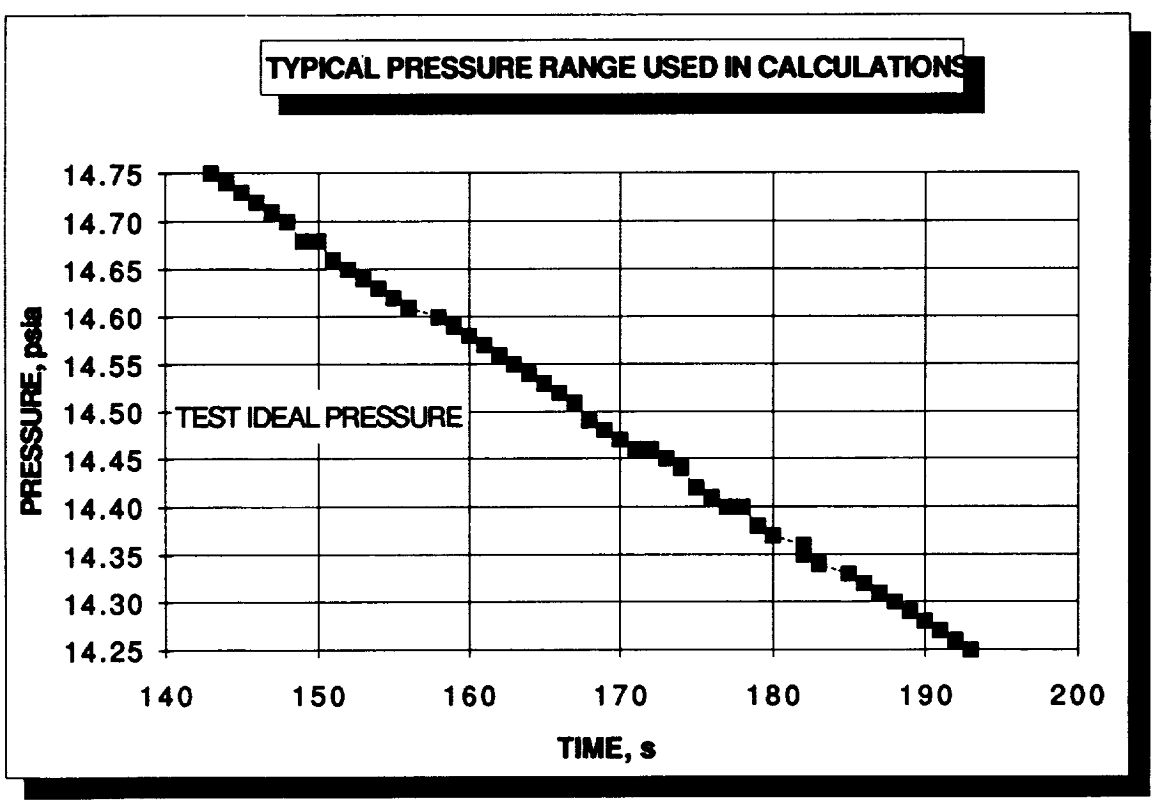



Figure 4. Pressure range example plot.

Assuming the small changes in absolute pressures acting on seal under the different test conditions do not affect the geometry of the leak path, equation (2) can be simplified as:

$$Q = C\cdot(P_e^2 - P_i^2) \ , \tag{3}$$

where $C$ is constant for a certain flaw and various pressure ratios under consideration. Relating leakage rates at different pressure ratios becomes an exercise in mathematic ratios:

$$\frac{Q_{a/b}}{Q_{c/d}} = \frac{(P_a^2 - P_b^2)}{(P_c^2 - P_d^2)} \ , \tag{4}$$

$\therefore$

$$\frac{Q_{2/1}}{Q_{1/0}} = \frac{(P_2^2 - P_1^2)}{(P_1^2 - P_0^2)} \quad \text{or} \quad Q_{2/1} = \frac{(P_2^2 - P_1^2)}{(P_1^2 - P_0^2)}\cdot Q_{1/0} \ ,$$

$$Q_{2/1} = \frac{(2^2 - 1^2)}{(1^2 - 0^2)}\cdot Q_{1/0} = \frac{3}{1}\cdot Q_{1/0} \ .$$

### 4.3 Results

Complete results of each test are included as appendix A. Average results from each series are shown on page 10. Each test is identified by a series of alphanumeric digits that define the test pressures, flaw size included, configuration number, and run number. A typical test identification example would be:

2/1 – 004 – 1 – 2

where

2/1 = pressure ratio across seal

004 = flaw size (wire diameter in thousandths of an inch)

1 = configuration number (1–first seal, 2–second, ...)

2 = test run number for particular configuration (1, 2, or 3).

The baseline (no flaw) and 0.0018-in flaw tests were repeated after initial data analysis because of erroneously high ratios (some at 8 to 1). The test fixture was set up using flex lines connecting the pressure transducers to the remainder of the system. It appeared permeation through the lines was causing as much or more leakage as the leakage through the seal when subjected to pressures above one atmosphere. When testing with one atmosphere internal pressure, the flex lines did not have any pressure differential across them, which eliminated the tendency for the gas to permeate. The flex lines were replaced by hard tubing and the test results were much better. Figure 5 shows the data plotted with flow ratio versus flaw. The flaws are arranged in order of increasing leakage rate. The remaining five ratios that can be calculated from the data are plotted and included in appendix B.

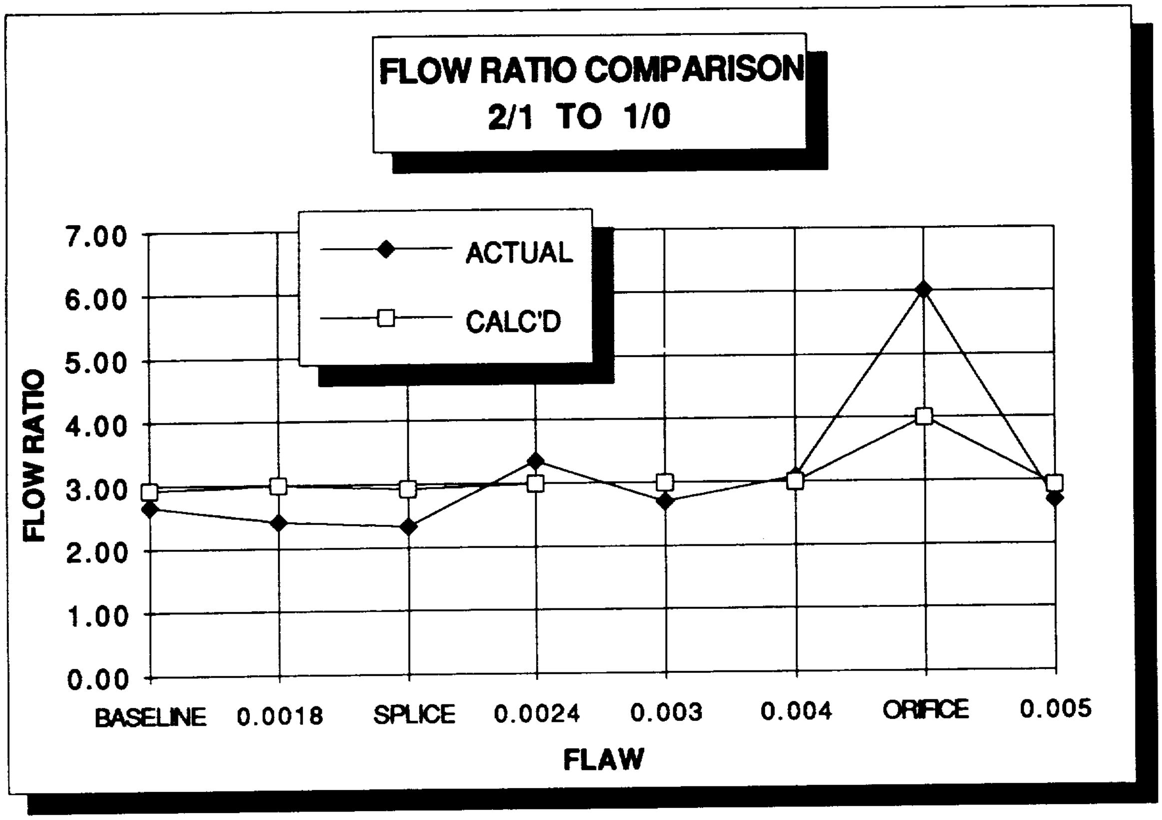



Figure 5. Flow ratio versus flaw plot.

The test series labeled "SPLICE" on the graph was an added bonus in the matrix. During the first test attempt, it was noticed immediately that the leak rate was much too high for a baseline configuration. The fixture was disassembled and examined. The O-ring used has a poor splice that left a "necked down" section with a radially directed valley that created a leak path. A different O-ring with a good splice was used for all other test series.

The test series which incorporated an orifice was included after the tubing configuration change. The orifice was created by drilling a 0.001-in hole in the end of a flare fitting cap as shown in figure 6. The cap was connected to a spare bulkhead fitting in the pneumatic circuit. The "good" seal (no flaw) was used in this series.

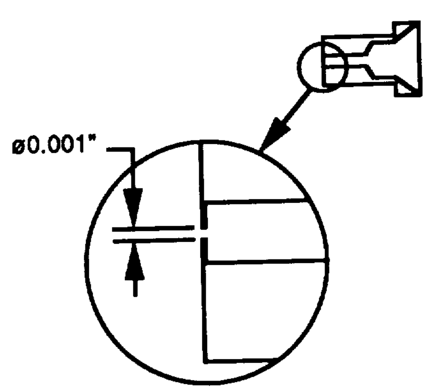



Figure 6. Orifice cap configuration.

Results from these tests did not correspond as well as other series in the matrix, even though 2/1 rates were higher. It appears the flow had become "choked" in nature because of the configuration. The flow through the orifice could not increase once exit pressures were below the critical value given by:

$$P_{cr} = P_r \cdot \{2/(k+1)\}^{\{k/(k-1)\}} \,, \tag{5}$$

which, for gaseous nitrogen equals 0.53. During 1/0 tests, for a fixture pressure of 14.5 psia, flow could not increase after the external pressure dropped below 7.7 psia. Still the flow ratio calculated using this method to determine the exit pressure does not match the actual flow ratios measured. Equation (4) was developed based on laminar flow. Critical flow through the orifice does not follow this behavior, resulting in the discrepancy.

## APPENDIX A

### Test Data Listing

# DELTA PRESSURE LEAK RATE COMPARISON TEST RESULTS

## FLOW DATA

| | PRESSURE RATIO | | | |
|---|---|---|---|---|
| | '2/1' | '1.5/1' | '1.5/0' | '1/0' |
| FLAW | | | | |
| 0.0050 | 5.82E-1 | 3.10E-1 | 3.89E-1 | 2.16E-1 |
| ORIFICE | 5.07E-1 | 2.57E-1 | 1.26E-1 | 8.43E-2 |
| 0.0040 | 2.06E-1 | 9.10E-2 | 1.37E-1 | 6.70E-2 |
| 0.0030 | 1.75E-1 | 7.99E-2 | 1.33E-1 | 6.45E-2 |
| 0.0024 | 4.43E-2 | 1.57E-2 | 2.87E-2 | 1.32E-2 |
| SPLICE | 4.21E-3 | 1.78E-3 | 3.72E-3 | 1.79E-3 |
| 0.0018 | 4.19E-3 | 1.75E-3 | 3.50E-3 | 1.73E-3 |
| BASELINE | 1.65E-4 | 7.48E-5 | 1.06E-4 | 6.20E-5 |

| | 2/1-1/0 FLOW RATIO | | | 2/1-1.5/0 FLOW RATIO | | | 2/1-1.5/1 FLOW RATIO | | |
|---|---|---|---|---|---|---|---|---|---|
| | ACTUAL | CALC'D | % DIFF. | ACTUAL | CALC'D | % DIFF. | ACTUAL | CALC'D | % DIFF. |
| FLAW | | | | | | | | | |
| 0.0050 | 2.70 | 2.93 | 9 | 1.50 | 1.33 | -11 | 1.88 | 2.39 | 27 |
| ORIFICE | 6.01 | 4.00 | -33 | 4.02 | 1.78 | -56 | 1.97 | 2.31 | 17 |
| 0.0040 | 3.08 | 3.00 | -3 | 1.50 | 1.33 | -11 | 2.27 | 2.40 | 6 |
| 0.0030 | 2.71 | 3.00 | 11 | 1.31 | 1.33 | 1 | 2.19 | 2.40 | 10 |
| 0.0024 | 3.35 | 3.00 | -11 | 1.54 | 1.33 | -14 | 2.82 | 2.40 | -15 |
| SPLICE | 2.35 | 2.92 | 25 | 1.13 | 1.33 | 18 | 2.36 | 2.45 | 4 |
| 0.0018 | 2.42 | 3.00 | 24 | 1.20 | 1.33 | 11 | 2.39 | 2.40 | 0 |
| BASELINE | 2.67 | 2.93 | 10 | 1.56 | 1.29 | -17 | 2.21 | 2.36 | 7 |

| | 1.5/1-1/0 FLOW RATIO | | | 1.5/1-1.5/0 FLOW RATIO | | |
|---|---|---|---|---|---|---|
| | ACTUAL | CALC'D | % DIFF. | ACTUAL | CALC'D | % DIFF. |
| FLAW | | | | | | |
| 0.0050 | 1.44 | 1.25 | -13 | 0.80 | 0.56 | -30 |
| ORIFICE | 3.05 | 1.73 | -43 | 2.04 | 0.77 | -62 |
| 0.0040 | 1.36 | 1.25 | -8 | 0.66 | 0.56 | -16 |
| 0.0030 | 1.24 | 1.25 | 1 | 0.60 | 0.56 | -8 |
| 0.0024 | 1.19 | 1.25 | 5 | 0.55 | 0.56 | 2 |
| SPLICE | 0.99 | 1.22 | 22 | 0.48 | 0.56 | 16 |
| 0.0018 | 1.01 | 1.25 | 23 | 0.50 | 0.56 | 11 |
| BASELINE | 1.21 | 1.25 | 4 | 0.71 | 0.56 | -22 |

| | 1.5/0-1/0 FLOW RATIO | | |
|---|---|---|---|
| | ACTUAL | CALC'D | % DIFF. |
| FLAW | | | |
| 0.0050 | 1.80 | 2.25 | 25 |
| ORIFICE | 1.49 | 2.25 | 51 |
| 0.0040 | 2.05 | 2.25 | 10 |
| 0.0030 | 2.06 | 2.25 | 9 |
| 0.0024 | 2.17 | 2.25 | 4 |
| SPLICE | 2.08 | 2.19 | 6 |
| 0.0018 | 2.02 | 2.25 | 11 |
| BASELINE | 1.70 | 2.25 | 32 |

000-3 Average Data

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **2/1-000-3** | T96 Stats | | T97 Stats | | T98 Stats | | | | |
| | P1 | P2 | P1 | P2 | P1 | P2 | | **2/1-000-3** | |
| | Stats | Stats | Stats | Stats | Stats | Stats | | Averages | |
| **SLOPE** | -0.00012 | -0.00013 | -0.00017 | -0.00017 | -0.00021 | -0.00020 | | **-0.00017** | **sccs** |
| **INTERCEPT** | 249.1 | 249.5 | 244.2 | 244.4 | 244.4 | 244.6 | | 246.0 | scc |
| R^2 | 0.9920 | 0.9808 | 0.9910 | 0.9910 | 0.9888 | 0.9951 | | 0.9898 | |
| | | | | | | | | | |
| **1.5/1-000-3** | T93 Stats | | T94 Stats | | T95 Stats | | | | |
| | P1 | P2 | P1 | P2 | P1 | P2 | | **1.5/1-000-3** | |
| | Stats | Stats | Stats | Stats | Stats | Stats | | Averages | |
| **SLOPE** | -0.00010 | -0.00011 | -0.00011 | -0.00004 | -0.00005 | -0.00004 | | **-0.00007** | **sccs** |
| **INTERCEPT** | 183.5 | 183.7 | 185.2 | 184.9 | 185.3 | 185.3 | | 184.7 | scc |
| R^2 | 0.9434 | 0.9695 | 0.9945 | 0.9243 | 0.9717 | 0.9906 | | 0.9656 | |
| | | | | | | | | | |
| **1.5/0-000-3** | T120 Stats | | T121 Stats | | T122 Stats | | | | |
| | P1 | P2 | P1 | P2 | P1 | P2 | | **1.5/0-000-3** | |
| | Stats | Stats | Stats | Stats | Stats | Stats | | Averages | |
| **SLOPE** | -0.00017 | -0.00012 | -0.00009 | -0.00008 | -0.00009 | -0.00008 | | **-0.00011** | **sccs** |
| **INTERCEPT** | 187.7 | 188.2 | 187.8 | 188.5 | 187.6 | 188.4 | | 188.0 | scc |
| R^2 | 0.9715 | 0.9797 | 0.9967 | 0.9879 | 0.9833 | 0.9983 | | 0.9862 | |
| | | | | | | | | | |
| **1/0-000-3** | T117 Stats | | T118 Stats | | T119 Stats | | | | |
| | P1 | P2 | P1 | P2 | P1 | P2 | | **1/0-000-3** | |
| | Stats | Stats | Stats | Stats | Stats | Stats | | Averages | |
| **SLOPE** | -0.00011 | -0.00004 | -0.00008 | -0.00006 | -0.00005 | -0.00004 | | **-0.00006** | **sccs** |
| **INTERCEPT** | 124.7 | 124.9 | 124.7 | 125.2 | 124.7 | 125.2 | | 124.9 | scc |
| R^2 | 0.9757 | 0.9040 | 0.9690 | 0.9680 | 0.9966 | 0.9661 | | 0.9632 | |

## 0018-3 Average Data

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **2/1-0018-3** | T114 Stats | | T115 Stats | | T116 Stats | | | **2/1-0018-3** |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | | Averages |
| SLOPE | -0.00418 | -0.00422 | -0.00422 | -0.00418 | -0.00418 | -0.00415 | | **-0.00419 sccs** |
| INTERCEPT | 251.9 | 252.5 | 251.9 | 252.5 | 251.7 | 252.5 | | 252.2 scc |
| R^2 | 0.9998 | 0.9993 | 0.9999 | 0.9997 | 0.9997 | 0.9996 | | 0.9997 |
| | | | | | | | | |
| **1.5/1-0018-3** | T111 Stats | | T112 Stats | | T113 Stats | | | **1.5/1-0018-3** |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | | Averages |
| SLOPE | -0.00175 | -0.00174 | -0.00175 | -0.00174 | -0.00177 | -0.00177 | | **-0.00175 sccs** |
| INTERCEPT | 188.2 | 188.8 | 188.3 | 188.9 | 188.3 | 188.9 | | 188.6 scc |
| R^2 | 0.9991 | 0.9992 | 0.9994 | 0.9993 | 0.9995 | 0.9995 | | 0.9993 |
| | | | | | | | | |
| **1.5/0-0018-3** | T108 Stats | | T109 Stats | | T110 Stats | | | **1.5/0-0018-3** |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | | Averages |
| SLOPE | -0.00354 | -0.00353 | -0.00347 | -0.00346 | -0.00348 | -0.00352 | | **-0.00350 sccs** |
| INTERCEPT | 188.9 | 189.5 | 188.8 | 189.4 | 188.8 | 189.5 | | 189.2 scc |
| R^2 | 0.9997 | 0.9995 | 0.9998 | 0.9997 | 0.9999 | 0.9998 | | 0.9997 |
| | | | | | | | | |
| **1/0-0018-3** | T105 Stats | | T106 Stats | | T107 Stats | | | **1/0-0018-3** |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | | Averages |
| SLOPE | -0.00175 | -0.00175 | -0.00175 | -0.00175 | -0.00172 | -0.00167 | | **-0.00173 sccs** |
| INTERCEPT | 126.5 | 126.1 | 126.4 | 126.0 | 127.3 | 127.4 | | 126.6 scc |
| R^2 | 0.9994 | 0.9995 | 0.9996 | 0.9996 | 0.9987 | 0.9986 | | 0.9992 |

Poor Splice Average Data

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **2/1-SPLICE-3** | T84 Stats | | T85 Stats | | T86 Stats | | | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | **2/1-SPLICE-3** Averages | |
| SLOPE | -0.00416 | -0.00419 | -0.00420 | -0.00417 | -0.00427 | -0.00424 | **-0.00421** | **sccs** |
| INTERCEPT | 246.1 | 245.6 | 245.9 | 245.5 | 246.0 | 245.5 | 245.8 | scc |
| R^2 | 0.9995 | 0.9993 | 0.9999 | 0.9997 | 0.9995 | 0.9993 | 0.9995 | |
| **1.5/1-SPLICE-3** | T81 Stats | | T82 Stats | | T83 Stats | | | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | **1.5/1-SPLICE-3** Averages | |
| SLOPE | -0.00180 | -0.00179 | -0.00179 | -0.00177 | -0.00180 | -0.00176 | **-0.00178** | **sccs** |
| INTERCEPT | 185.3 | 185.1 | 185.4 | 185.2 | 185.8 | 185.5 | 185.4 | scc |
| R^2 | 0.9981 | 0.9977 | 0.9995 | 0.9970 | 0.9995 | 0.9991 | 0.9985 | |
| **1.5/0-SPLICE-3** | T78 Stats | | T79 Stats | | T80 Stats | | | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | **1.5/0-SPLICE-3** Averages | |
| SLOPE | -0.00364 | -0.00366 | -0.00369 | -0.00370 | -0.00382 | -0.00383 | **-0.00372** | **sccs** |
| INTERCEPT | 185.2 | 185.0 | 185.5 | 185.3 | 185.7 | 185.4 | 185.4 | scc |
| R^2 | 0.9996 | 0.9994 | 0.9998 | 0.9998 | 0.9999 | 0.9996 | 0.9997 | |
| **1/0-SPLICE-3** | T75 Stats | | T76 Stats | | T77 Stats | | | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | **1/0-SPLICE-3** Averages | |
| SLOPE | -0.00159 | -0.00153 | -0.00185 | -0.00182 | -0.00200 | -0.00197 | **-0.00179** | **sccs** |
| INTERCEPT | 126.5 | 126.5 | 126.5 | 126.4 | 126.5 | 126.5 | 126.5 | scc |
| R^2 | 0.9991 | 0.9966 | 0.9998 | 0.9988 | 0.9999 | 0.9985 | 0.9988 | |

0024-2 Average Data

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **2/1-0024-2** | T51 Stats | | T52 Stats | | T53 Stats | | **2/1-0024-2** | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | Averages | |
| SLOPE | -0.04672 | -0.04623 | -0.04383 | -0.04345 | -0.04287 | -0.04250 | **-0.04427** | **sccs** |
| INTERCEPT | 246.3 | 246.1 | 246.5 | 246.2 | 246.6 | 246.3 | 246.3 | scc |
| R^2 | 0.9992 | 0.9989 | 0.9995 | 0.9992 | 0.9997 | 0.9993 | 0.9993 | |
| | | | | | | | | |
| **1.5/1-0024-2** | T60 Stats | | T61 Stats | | T62 Stats | | **1.5/1-0024-2** | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | Averages | |
| SLOPE | -0.01593 | -0.01550 | -0.01575 | -0.01572 | -0.01566 | -0.01552 | **-0.01568** | **sccs** |
| INTERCEPT | 185.4 | 185.3 | 185.4 | 185.3 | 185.4 | 185.3 | 185.3 | scc |
| R^2 | 0.9997 | 0.9974 | 0.9998 | 0.9974 | 0.9993 | 0.9987 | 0.9987 | |
| | | | | | | | | |
| **1.5/0-0024-2** | T57 Stats | | T58 Stats | | T59 Stats | | **1.5/0-0024-2** | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | Averages | |
| SLOPE | -0.02922 | -0.02845 | -0.02870 | -0.02838 | -0.02877 | -0.02847 | **-0.02867** | **sccs** |
| INTERCEPT | 185.6 | 185.5 | 185.5 | 185.5 | 185.4 | 185.4 | 185.5 | scc |
| R^2 | 0.9995 | 0.9958 | 0.9992 | 0.9962 | 0.9998 | 0.9972 | 0.9980 | |
| | | | | | | | | |
| **1/0-0024-2** | T54 Stats | | T55 Stats | | T56 Stats | | **1/0-0024-2** | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | Averages | |
| SLOPE | -0.01302 | -0.01322 | -0.01304 | -0.01329 | -0.01315 | -0.01349 | **-0.01320** | **sccs** |
| INTERCEPT | 126.4 | 127.1 | 126.2 | 126.7 | 126.4 | 126.8 | 126.6 | scc |
| R^2 | 0.9998 | 0.9977 | 0.9998 | 0.9985 | 0.9997 | 0.9979 | 0.9989 | |

003-2 Average Data

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **2/1-003-2** | T36 Stats | | T37 Stats | | T38 Stats | | | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | **2/1-003-2** Averages | |
| SLOPE | -0.17354 | -0.17274 | -0.17557 | -0.17550 | -0.17614 | -0.17475 | **-0.17471** | **sccs** |
| INTERCEPT | 245.7 | 245.5 | 245.9 | 245.7 | 245.9 | 245.7 | 245.7 | scc |
| R^2 | 0.9992 | 0.9991 | 0.9993 | 0.9994 | 0.9994 | 0.9993 | 0.9993 | |
| **1.5/1-003-2** | T33 Stats | | T34 Stats | | T35 Stats | | | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | **1.5/1-003-2** Averages | |
| SLOPE | -0.07984 | -0.08123 | -0.07987 | -0.07978 | -0.07926 | -0.07964 | **-0.07994** | **sccs** |
| INTERCEPT | 185.2 | 185.3 | 185.2 | 185.3 | 185.2 | 185.2 | 185.2 | scc |
| R^2 | 0.9989 | 0.9986 | 0.9990 | 0.9987 | 0.9983 | 0.9973 | 0.9984 | |
| **1.5/0-003-2** | T30 Stats | | T31 Stats | | T32 Stats | | | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | **1.5/0-003-2** Averages | |
| SLOPE | -0.13293 | -0.13370 | -0.13316 | -0.13410 | -0.13207 | -0.13154 | **-0.13292** | **sccs** |
| INTERCEPT | 185.2 | 185.2 | 185.2 | 185.2 | 185.3 | 185.4 | 185.3 | scc |
| R^2 | 0.9992 | 0.9987 | 0.9991 | 0.9982 | 0.9991 | 0.9981 | 0.9987 | |
| **1/0-003-2** | T27 Stats | | T28 Stats | | T29 Stats | | | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | **1/0-003-2** Averages | |
| SLOPE | -0.06515 | -0.06554 | -0.06438 | -0.06424 | -0.06330 | -0.06409 | **-0.06445** | **sccs** |
| INTERCEPT | 130.0 | 130.3 | 130.0 | 130.2 | 129.8 | 130.2 | 130.1 | scc |
| R^2 | 0.9984 | 0.9978 | 0.9986 | 0.9983 | 0.9980 | 0.9979 | 0.9982 | |

004-2 Average Data

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **2/1-004-2** | T15 Stats | | T16 Stats | | T17 Stats | | | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | | **2/1-004-2** Averages |
| SLOPE | -0.2124 | -0.2113 | -0.2063 | -0.2031 | -0.2036 | -0.2013 | | **-0.2063 sccs** |
| INTERCEPT | 246.1 | 246.0 | 246.1 | 245.9 | 246.0 | 245.8 | | 246.0 scc |
| R^2 | 0.9985 | 0.9985 | 0.9986 | 0.9987 | 0.9990 | 0.9987 | | 0.9987 |
| | | | | | | | | |
| **1.5/1-004-2** | T18 Stats | | T19 Stats | | T20 Stats | | | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | | **1.5/1-004-2** Averages |
| SLOPE | -0.0910 | -0.0917 | -0.0914 | -0.0915 | -0.0897 | -0.0909 | | **-0.0910 sccs** |
| INTERCEPT | 185.4 | 185.6 | 185.3 | 185.5 | 185.3 | 185.5 | | 185.4 scc |
| R^2 | 0.9991 | 0.9992 | 0.9992 | 0.9988 | 0.9992 | 0.9988 | | 0.9991 |
| | | | | | | | | |
| **1.5/0-004-2** | T21 Stats | | T22 Stats | | T23 Stats | | | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | | **1.5/0-004-2** Averages |
| SLOPE | -0.1371 | -0.1378 | -0.1374 | -0.1383 | -0.1367 | -0.1372 | | **-0.1374 sccs** |
| INTERCEPT | 185.5 | 185.7 | 185.5 | 185.7 | 185.5 | 185.7 | | 185.6091 scc |
| R^2 | 0.9994 | 0.9994 | 0.9992 | 0.9991 | 0.9995 | 0.9994 | | 0.9993 |
| | | | | | | | | |
| **1/0-004-2** | T24 Stats | | T25 Stats | | T26 Stats | | | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | | **1/0-004-2** Averages |
| SLOPE | -0.0667 | -0.0672 | -0.0664 | -0.0675 | -0.0667 | -0.0674 | | **-0.0670 sccs** |
| INTERCEPT | 130.1 | 130.6 | 130.1 | 130.6 | 130.1 | 130.5 | | 130.3 scc |
| R^2 | 0.9987 | 0.9981 | 0.9993 | 0.9989 | 0.9989 | 0.9988 | | 0.9988 |

Orifice Cap Average Data

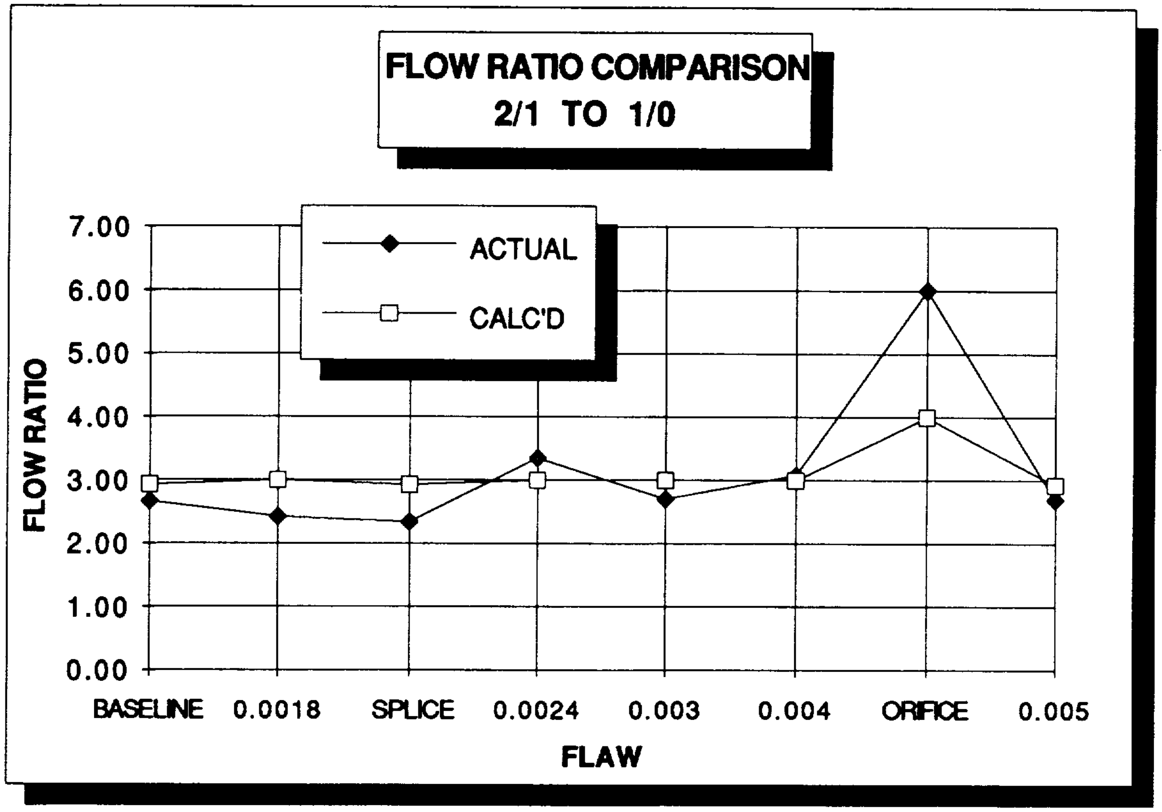
| **2/1-CAP-3** | T90 Stats | | T91 Stats | | T92 Stats | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | P1 | P2 | P1 | P2 | P1 | P2 | | **2/1-CAP-3** | |
| | Stats | Stats | Stats | Stats | Stats | Stats | | Averages | |
| SLOPE | -0.5049 | -0.5069 | -0.5068 | -0.5086 | -0.5067 | -0.5079 | | **-0.5070** | **sccs** |
| INTERCEPT | 260.0 | 260.3 | 259.4 | 259.7 | 259.9 | 260.2 | | 259.9 | scc |
| R^2 | 0.9974 | 0.9974 | 0.9974 | 0.9974 | 0.9977 | 0.9978 | | 0.9975 | |
| | | | | | | | | | |
| **1.5/1-CAP-3** | T87 Stats | | T88 Stats | | T89 Stats | | | | |
| | P1 | P2 | P1 | P2 | P1 | P2 | | **1.5/1-CAP-3** | |
| | Stats | Stats | Stats | Stats | Stats | Stats | | Averages | |
| SLOPE | -0.2571 | -0.2569 | -0.2579 | -0.2577 | -0.2578 | -0.2576 | | **-0.2575** | **sccs** |
| INTERCEPT | 199.6 | 199.7 | 199.7 | 199.8 | 199.9 | 200.0 | | 199.8 | scc |
| R^2 | 0.9928 | 0.9926 | 0.9927 | 0.9923 | 0.9928 | 0.9925 | | 0.9926 | |
| | | | | | | | | | |
| **1.5/0-CAP-3** | T102 Stats | | T103 Stats | | T104 Stats | | | | |
| | P1 | P2 | P1 | P2 | P1 | P2 | | **1.5/0-CAP-3** | |
| | Stats | Stats | Stats | Stats | Stats | Stats | | Averages | |
| SLOPE | -0.1261 | -0.1261 | -0.1262 | -0.1262 | -0.1257 | -0.1258 | | **-0.1260** | **sccs** |
| INTERCEPT | 189.6 | 189.4 | 189.7 | 189.5 | 189.7 | 189.4 | | 189.5 | scc |
| R^2 | 0.9997 | 0.9997 | 0.9997 | 0.9997 | 0.9997 | 0.9997 | | 0.9997 | |
| | | | | | | | | | |
| **1/0-CAP-3** | T99 Stats | | T100 Stats | | T101 Stats | | | | |
| | P1 | P2 | P1 | P2 | P1 | P2 | | **1/0-CAP-3** | |
| | Stats | Stats | Stats | Stats | Stats | Stats | | Averages | |
| SLOPE | -0.0856 | -0.0858 | -0.0840 | -0.0840 | -0.0833 | -0.0833 | | **-0.0843** | **sccs** |
| INTERCEPT | 137.1 | 136.8 | 130.7 | 130.3 | 130.7 | 130.3 | | 132.7 | scc |
| R^2 | 0.9991 | 0.9989 | 0.9996 | 0.9995 | 0.9995 | 0.9994 | | 0.9993 | |

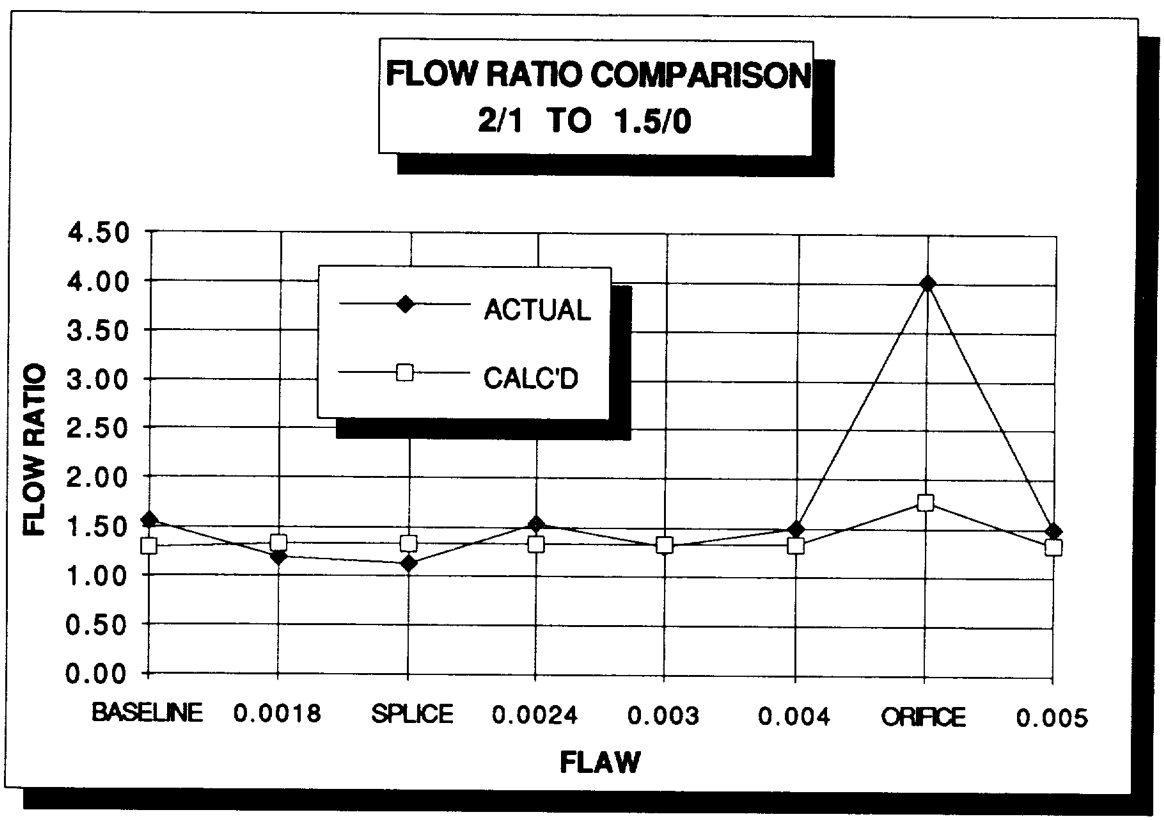
## 005-2 Average Data

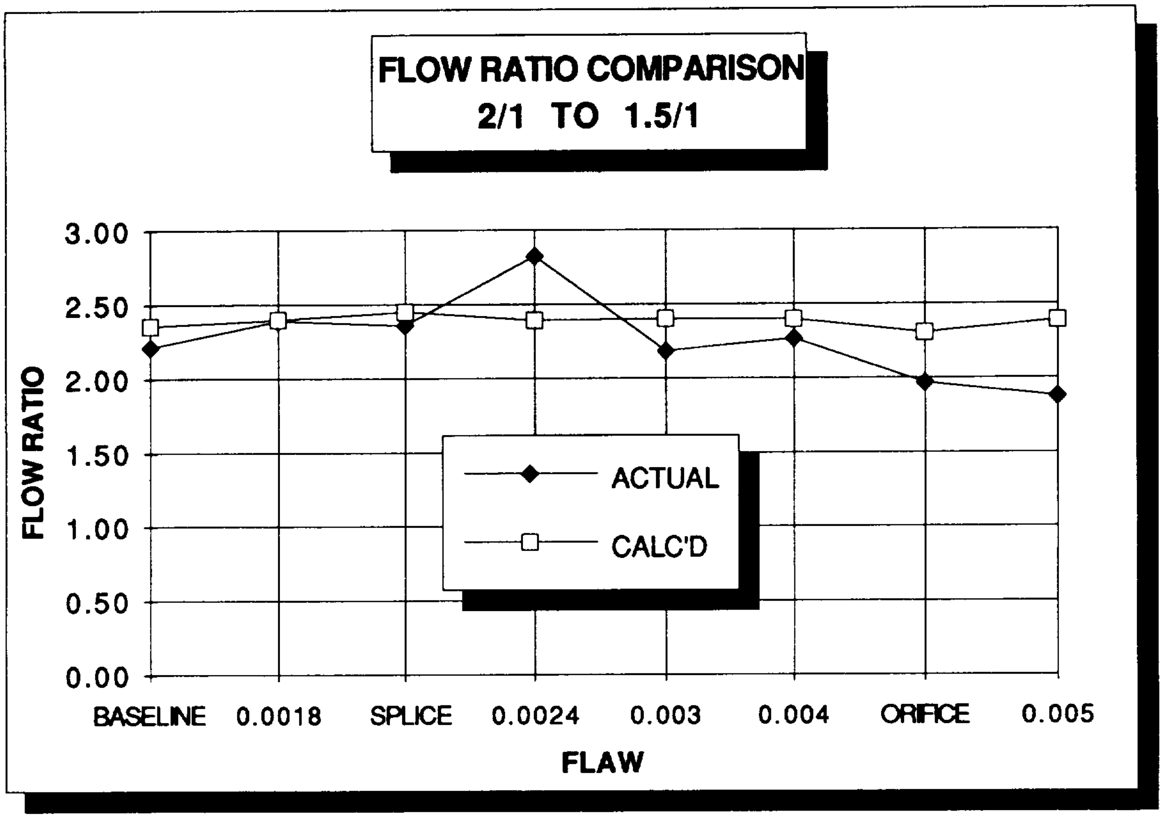
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **2/1-005-2** | T66 Stats | | T67 Stats | | T68 Stats | | | **2/1-005-2** | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | | Averages | |
| SLOPE | -0.5892 | -0.5841 | -0.5820 | -0.5762 | -0.5836 | -0.5792 | | **-0.5824** | **sccs** |
| INTERCEPT | 260.5 | 259.9 | 260.2 | 259.6 | 260.4 | 259.8 | | 260.1 | scc |
| R^2 | 0.9990 | 0.9990 | 0.9988 | 0.9987 | 0.9984 | 0.9982 | | 0.9987 | |
| | | | | | | | | | |
| **1.5/1-005-2** | T63 Stats | | T64 Stats | | T65 Stats | | | **1.5/1-005-2** | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | | Averages | |
| SLOPE | -0.3075 | -0.3080 | -0.3239 | -0.3228 | -0.2995 | -0.2998 | | **-0.3102** | **sccs** |
| INTERCEPT | 199.9 | 199.8 | 202.0 | 201.8 | 199.9 | 199.8 | | 200.5 | scc |
| R^2 | 0.9977 | 0.9980 | 0.9977 | 0.9980 | 0.9986 | 0.9987 | | 0.9981 | |
| | | | | | | | | | |
| **1.5/0-005-2** | T72 Stats | | T73 Stats | | T74 Stats | | | **1.5/0-005-2** | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | | Averages | |
| SLOPE | -0.4087 | -0.4098 | -0.3790 | -0.3788 | -0.3785 | -0.3791 | | **-0.3890** | **sccs** |
| INTERCEPT | 200.2 | 200.2 | 200.6 | 200.4 | 200.6 | 200.9 | | 200.5 | scc |
| R^2 | 0.9991 | 0.9992 | 0.9994 | 0.9995 | 0.9992 | 0.9993 | | 0.9993 | |
| | | | | | | | | | |
| **1/0-005-2** | T69 Stats | | T70 Stats | | T71 Stats | | | **1/0-005-2** | |
| | P1 Stats | P2 Stats | P1 Stats | P2 Stats | P1 Stats | P2 Stats | | Averages | |
| SLOPE | -0.2170 | -0.2157 | -0.2162 | -0.2166 | -0.2157 | -0.2143 | | **-0.2159** | **sccs** |
| INTERCEPT | 126.4 | 126.4 | 126.2 | 126.3 | 126.4 | 126.4 | | 126.3 | scc |
| R^2 | 0.9987 | 0.9988 | 0.9994 | 0.9993 | 0.9991 | 0.9992 | | 0.9991 | |

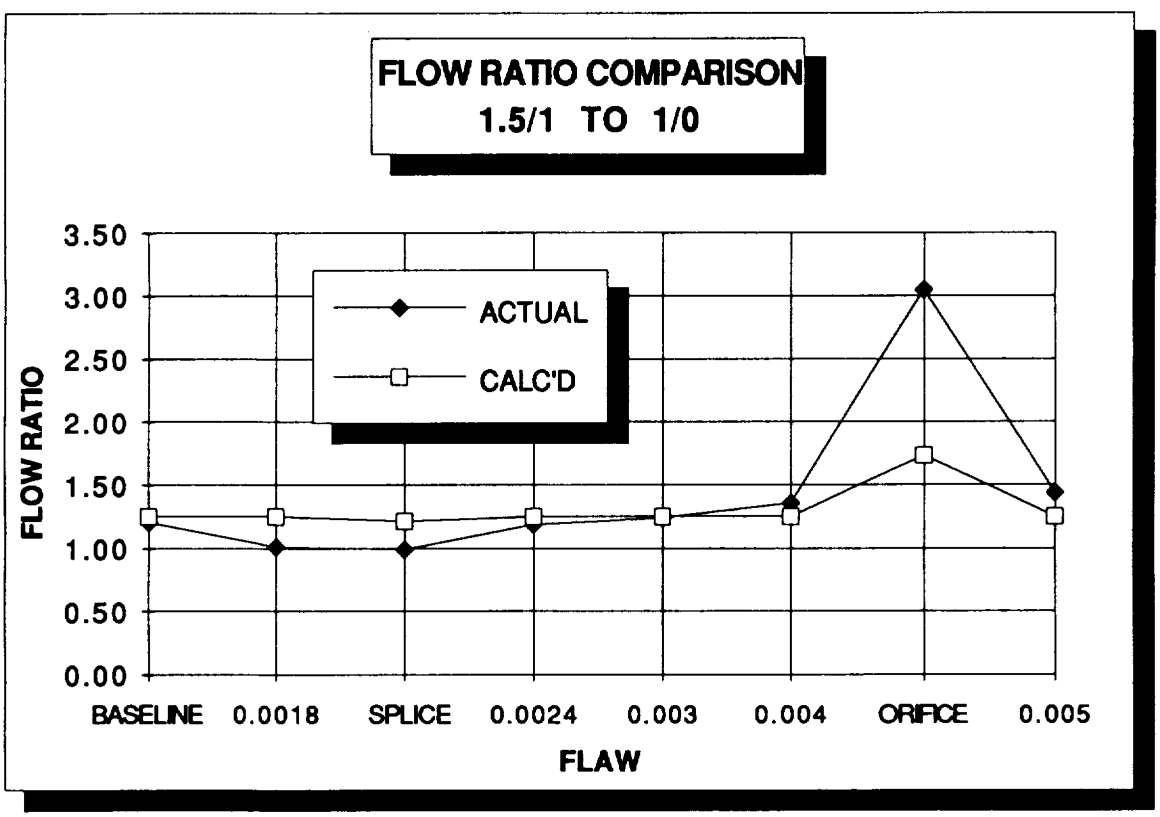
## APPENDIX B

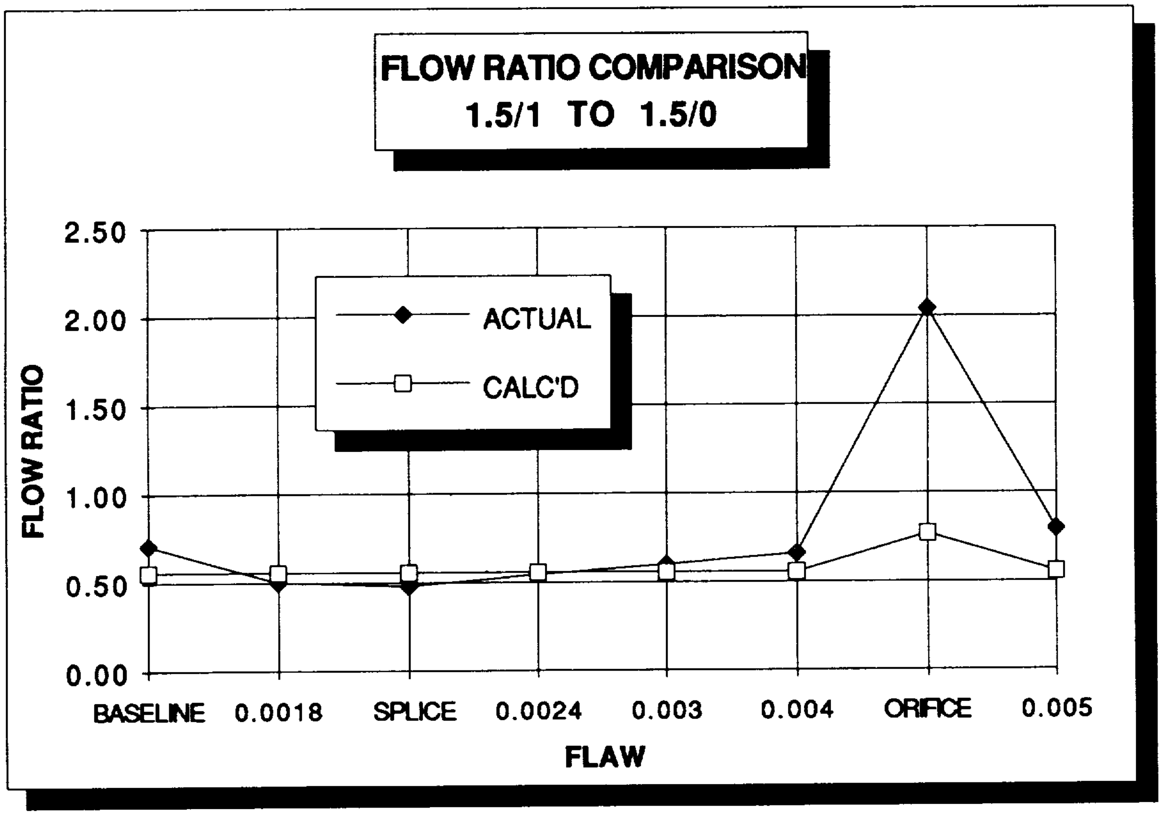
## Flow Ratio Plots

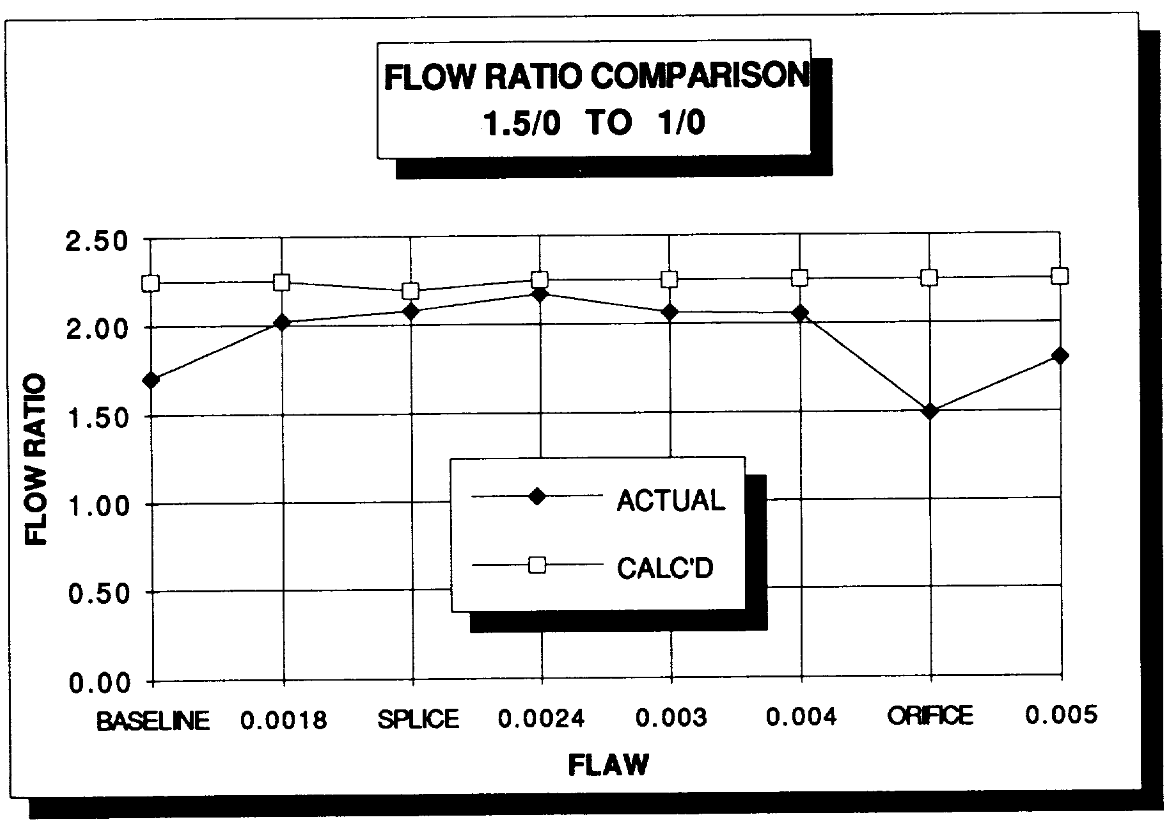

FLOW RATIO COMPARISON
2/1 TO 1/0
ACTUAL
CALC'D
FLOW RATIO
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
BASELINE
0.0018
SPLICE
0.0024
0.003
0.004
ORIFICE
0.005
FLAW


FLOW RATIO COMPARISON
2/1 TO 1.5/0
ACTUAL
CALC'D
FLOW RATIO
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
BASELINE
0.0018
SPLICE
0.0024
0.003
0.004
ORIFICE
0.005
FLAW


FLOW RATIO COMPARISON
2/1 TO 1.5/1
3.00
2.50
2.00
1.50
1.00
0.50
0.00
FLOW RATIO
ACTUAL
CALC'D
BASELINE
0.0018
SPLICE
0.0024
0.003
0.004
ORIFICE
0.005
FLAW


FLOW RATIO COMPARISON
1.5/1 TO 1/0
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
FLOW RATIO
ACTUAL
CALC'D
BASELINE
0.0018
SPLICE
0.0024
0.003
0.004
ORIFICE
0.005
FLAW


FLOW RATIO COMPARISON
1.5/1 TO 1.5/0
2.50
2.00
1.50
1.00
0.50
0.00
FLOW RATIO
ACTUAL
CALC'D
BASELINE
0.0018
SPLICE
0.0024
0.003
0.004
ORIFICE
0.005
FLAW


FLOW RATIO COMPARISON
1.5/0 TO 1/0
2.50
2.00
1.50
1.00
0.50
0.00
FLOW RATIO
ACTUAL
CALC'D
BASELINE
0.0018
SPLICE
0.0024
0.003
0.004
ORIFICE
0.005
FLAW

## REFERENCE


1. McMaster, R.C.: "Nondestructive Testing Handbook, Second Edition, Volume One—Leak Testing." American Society for Nondestructive Testing, American Society for Metals, 1982.

## APPROVAL

## SPACE STATION *FREEDOM* DELTA PRESSURE LEAKAGE RATE COMPARISON TEST DATA ANALYSIS REPORT

By E.B. Sorensen

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

J.P. McCarty

J.P. MCCARTY
Director, Propulsion Laboratory

☆ U. S. GOVERNMENT PRINTING OFFICE 1992 — 631—060 /60088

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
February 1992

**3. REPORT TYPE AND DATES COVERED**
Technical Memorandum

**4. TITLE AND SUBTITLE**
Space Station *Freedom* Delta Pressure Leakage Rate Comparison Test Data Analysis Report

**5. FUNDING NUMBERS**

**6. AUTHOR(S)**
E.B. Sorensen

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
National Aeronautics and Space Administration
Washington, DC 20546

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
NASA TM-103576

**11. SUPPLEMENTARY NOTES**
Prepared by Propulsion Laboratory, Science and Engineering Directorate.

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
Unclassified — Unlimited

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

This report provides results of a series of tests performed to identify the relationship between gas leakage rates across a seal at various internal to external pressure ratios. This report is intended to complement the results and provide insight into the analysis technique used to obtain the results presented in MSFC SSF/DEV/EL91-008, "Space Station *Freedom* (S.S. *Freedom*) Seal Flaw Study With Delta Pressure Leak Rate Comparison Test Report."

**14. SUBJECT TERMS**
Seal Verification, Leak Testing, Seal Leakage, Leak Rate, Differential Pressure, Seal Flaw

**15. NUMBER OF PAGES**
27

**16. PRICE CODE**
NTIS

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | Unlimited |