

PROJECT ADMINISTRATION DATA SHEET

ORIGINAL REVISION NO. _____

Project No. E-16-648

DATE 12/28/81

Project Director: Howard McMahon

School/Lab AE

Sponsor: Rolls-Royce, Inc.; Atlanta, GA

Type Agreement: Letter of 11/25/81

Award Period: From 11/25/81 To 12/31/81 (Performance) _____ (Reports) _____

Sponsor Amount: \$4,399 Contracted through: _____

Cost Sharing: N/A GTRI/STF _____

Title: Effect of Tip Radius on the Discharge Coefficient of a Flat Plate/Endwall Nozzle

ADMINISTRATIVE DATA

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Defense Priority Rating: N/A

Security Classification: N/A

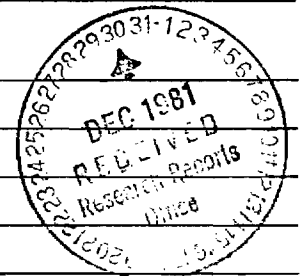
RESTRICTIONS

See Attached N/A Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval - Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of \$500 or 125% of approved proposal budget category.

Equipment: Title vests with N/A

COMMENTS:



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SPONSORED PROJECT TERMINATION SHEET

Date 2/5/82

Project Title: Effect of Tip Radius on the Discharge Coefficient of a Flat Plate/Endwall
Nozzle

Project No: E-16-648

Project Director: Howard McMahon

Sponsor: Rolls-Royce, Inc.; Atlanta, GA

Effective Termination Date: 12/31/81

Clearance of Accounting Charges: _____

Grant/Contract Closeout Actions Remaining:

- Final Invoice and Closing Documents
- Final Fiscal Report
- Final Report of Inventions
- Govt. Property Inventory & Related Certificate
- Classified Material Certificate
- Other _____

Assigned to: AE (School/Laboratory)

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EES Public Relations (2)
 Computer Input
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 Other _____

E-16-648

EFFECT OF TIP RADIUS
ON THE
DISCHARGE COEFFICIENT
OF A
FLAT PLATE/ENDWALL NOZZLE

FINAL REPORT
TO
ROLLS-ROYCE INC.
CONTRACT E-16-648

B. R. Daniel and H. M. McMahon

School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

January 22, 1982

INTRODUCTION

New compressor blades in the Rolls-Royce RB 211 engine have tips with square edges. However, during engine overhaul it is customary to polish the blades that have been removed from the engine before these blades are installed again. During this polishing process, the sharp edge of the blade tip is slightly rounded.

The question has arisen as to whether this very small amount of rounding (to a corner radius of approximately 0.008" to 0.012") can have a significant effect on the discharge coefficient of the flow through the blade-tip clearance and hence affect the performance of the engine.

In order to assess the sensitivity of a flow to such a small change in geometry, tests were conducted to determine the discharge coefficient for a simple two-dimensional flow past a flat plate having a sharp edge which simulates the unpolished blade. These results were compared with the discharge coefficients for two similar flat plates which were subjected to one and two polishing cycles, respectively. The discharge coefficients also were evaluated as a function of gap size and pressure ratio. This report presents the procedure used and the results obtained from this two-dimensional test program.

TEST ARTICLE AND PROCEDURES

To minimize positioning errors the blades (i.e., the flat plates) were designed to fit into a slot in the chamber section and to be positioned flush against the top plate (See Figure 1). The gap simulating the blade clearance is a machined recess in the top plate. Three top plates with gap heights of 0.020", 0.030" and 0.040" were used. Measuring equipment considerations led to the selection of a gap width of 4.0". Since it was expected that the effect of the edge ablation on the discharge coefficient would be very small, an accuracy and repeatability of $\pm 1.0\%$ of the discharge coefficient value was set as a goal. Considering the gap dimensions, an error in blade position of 0.001" would lead to a 2.5-5.0% error in area and hence in mass flow. Detailed fabrication drawings, RR-1 through RR-8, have been submitted to Rolls-Royce*.

*The machining work on the test articles was done by Mr. Dewey Ransom of the Aerospace Engineering Machine Shop.

The blades were made of titanium and were 0.049" thick. Three blades were used;

Blade #1 - Reference blade, square edges

Blade #2 - Same as reference blade, except put through one polishing operation

Blade #3 - Same as reference blade, except put through two polishing operations.

The polished blades were supplied by Rolls-Royce.

Air for the test was provided by the 500 cubic foot, 125 psig air supply in the Aerospace Engineering Laboratory. A schematic of the flow system is shown in Figure 2. Photographs of the test set-up are included as Figure 3 and 4.

The airflow rate was measured using a Fischer and Porter Rotameter (Tube No. 5-35-600/CD-10-1085) which has a tube 600 mm long graduated to read flows from 3.0 to 12.0 lbf/min at 220 psig and 70°F. The actual metering pressure (20-60 psig) was read using a 12" diameter Heise Gauge indicating 0-250 psig with 0.25 psi graduations. The metering temperature was read with a thermocouple and displayed on a digital Doric, Type K readout which has a compensated cold junction.

Five pressure ratios (i.e., the ratio of the pressure in the stilling chamber, p_c , to the ambient pressure p_a) were used: 1.2, 1.4, 1.6, 1.8 and 2.0. The ambient pressure was read on a 4" diameter Aneroid Barometer having 0.02" Hg. graduations.

The chamber temperature was measured with a thermocouple and read on a second channel of the Doric digital readout. As was expected, the metering temperature and the chamber temperature agreed within $\pm 1^\circ\text{F}$ so that only the latter temperature was read and recorded.

DATA ANALYSIS

A computer program was written to evaluate the discharge coefficient, C_D , from the measured mass flows, pressures, and temperatures where

$$C_D = \frac{\text{actual mass flow}}{\text{ideal (isentropic) mass flow}} = \frac{\dot{m}_{\text{act}}}{\dot{m}_{\text{ideal}}} \quad (1)$$

The value of \dot{m}_{act} was determined by correcting the rotameter reading (\dot{m}_{std}) to account for the actual metering conditions. If the density of the meter float (steel) is much greater than the density of the fluid (air), the required expression is

$$\dot{m}_{act} = \dot{m}_{std} \sqrt{\frac{P_r}{P_{std}} \cdot \frac{T_{std}}{T_r}} \quad (2)$$

Where \dot{m}_{act} = actual mass flow rate

\dot{m}_{std} = mass flow rate as read from meter scale

P_{std} = 220 psig + p_a

p_a = ambient pressure

T_{std} = 70°F + 460

P_r = metering pressure used (psia)

T_r = metering temperature, here taken to be the temperature in the stilling chamber, T_c .

Under the assumptions that the flow is isentropic and that the velocity in the stilling chamber is negligible compared to the velocity in the slot, then

$$\dot{m}_{ideal} = Ap_c \left\{ \frac{2g}{RT_c} \left[\frac{\Delta p}{p_c} \left(1 - \frac{3}{2\gamma} \frac{\Delta p}{p_c} \right) \right] \right\}^{1/2} \quad (3)$$

or, when choked (i.e., $p_a < (0.528)(p_c)$)

$$\dot{m}_{ideal} = Ap_c \left\{ \frac{g\gamma}{RT_c} \cdot \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{\gamma-1}} \right\}^{1/2} \quad (4)$$

where \dot{m}_{ideal} = ideal (isentropic) mass flow rate

A = slot area

p_c = chamber pressure

Δp = $p_c - p_a$

p_a = ambient pressure

T_c = chamber temperature

R = gas constant for air

γ = ratio of specific heats

g = acceleration due to gravity

The first equation for \dot{m}_{ideal} is an approximation to the exact expression valid when $\Delta p/p_c$ is small, which is satisfied for these tests.

In calculating the discharge coefficient, the mass flow ratio in Equation 1 is independent of temperature if the metering temperature and the chamber temperature are

the same (as was the case here) since the resulting temperature ratio is unity. However, the two temperatures have been input in the computer program so that the values of \dot{m}_{act} and \dot{m}_{ideal} (which are output in addition to C_D) will be precise.

RESULTS AND DISCUSSION

A summary of the 17 test runs made during this study is shown in Table 1 and the values of the discharge coefficients for each of the three gap sizes are presented in Figures 5, 6, and 7 as a function of pressure ratio and blade edge condition.

It is seen that the repeatability of the data is good, most results being contained within a scatter band of $\pm 1\%$ as was set as an initial goal. Repeatability here means testing one blade and then completely removing it and testing one or more other blades before the subject blade is re-installed for a repeatability check.

At all pressure ratios and gap sizes, the effect of the edge rounding is to increase the discharge coefficient by a significant amount which is much larger than the data scatter in the individual tests. This increase in discharge coefficient is in the range of 10-14% for moderate pressure ratios.

Over most of the pressure ratios tested, the change in discharge coefficient between one polishing and two polishes is small or negligible compared to the change in the discharge coefficient between the reference (square) blade and one polishing. For the smallest pressure ratio (1.2) and the smaller gap sizes (0.020" and 0.030") the second polishing decreases the discharge coefficient relative to its value after the first polishing.

These two-dimensional tests indicate that the small amount of edge rounding due to polishing may significantly increase the discharge coefficient of a compressor blade as compared with the value for a square-tip blade. Also, most of the increase occurs as a result of one polishing, with the second polishing in general leading to much smaller changes in discharge coefficient.

Table 1

SUMMARY OF TEST RUNS

BLADE	GAP		
	0.020	0.030	0.040
1	4*,5*,16	10	1, 15
2	6, 17	9,11	14
3	3, 7	8,12	2,13

*Runs not plotted:

- 4, 5 - Blade probably not in proper position since it was installed without removing chamber top.

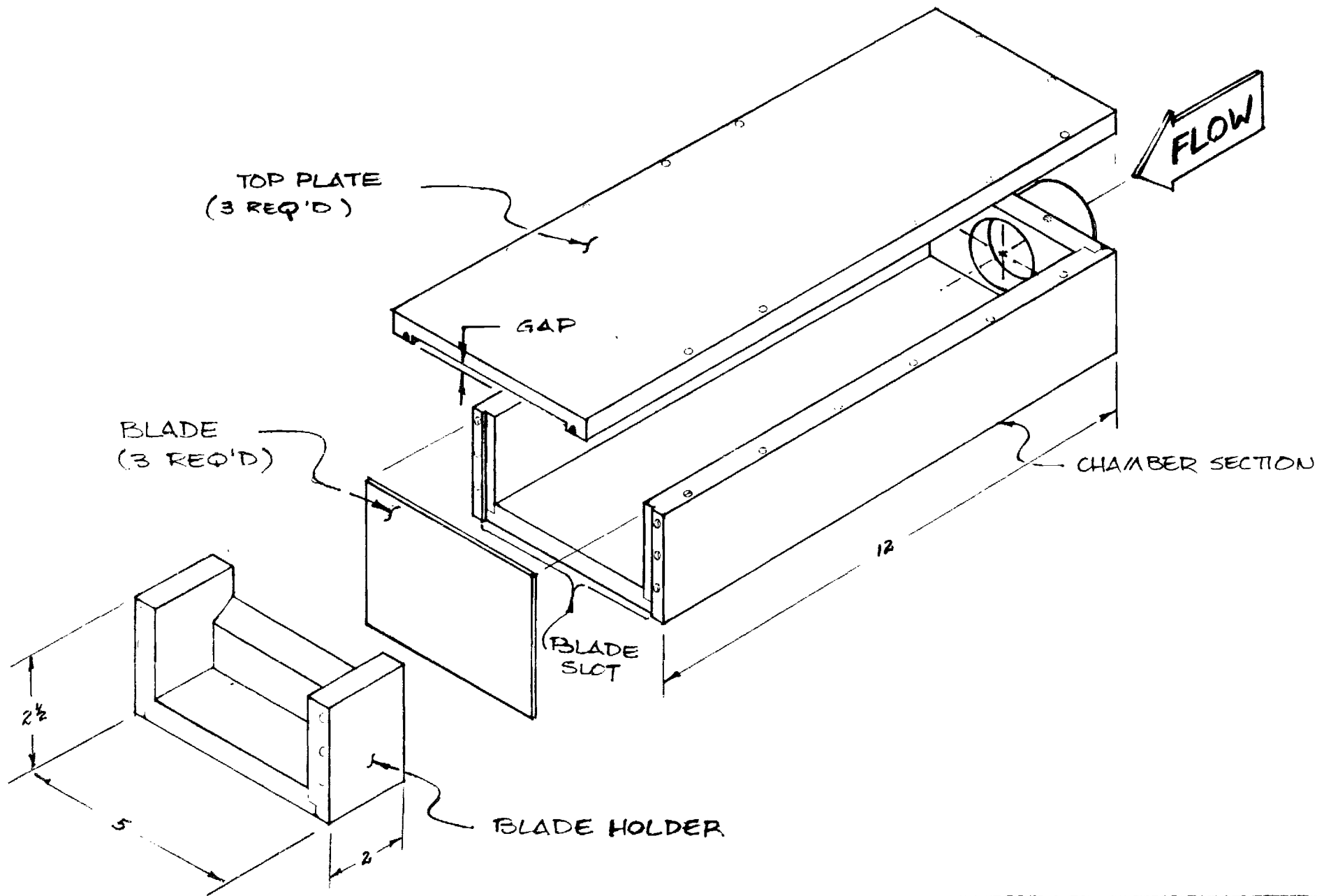


Figure 1 Sketch of Test Article with Components disassembled.

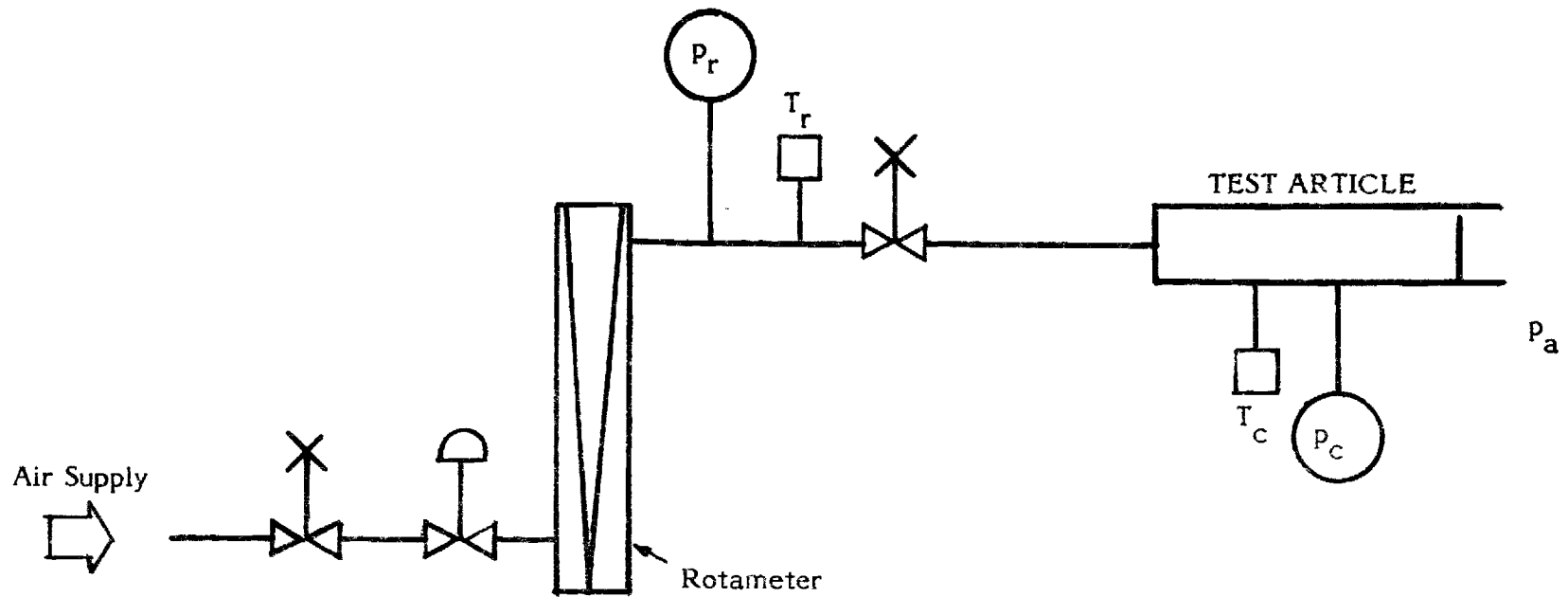


Figure 2 Schematic of Flow System

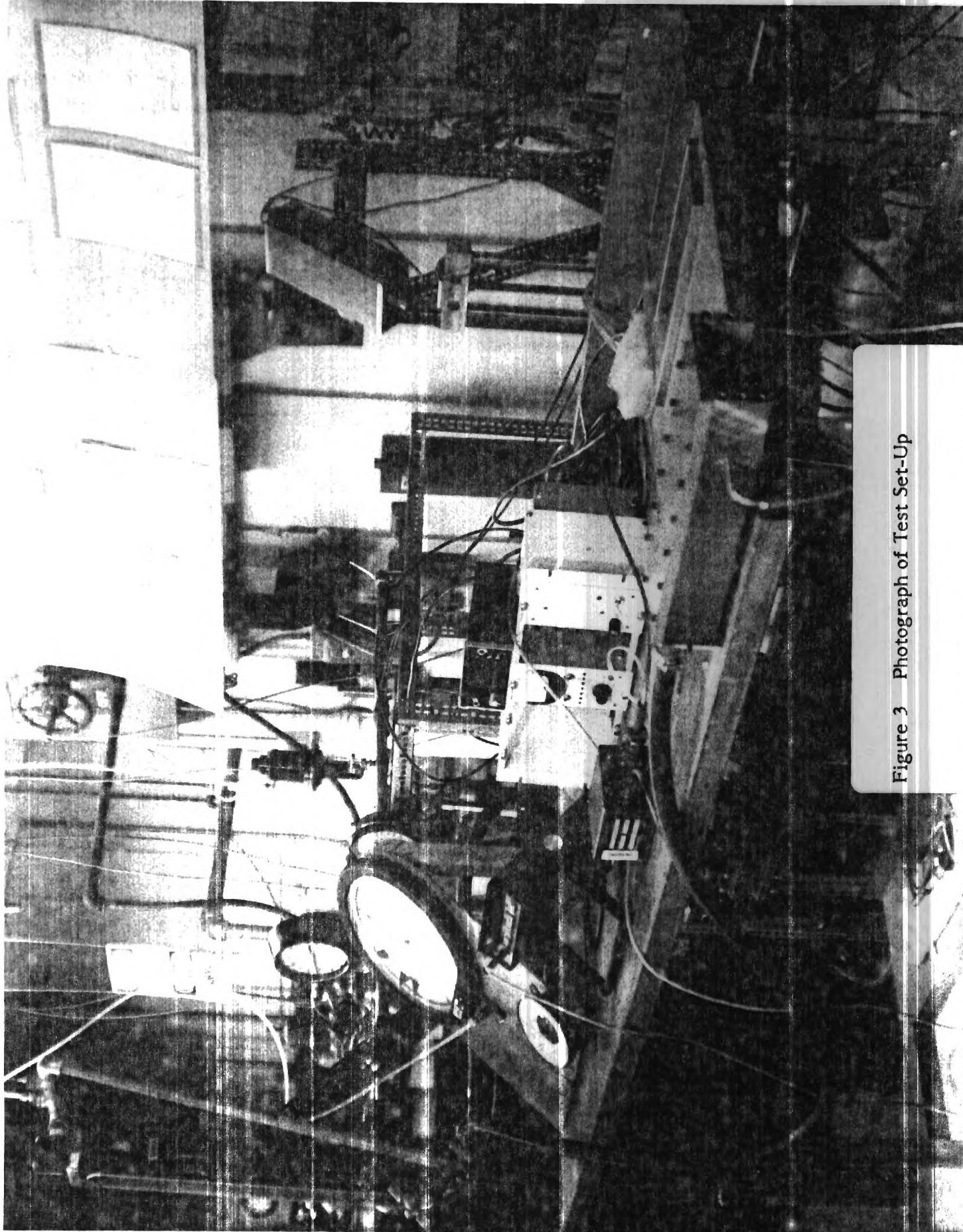


Figure 3 Photograph of Test Set-Up



Figure 4 Test Article With Top Plate
Removed

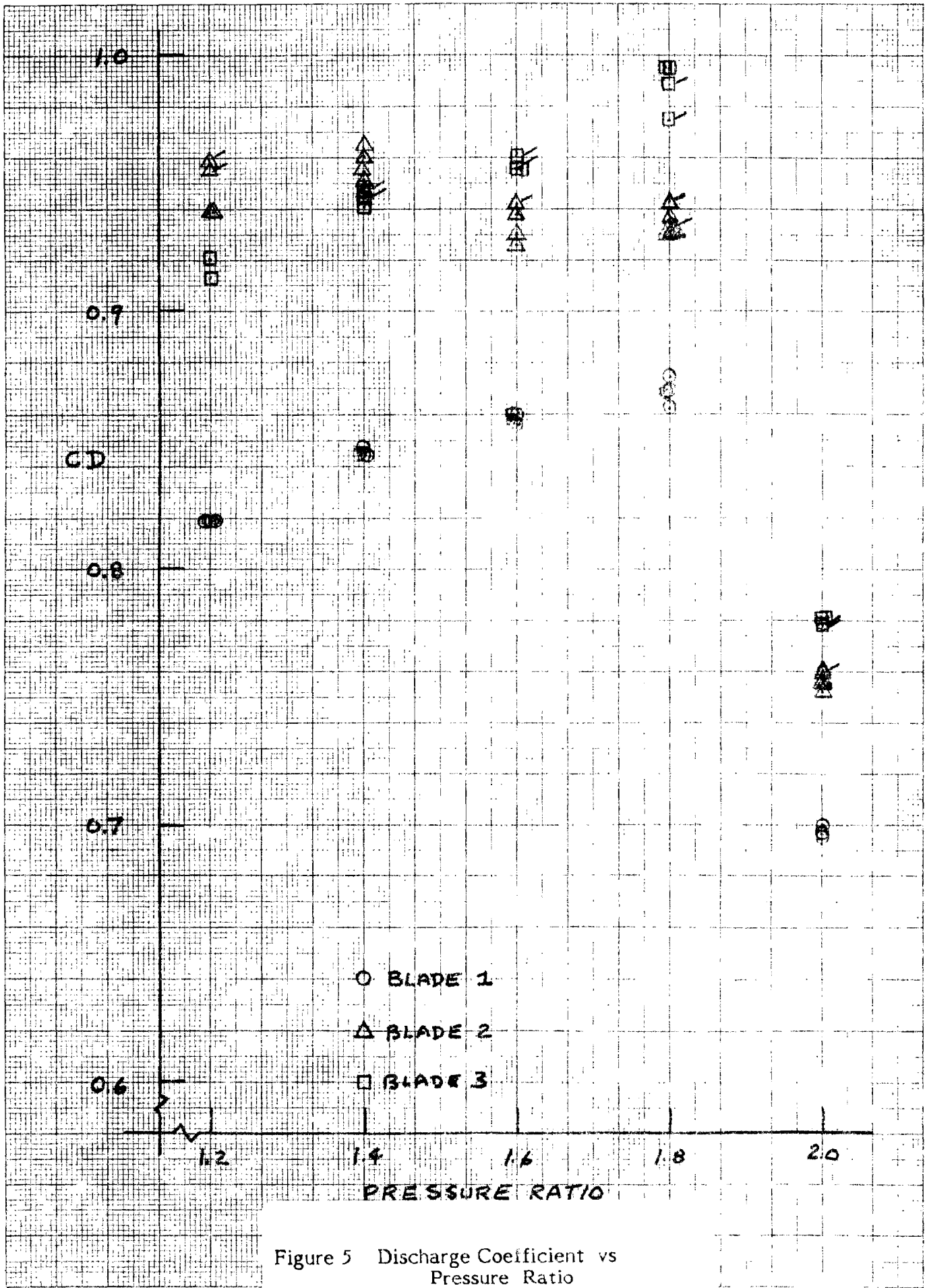


Figure 5 Discharge Coefficient vs Pressure Ratio
Gap = 0.020"

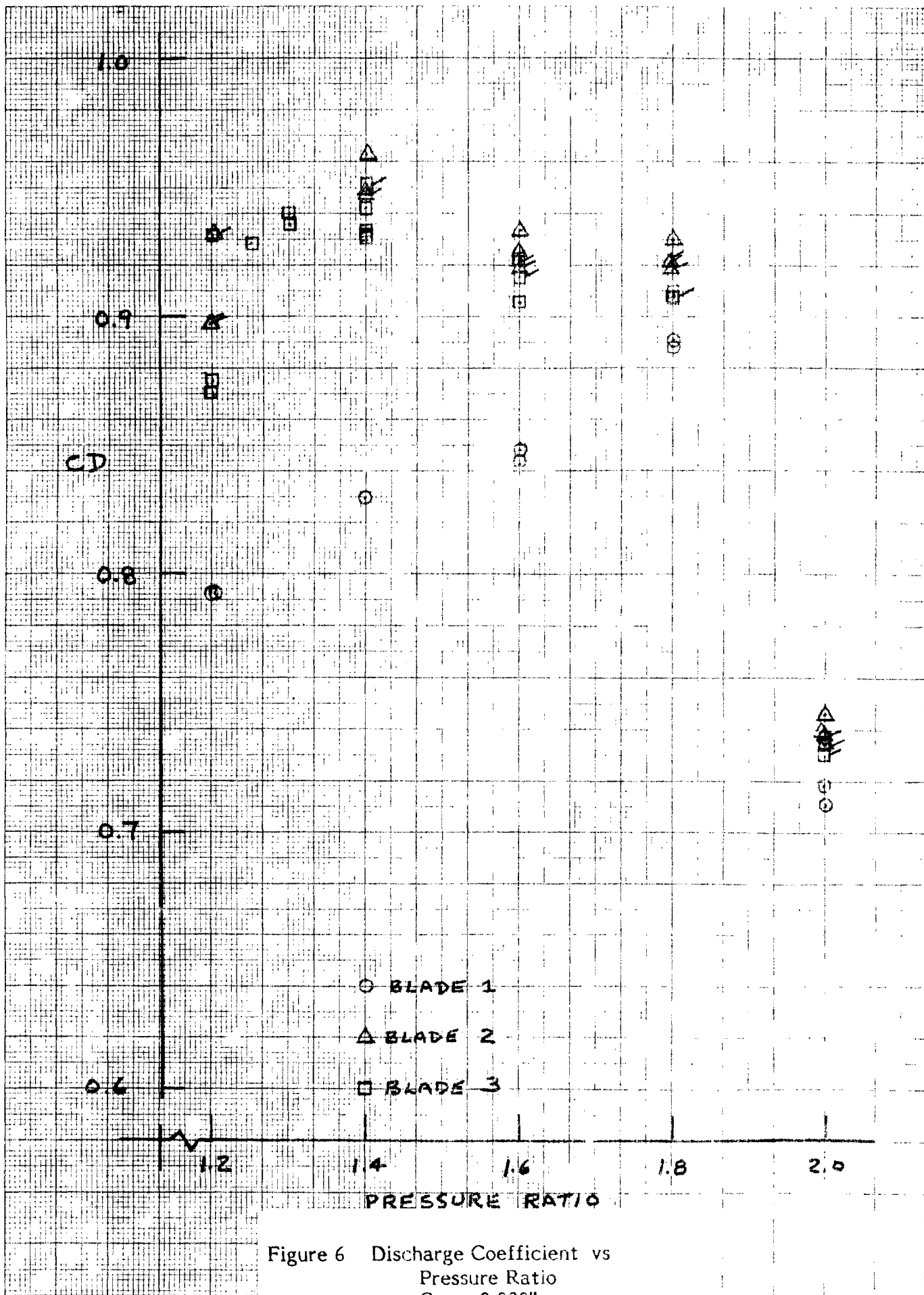


Figure 6 Discharge Coefficient vs Pressure Ratio
Gap = 0.030"

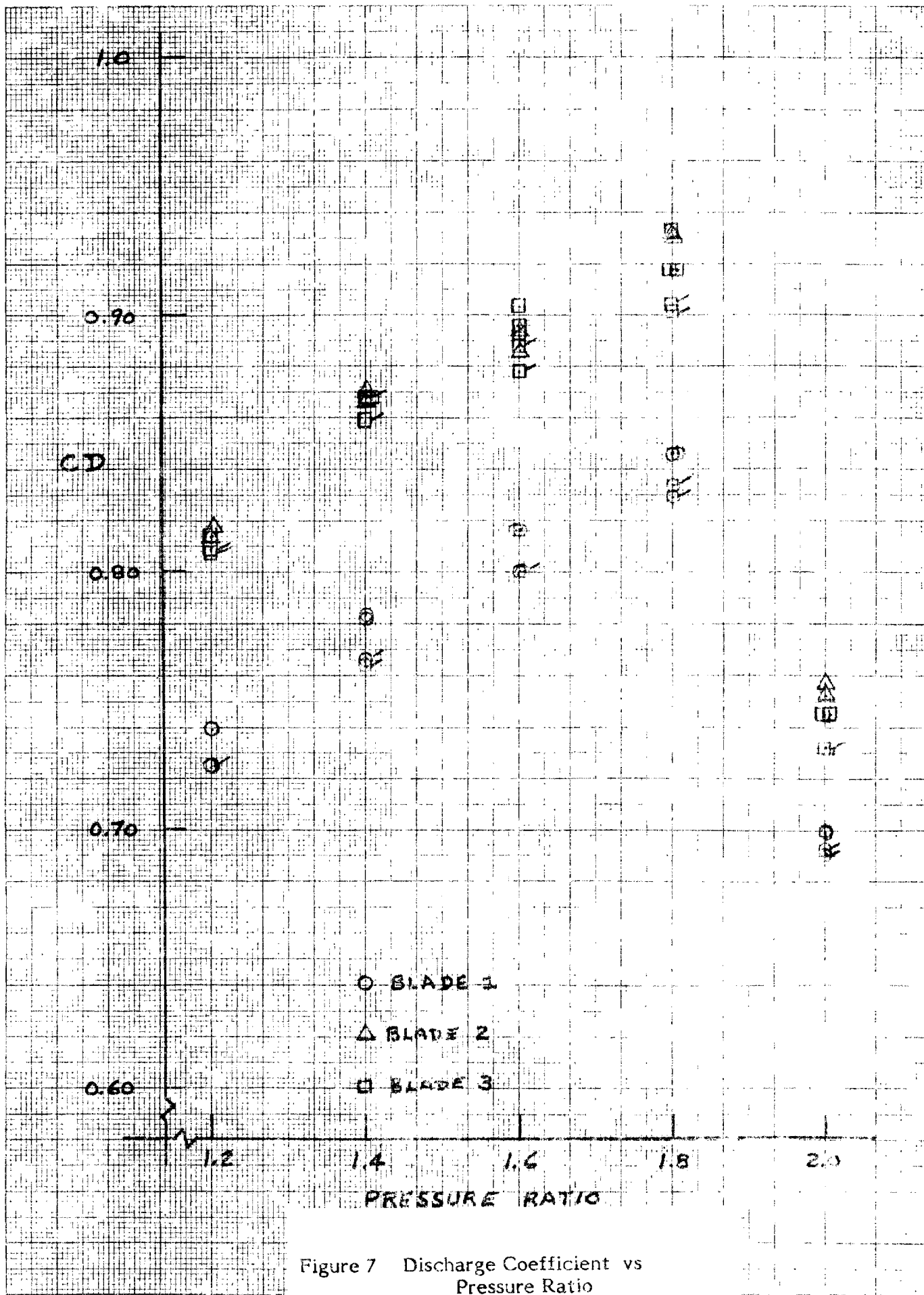


Figure 7 Discharge Coefficient vs Pressure Ratio
Gap = 0.040"