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A STUDY OF PRESSURE PREDICTION METHODS FOR RADIAL FLOW IMPELLERS

PHASE III
PREPARED UNDER
CONTRACT NAS8-5442
FOR NASA-MSFC

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FOREWORD

This report was prepared by Pratt & Whitney Aircraft under Contract NAS8-5442 (Modification No. 4) Phase III, "Investigation of Pressure Prediction Methods for Radial Flow Impellers," for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Engine Systems Branch, Mr. Loren C. Gross, Program Manager.

SECTION I
INTRODUCTION

This report covers the first quarterly reporting period from 13 June 1965 to 13 September 1965 of Phase III of Contract NAS8-5442, "Investigation of Pressure Prediction Methods for Radial Flow Impellers." During this reporting period, the first six of the proposed fifteen tests were completed. These tests included smooth disk tests, with and without an inlet hub, in water and liquid hydrogen, a smooth disk reverse flow test with hydrogen, and a high-pressure (650 psia) liquid hydrogen smooth disk test. The data from the first five tests have been reduced and the results are discussed in this report. Data from the high-pressure test are being reduced and will be presented in the next report.

SECTION II
PROGRESS DURING CURRENT REPORTING PERIOD

A. GENERAL

Phase III of the program is intended to complete and verify the data collected during Phases I and II and to investigate one additional configuration, that of a smooth disk with a bladed housing. The first four tests, two in hydrogen and two in water, were planned to determine the effect of various disk-to-housing clearances with and without an inlet hub on the smooth disk.

Test number five was also conducted with a smooth disk but with the flow through the test rig reversed. The physical limitations of the rig make it impossible to obtain inward flow data at radius ratios below 0.7 under normal flow conditions. The reverse flow test allows inward flow data to be taken on the back side of the disk at a radius ratio down to 0.5.

Test number 6 will provide information on pressure distribution while operating above the critical pressure of hydrogen (187.7 psia). In this test the inlet pressure will be approximately 650 psia compared to an inlet pressure of about 90 psia in previous tests.

Three tests are planned to complete the investigation of the effect of tip blockage that simulates the overhang of the housing over the disk. The three tests will be conducted at different values of tip clearance.

The last series of tests will be conducted to investigate a configuration in which a smooth disk is used with a vaned housing. This configuration should produce a minimum pressure drop along the radial span of the disk and could be employed where a high axial force is required to pressure balance a disk or rotor. Three tests each are planned in water and liquid hydrogen at various disk-to-housing clearances.

The data accumulated in all three phases of the program will then be combined into a Fortran II computer program suitable for use on the IBM 7090 computer. With this program it will be possible to predict the distribution of pressure for any given set of operating conditions and geometries within the scope covered by this program.

All of the tests are being conducted in the test rig shown in figure II-1. Each configuration is tested over a range of speed and flow, and the data are reduced as described in Reference 1. Briefly, the data reduction involves calculation of the head distribution from the test data, which is then plotted against impeller radius squared. The ratio (K) of fluid angular velocity to impeller angular velocity is computed from the slope of the head distribution curves. This K value can then be used to modify the forced vortex equation to determine the head rise for a similar configuration at other operating conditions.

A detailed discussion of the conducted tests is presented in the following paragraphs. The test conditions are summarized in table II-1.

1. Inlet Hub Tests

Four tests have been conducted, two in hydrogen and two in water, to further investigate the effect of an inlet hub on the smooth disk pressure distribution. One test in each fluid was conducted without a hub to reestablish the baseline at a disk-to-housing clearance of 0.057 in. For the second tests in each fluid a 1.00-in. diameter hub was installed in the inlet to the test rig. In previous testing the addition of the hub resulted in a change in K value for both fluids, an increase in K in hydrogen and a decrease in K in water; however, in the tests in Phase III no distinguishable effect was noted with the addition of the hub in either fluid. (See figures II-2 and II-3.) In addition, the K values calculated from the Phase III test data without an inlet hub were approximately 10% lower than the value predicted based on the previous test results. This difference in test results is attributed to the fact that special Rosemount temperature probes were installed in the housing along the radial span of the disk in an attempt to determine the temperature profile. These special probes required slots in the housing that could create local disturbances

along the wall resulting in a reduced fluid velocity and,therefore, K value. The losses created by the slots could also mask or offset the effect of adding the inlet hub. New flush-mounted probes have been designed and will be used on future tests. The head versus radius squared curves from these tests are being compared with previous test data in an attempt to pinpoint the region of high losses and correlate the low loss region with previous results.

2. Reverse Flow Test

One test was conducted in liquid hydrogen with flow direction through the rig reversed. Pressure measurements can not be taken on the rear or inward flow side of the disk below a radius ratio of approximately 0.7 because of the location of the discharge manifold. (See figure II-1.) Frequently,in pump designs, pressure distribution must be predicted over areas well below a radius ratio of 0.7, thus requiring extrapolation of the K value from previous data. By reversing the flow through the test rig, pressure measurements can be obtained at a radius ratio of 0.5 for the radially inward flow condition.

Values of K, computed from this test, are shown plotted versus radius ratio in figure II-4. The curve is in generally good agreement with a predicted curve from Phase II data down to a radius ratio squared of 0.4. The disk-to-housing clearance established for this test was 0.055 in., but with the flow reversed the thrust load on the rotor was also reversed, which would result in the rotor shifting forward by approximately 0.030 in. Therefore, the test data were compared with predicted values for a clearance of 0.020 in. The prediction system for this configuration (smooth disk-inward flow) will be modified to reflect the data obtained at the lower radii.

3. High-Pressure Test

Test number six of Phase III was conducted in liquid hydrogen with the smooth disk at an inlet pressure of approximately 650 psia. All of the previous tests had been conducted with the inlet pressure between 90 and 100 psia. The high-pressure test was planned to determine the effect on pressure distribution of operating in a different p-v-t region

for liquid hydrogen. The test was completed near the end of the reporting period and the data are presently being analyzed. Because of the high pressures and low pressure rise across the face of the disk, the accuracy required in measuring disk pressures could only be obtained by using low range (0 to 15 and 0 to 25 psi) transducers. However, several of the transducers on both the front and rear faces were over-ranged during transients and failed. Loss of the readings at these stations will complicate the data analysis.

4. Tip Blockage Tests

The test rig is being modified for the bladed disk tip blockage tests and testing will begin late in September. Three tests will be conducted at various tip and disk-to-housing clearances.

The special Rosemount type 146L temperature sensors installed for the tests of Phase III to confirm the temperature distribution with liquid hydrogen were only partially successful. These probes were specially designed to measure cryogenic fluid temperatures on the surface of a wall. However, a majority of the probes initially installed failed early in the testing due in part to the method of installation and the fragility of the probe. A new probe design that provides improved strength and simplifies the mounting was incorporated in the high-pressure test and functioned satisfactorily.

Work on the compilation of the data from all three phases into a Fortran II computer program for use on the IBM 7090 computer has been initiated.

Table II-1. Test Summary

Test No.	Axial Cl., in.	Blade Height, in.	Shaft, rpm	Flow Rate, gpm	Flow Coefficient	Rey. No., 10^6	Remarks
1.01	0.057	0	10,392	45.2	0.0163	82.0	No inlet hub - Fluid:
1.02	0.057	0	10,268	78.8	0.0283	84.0	LH_2
1.03	0.057	0	10,200	108.0	0.0383	86.0	
1.04	0.057	0	14,158	55.3	0.0151	109.0	
1.05	0.057	0	14,095	94.5	0.0253	114.0	
1.06	0.057	0	14,005	124.8	0.0332	116.0	
1.07	0.057	0	13,878	149.2	0.0397	117.0	
1.08	0.057	0	16,916	57.5	0.0278	128.0	
1.09	0.057	0	16,764	69.9	0.0163	129.0	
1.10	0.057	0	16,662	80.8	0.0189	130.0	
2.01	0.057	0	10,144	41.8	0.0155	78.0	Inlet hub: 2/1 ratio
2.02	0.057	0	9,959	81.8	0.0303	81.0	Fluid: LH_2
2.03	0.057	0	9,921	98.0	0.0361	83.0	
2.04	0.057	0	13,870	48.1	0.0134	105.0	
2.05	0.057	0	13,961	99.1	0.0268	113.0	
2.06	0.057	0	13,995	136.5	0.0363	117.0	
2.07	0.057	0	16,603	61.4	0.0148	125.0	
2.08	0.057	0	16,499	69.3	0.0164	128.0	
2.09	0.057	0	16,428	78.3	0.0185	130.0	
3.01	0.057	0	10,295	42.5	0.0159	79.0	Inlet hub: 2/1 ratio.
3.02	0.057	0	10,222	54.1	0.0210	80.0	Reversed flow -
3.03	0.057	0	9,734	50.1	0.0202	77.0	Fluid: LH_2
3.04	0.057	0	12,023	39.1	0.0131	93.0	

Table II-1. Test Summary (Continued)

Test No.	Axial Cl., in.	Blade Height, in.	Shaft, rpm	Flow Rate, gpm	Flow Coefficient	Rey. No., 10^6	Remarks
4.01	0.057	0	2,105	33.8	0.0568	5.37	Inlet hub: 2/1 ratio
4.02	0.057	0	2,152	17.8	0.0293	5.48	Fluid: Water
4.03	0.057	0	2,191	5.3	0.00856	5.72	
4.04	0.057	0	3,071	25.4	0.0293	7.88	
4.05	0.057	0	3,155	5.6	0.00628	8.48	
4.06	0.057	0	3,156	11.9	0.0134	8.42	
4.07	0.057	0	3,974	20.7	0.0184	10.50	
4.08	0.057	0	4,036	12.0	0.0106	10.90	
4.09	0.057	0	4,000	3.9	0.0035	11.90	
5.01	0.057	0	2,019	32.6	0.0571	5.07	No inlet hub -
5.02	0.057	0	2,030	15.3	0.0267	5.12	Fluid: Water
5.03	0.057	0	2,009	7.4	0.0130	5.12	
5.04	0.057	0	3,063	23.7	0.0274	7.92	
5.05	0.057	0	2,981	17.3	0.0205	7.66	
5.06	0.057	0	3,035	5.9	0.0069	8.03	
5.07	0.057	0	4,046	19.7	0.0172	10.80	
5.08	0.057	0	4,066	9.9	0.0086	11.10	
5.09	0.057	0	4,144	2.9	0.0025	12.00	
6.01	0.055	0	6,050	66.8	0.0407	51.6	High pressure test
6.02	0.055	0	11,484	70.6	0.024	90.0	Fluid: LH_2
6.03	0.055	0	14,811	66.2	0.0188	106.6	Inlet pressure:
6.04	0.055	0	15,708	79.4	0.0215	110.6	650 psia
6.05	0.055	0	16,198	69.6	0.0190	107.5	
6.06	0.055	0	13,709	34.9	0.0114	86.4	
6.07	0.055	0	12,995	64.1	0.0199	98.7	

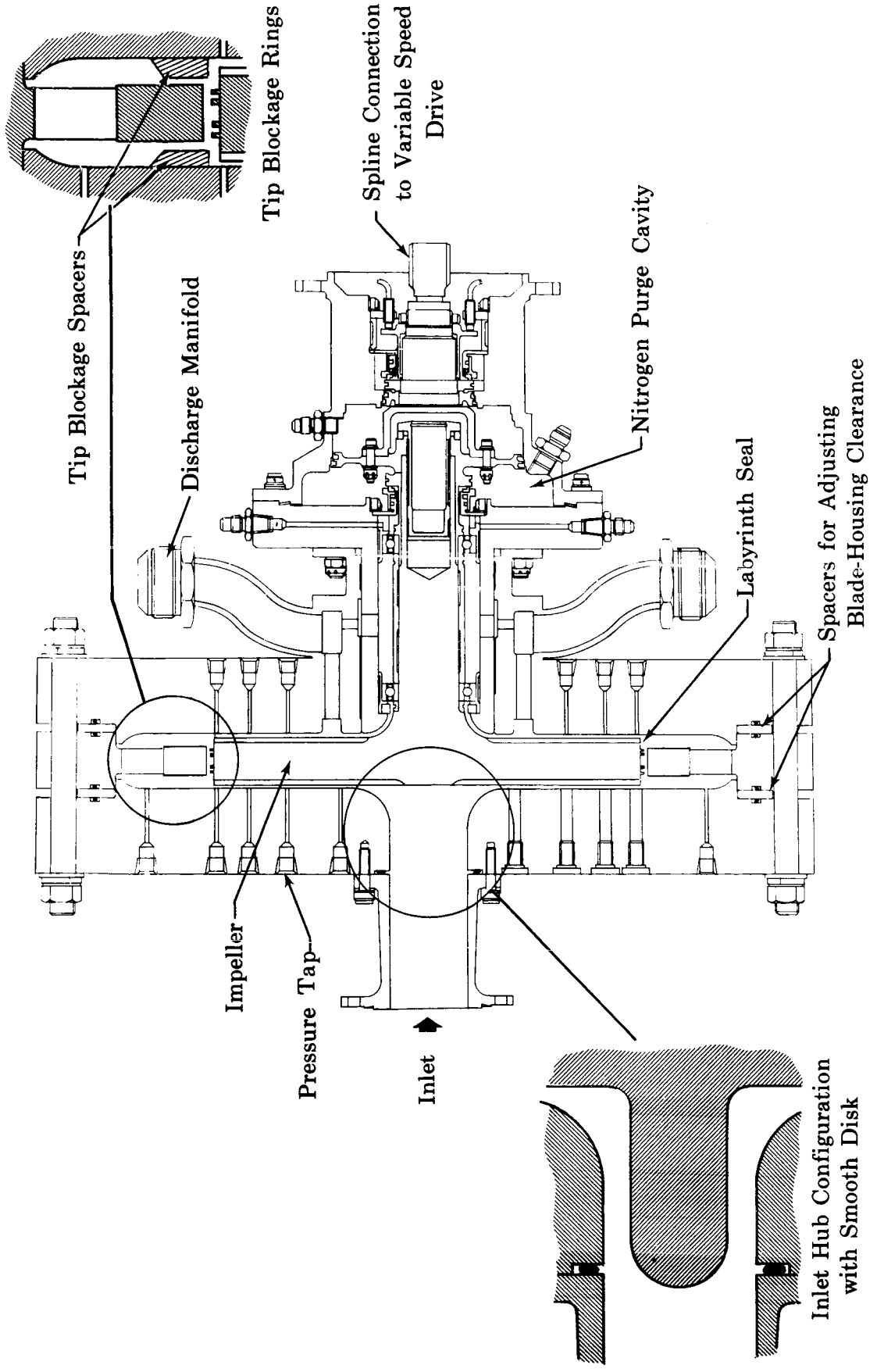


Figure II-1. Pressure Distribution Test Rig

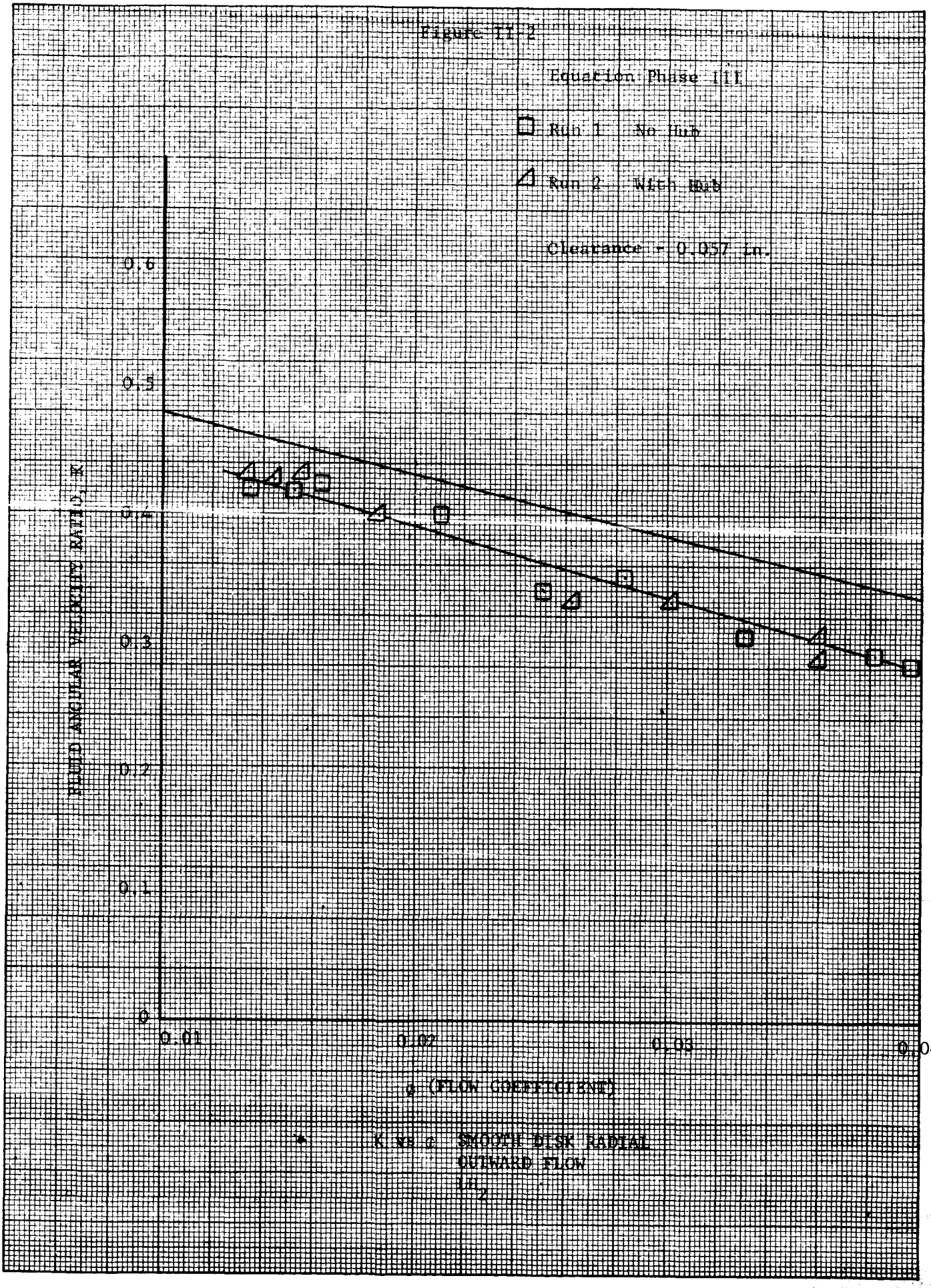


Figure II-2
Equation Phase III
Run 1 No Hub
Run 2 With Hub
Clearance = 0.057 in.
0.6
0.5
0.4
0.3
0.2
0.1
0
FLUID ANGULAR VELOCITY RATIO, K
0.01
0.02
0.03
0.04
φ (FLOW COEFFICIENT)
K vs φ SMOOTH DISK RADIAL OUTWARD FLOW
U2

Figure II-3

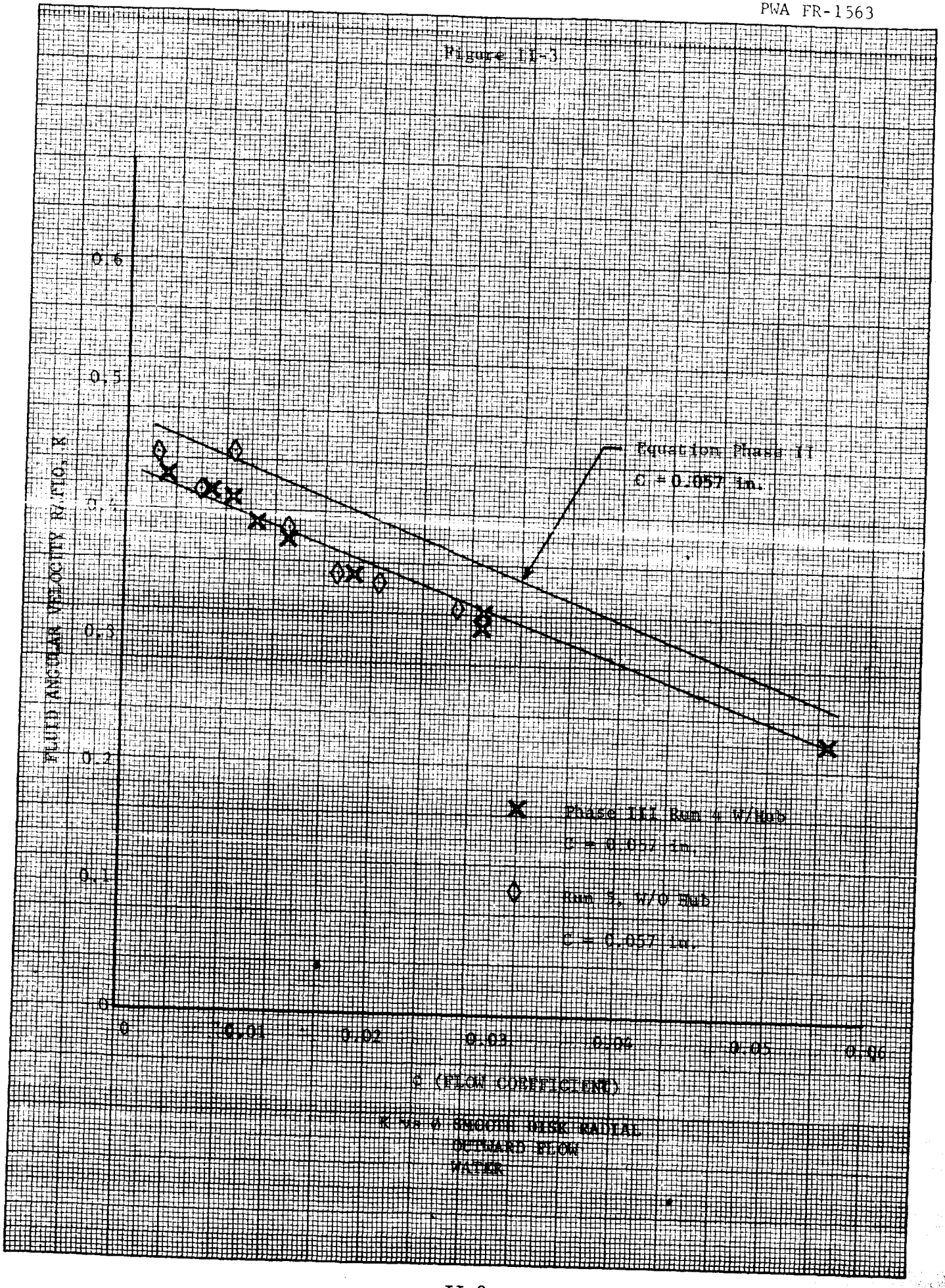
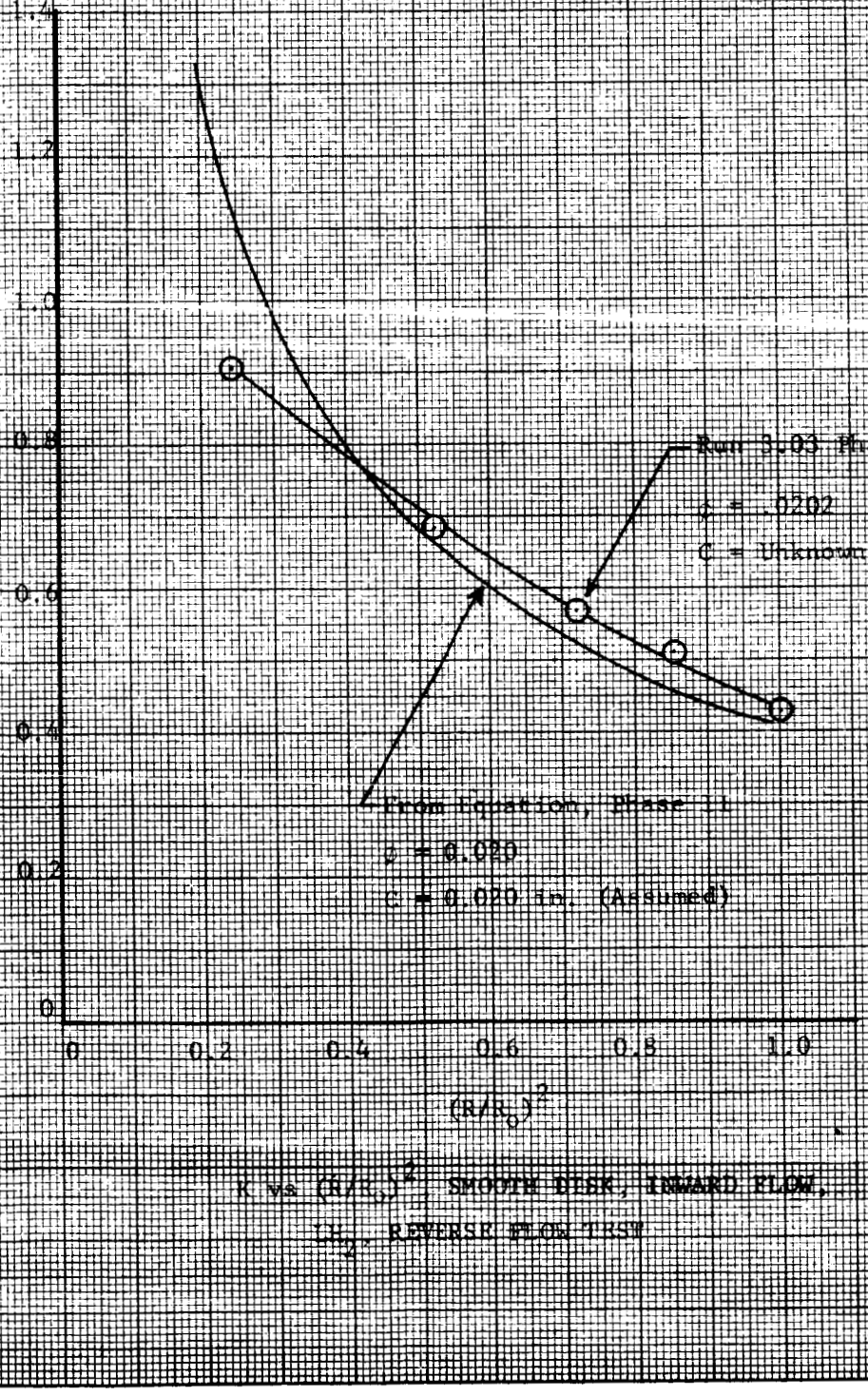

FLUID ANGULAR VELOCITY RATIO, K
0.6
0.5
0.3
0.2
0.1
0
0
0.01
0.02
0.03
0.04
0.05
0.06
Equation Phase II
C = 0.057 in.
Phase III Run 4 W/Hub
C = 0.057 in.
Run 5, W/O Hub
C = 0.057 in.
φ (FLOW COEFFICIENT)
K Vs φ SMOOTH DISK RADIAL OUTWARD FLOW WATER

Figure II-4



K vs $(R/R_o)^2$, SMOOTH DISK, INWARD FLOW, Re_2, REVERSE FLOW TRSW

SECTION III
PLANS FOR THE NEXT REPORTING PERIOD

The following work is scheduled during the next report period:

1. The tip blockage and bladed-housing tests will be completed.
2. The formulation of the Fortran II computer program will be continued and should be 75% completed by the end of the period.

SECTION IV
REFERENCE

"Investigation of Pressure Prediction Method for Radial Flow Impellers," FR-1276, Pratt & Whitney Aircraft, March 1965.