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**PRELIMINARY PERFORMANCE OF A 4.97-INCH RADIAL
TURBINE OPERATING IN A BRAYTON POWER SYSTEM
WITH A HELIUM-XENON GAS MIXTURE**

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Cleveland, Ohio
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PRELIMINARY PERFORMANCE OF A 4.97-INCH RADIAL TURBINE OPERATING IN A BRAYTON POWER SYSTEM WITH A HELIUM-XENON GAS MIXTURE

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SUMMARY

The performance characteristics of the Brayton-Rotating-Unit's 4.97-inch radial turbine were investigated with the turbine part of a power conversion system; the following system parameters were varied: turbine inlet temperature from 1200 to 1600°F; compressor inlet temperature from 60 to 120°F; compressor outlet pressure from 20 to 45 psia, and shaft speed from 90-110 percent of rated speed (36000 rpm). The working fluid of the system was a gas mixture of helium-xenon with a nominal molecular weight of 83.8.

Test results indicated that changes in system conditions had little effect on the turbine efficiency. At the design turbine inlet temperature of 1600°F and compressor inlet temperature of 80°F, an average turbine efficiency of 91 percent was obtained.

INTRODUCTION

The NASA Lewis Research Center is investigating a 2-to-15 kW Brayton space power system (ref. 1). The power system's Brayton Rotating Unit (BRU) consists of a turbine, an alternator, and a compressor mounted on a single shaft that is supported by self-acting gas bearings. The BRU is designed to operate at a rotative speed of 36000 rpm, a turbine inlet temperature of 1600°F, a compressor inlet temperature of 80°F and with a mixture of helium and xenon gases. The turbine has a 4.97-inch tip diameter, has radial inflow, and drives both a 4.25-inch-diameter radial-outflow compressor (ref. 2) and a Lundell-type four-pole brushless alternator (ref. 3).

Limited turbine performance data exist, especially with helium-xenon as the working fluid (ref. 4). Characteristics of the turbine operating with cold argon are reported in reference 5. Some turbine data with krypton as the working fluid are reported in reference 6. In order to extend the existing performance data of the turbine operating with a helium-xenon mixture, the BRU was tested over a wide range of system operating conditions. The following parameters were varied: turbine inlet temperature from 1200 to 1600°F; compressor

inlet temperature from 60^o to 120^oF; compressor discharge pressure from 20 to 45 psia, and at ± 10 percent of design speed of 36000 rpm.

This report describes the performance of the turbine during these tests. The effects of changes in compressor inlet temperature, shaft speed, and turbine inlet temperature on turbine pressure ratio and turbine output torque are shown as a function of system gas flow. Variations in turbine efficiency are discussed as system parameters are changed. A plot of calculated torque parameter as a function of blade-jet speed ratio over the range tested is also presented.

TEST PROCEDURE

A schematic diagram of the Brayton power conversion system test facility is shown in figure 1. Additional information on the test facility and instrumentation can be found in references 4 and 6.

The test program consisted of varying the following system parameters: compressor discharge pressure, compressor inlet temperature, shaft speed, and turbine inlet temperature. The compressor discharge static pressure was varied from 20 to 45 psia in 5 psi increments; the compressor inlet temperature was varied from 60^oF to 120^oF in 20^o increments. Data were obtained at rated speed (36000 rpm) and ± 10 percent of rated speed (32,400 and 39,600 rpm). Tests were conducted for turbine inlet temperatures of 1200, 1300, 1400, 1500 and the design value of 1600^oF. During the tests, electrical guard heaters were used at the turbine inlet and outlet to minimize the errors associated with the gas temperature measurements. The system gas flow rate was obtained from the Venturi flow meter located between the electric heat source and the recuperator. A gas mixture of helium and xenon at a nominal molecular weight of 83.8 was used as the working fluid. Test results were recorded and calculated on a digital data acquisition system (see ref. 7).

RESULTS AND DISCUSSION

Test results presented are preliminary in nature and no attempt is made to perform a detailed analysis. The results are discussed in four sections: (1) turbine pressure ratio, (2) turbine output torque, (3) turbine efficiency, and (4) torque parameter.

Turbine Pressure Ratio

The variation of turbine pressure ratio with flow as a function of turbine inlet temperature, compressor inlet temperature, and shaft speed are presented in figures 2a through 2e. Increases in pressure ratio resulted with increasing weight flow, increasing turbine inlet temperature, increasing speed and with decreasing

compressor inlet temperature. Speed had the largest effect on the pressure ratio. At the design turbine inlet and compressor inlet temperatures of 1600°F and 80°F respectively (fig. 2e), at a flow rate of 1.0 lb/sec, the pressure ratio obtained at 36000 rpm was approximately 1.785. Increasing speed 10 percent to 39,600 rpm resulted in a pressure ratio of approximately 1.96. A pressure ratio of approximately 1.62 was obtained when the speed was decreased to 32,400 rpm.

Turbine Output Torque

The variation of turbine output torque with flow rate as a function of turbine inlet temperature, compressor inlet temperature and shaft speed are presented in figures 3a through 3k. The torque increased with decreasing compressor inlet temperature, with increasing turbine inlet temperature, increasing speed and with increasing flow rate. Test results show that the torque is directly proportional to flow over the flow range tested. The torque-flow rate slope varied from 43 in.-lb-sec/lb at a turbine inlet temperature of 1200°F and a shaft speed of 32,400 rpm to a slope of 61 at a turbine inlet temperature of 1600°F and a shaft speed of 39,600 rpm. At a constant flow rate of 1.0 lb/sec, at a compressor inlet temperature of 80°F and at rated speed (36,000 rpm), an increase in turbine inlet temperature from 1200°F to 1600°F increased the torque from 43 to 56 in-lbs, figures 3b and 3j.

Turbine Efficiency

Figure 4 shows the efficiency of the turbine (including the diffuser) obtained at a shaft speed of 36,000 rpm. The efficiencies shown are based on the measured static pressures and total temperatures and are plotted as a function of flow rate. At turbine inlet temperatures of 1300°F to 1600°F, scatter exists in the preliminary data. Variation in compressor inlet temperature had no measurable effect on turbine efficiency. At a turbine inlet temperature of 1600°F and a compressor inlet temperature of 80°F, the efficiency was relatively constant with varying flow rate. An efficiency of approximately 91 percent was obtained at these conditions. This efficiency is slightly higher than the total-to-total overall efficiency of 89.4 percent that was obtained in the cold argon tests (ref. 5).

At a turbine inlet temperature of 1200°F, the effect of compressor inlet temperature on efficiency can be seen. Decreasing compressor inlet temperature from 120°F to 60°F increased the efficiency from approximately 87.5 percent to approximately 90.2 percent.

Torque Parameter

In figure 5, torque is expressed in the form of a parameter, turbine efficiency/blade-jet speed ratio. The torque parameter is plotted as a function of blade-jet speed ratio (the ratio of blade tip speed to ideal jet speed). The linearity obtained between torque and speed is due primarily to the limited range of the turbine test parameters. The torque parameter value of approximately 1.305 is in good agreement with the design value of 1.3 shown in reference 3.

CONCLUDING REMARKS

An experimental investigation of a 4.97-inch radial-inflow turbine is presented. Over a wide range of system operating conditions, the turbine efficiency stayed at a high level and remained relatively constant. Changes in flow rate did not significantly affect the turbine efficiency and at the design turbine inlet temperature of 1600°F and compressor inlet temperature of 80°F, an average turbine efficiency of 91 percent was obtained. As turbine inlet temperature was decreased from 1600 to 1300°F, the average turbine efficiency decreased slightly to 89.5 percent.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, December 23, 1971.

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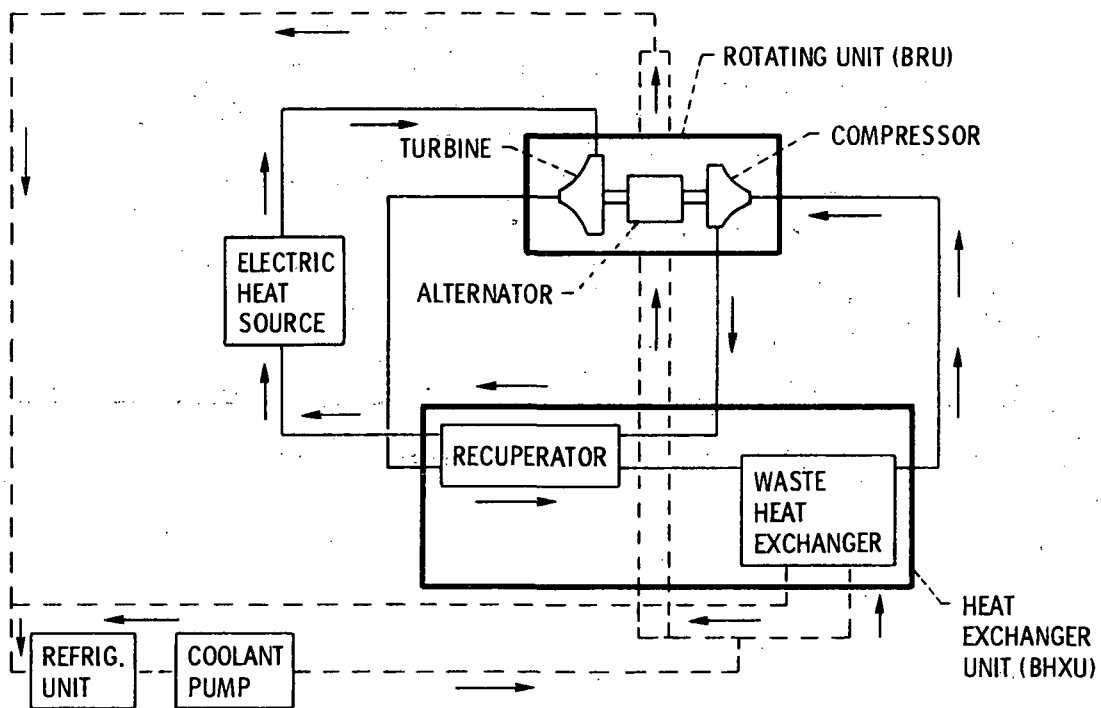
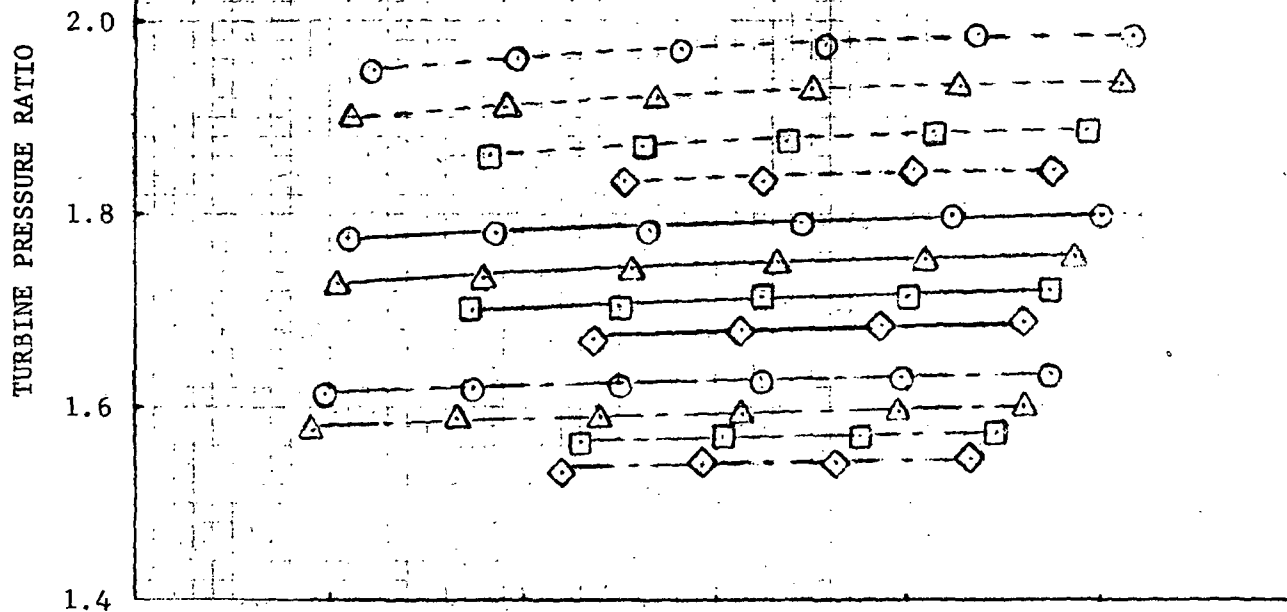
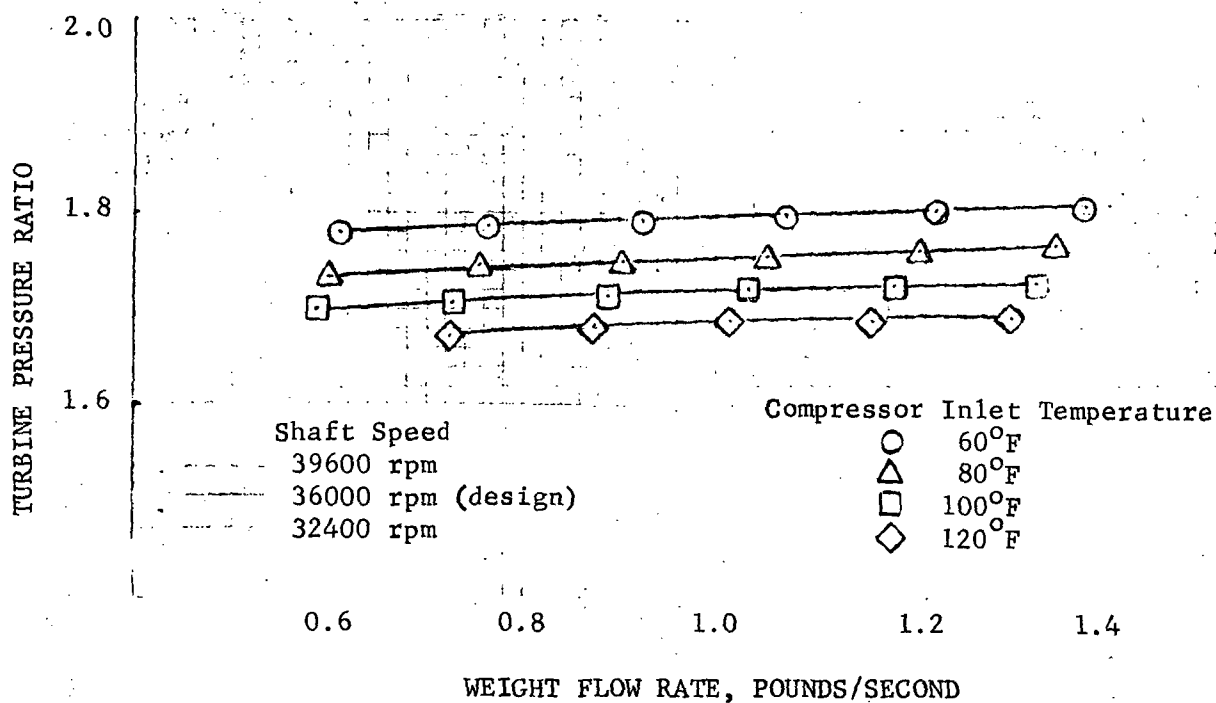


Figure 1. - Schematic of power conversion system.



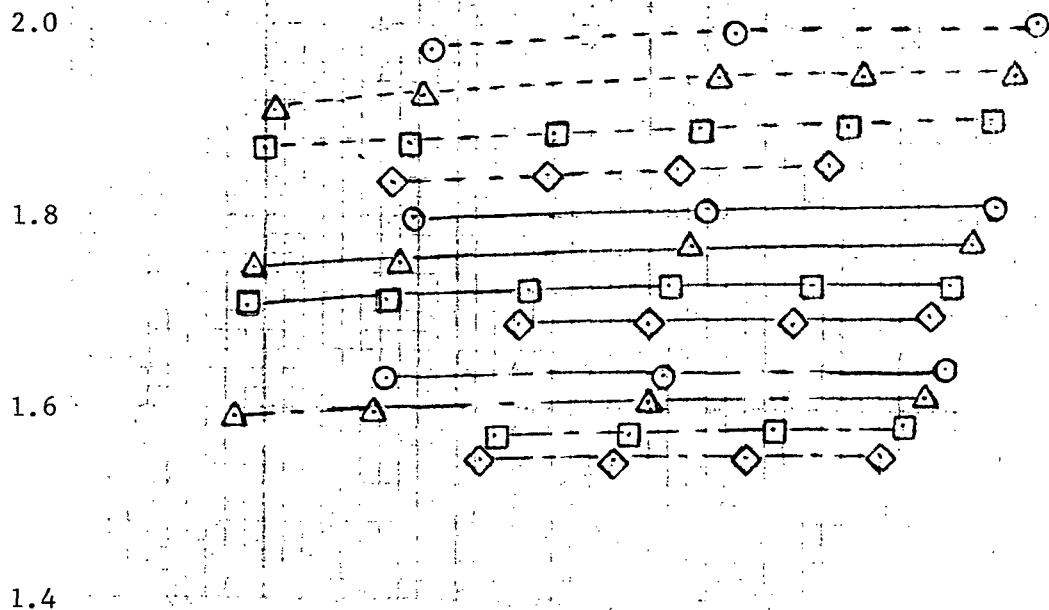
a) Turbine Inlet Temperature = 1200°F



b) Turbine Inlet Temperature = 1300°F

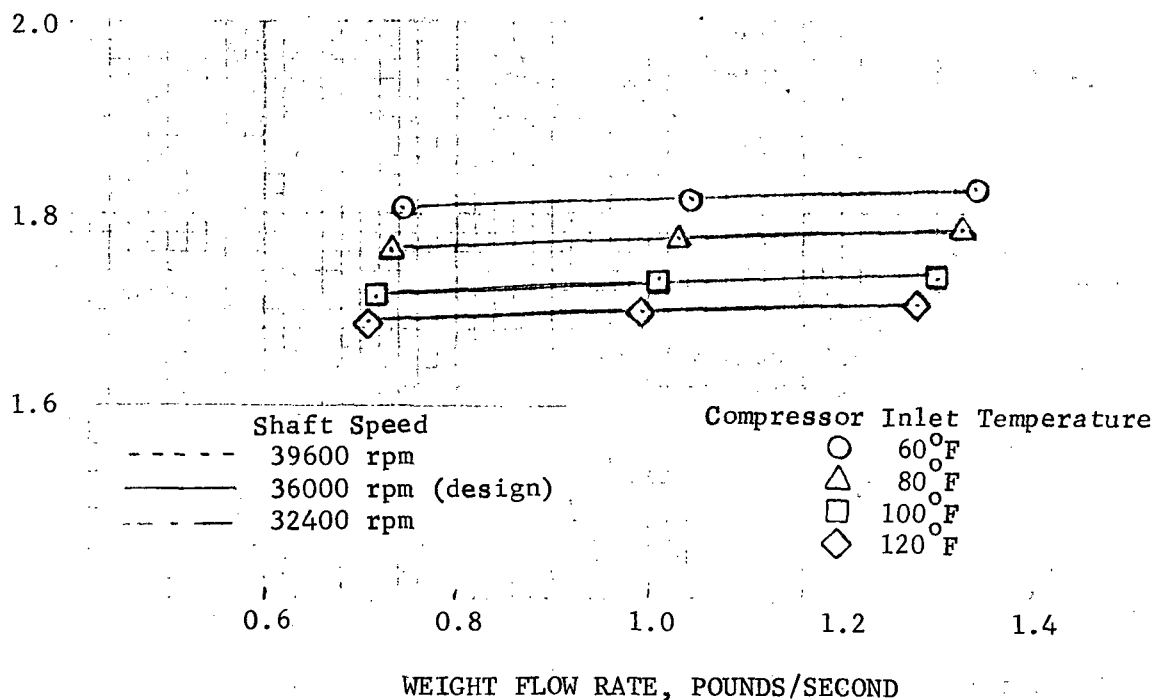
Figure 2 - Variation of Turbine Pressure Ratio with Weight Flow Rate

TURBINE PRESSURE RATIO



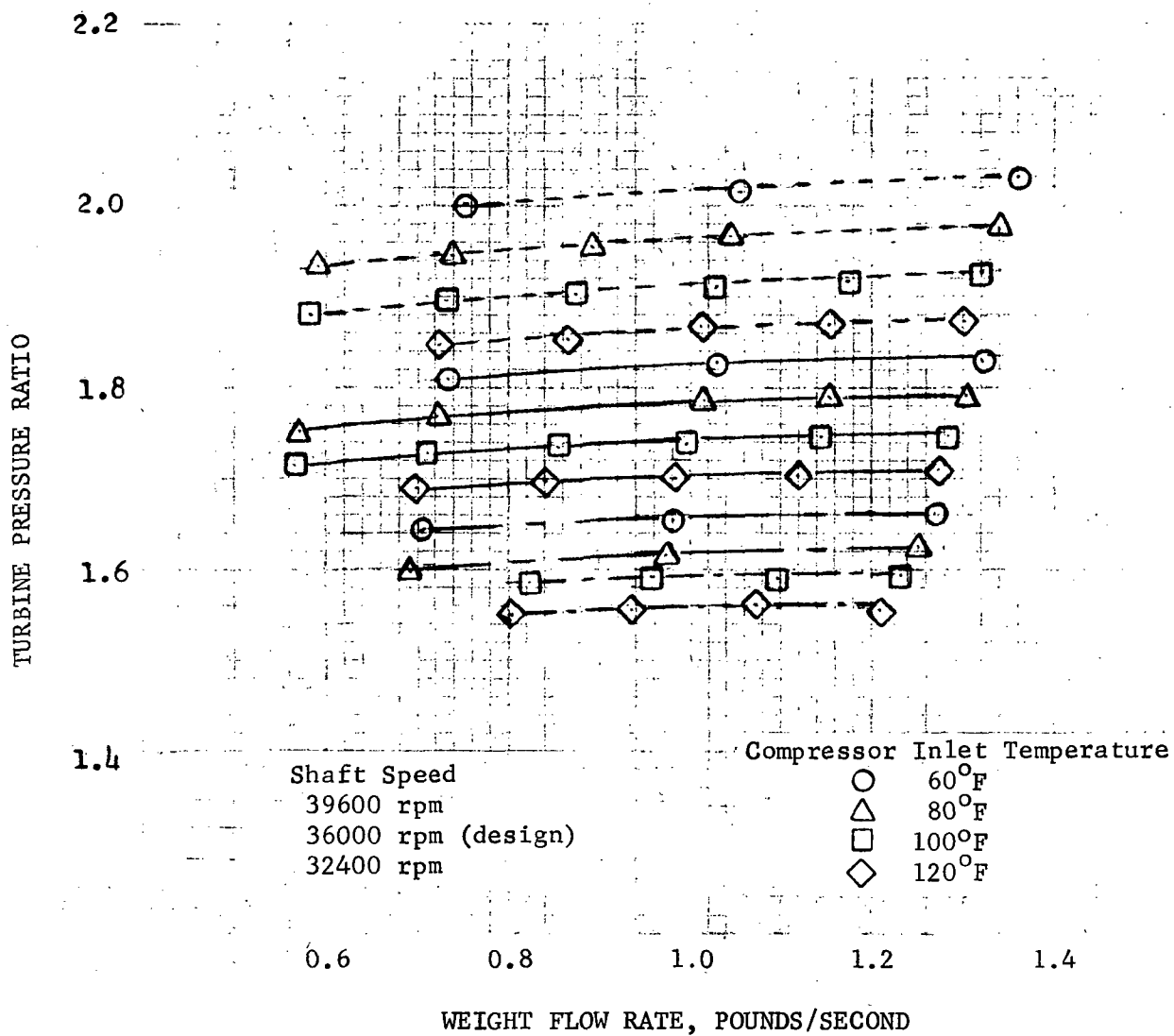
c) Turbine Inlet Temperature = 1400°F

TURBINE PRESSURE RATIO



d) Turbine Inlet Temperature = 1500°F

Figure 2 - Variation of Turbine Pressure Ratio with Weight Flow Rate



e) Turbine Inlet Temperature = 1600°F

Figure 2 - Variation of Turbine Pressure Ratio with Weight Flow Rate

TURBINE OUTPUT TORQUE, INCH-POUNDS

80

60

40

20

a) Turbine Inlet Temperature = 1200°F and Shaft Speed = 32,400 RPM

TURBINE OUTPUT TORQUE, INCH-POUNDS

80

60

40

20

Compressor Inlet Temperature
 ○ 60°F
 △ 80°F
 □ 100°F
 ◇ 120°F

0.4

0.6

0.8

1.0

1.2

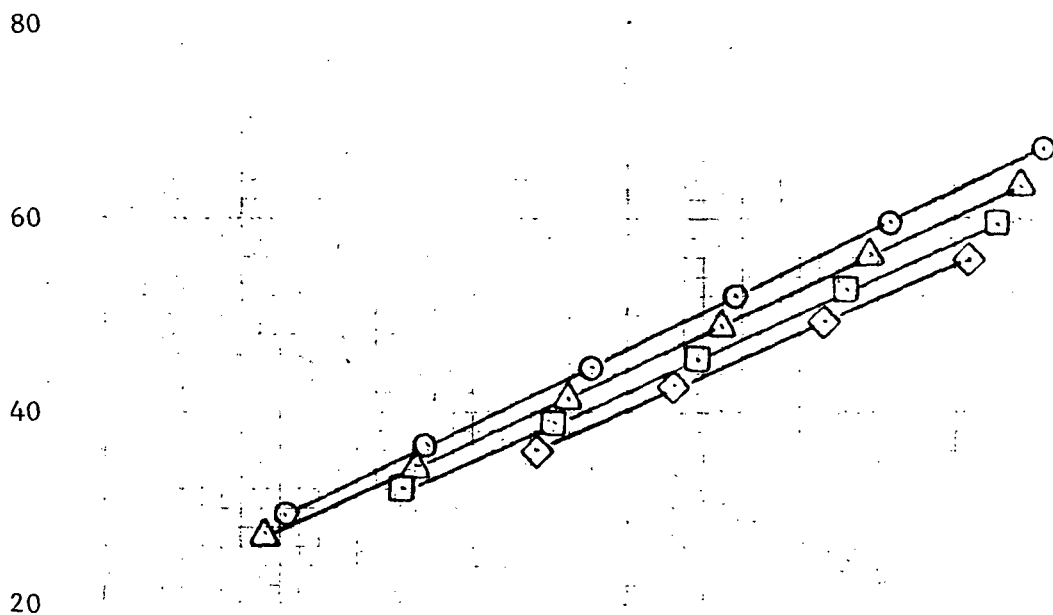
1.4

WEIGHT FLOW RATE, POUNDS/SECOND

b) Turbine Inlet Temperature = 1200°F and Shaft Speed = 36,000 RPM

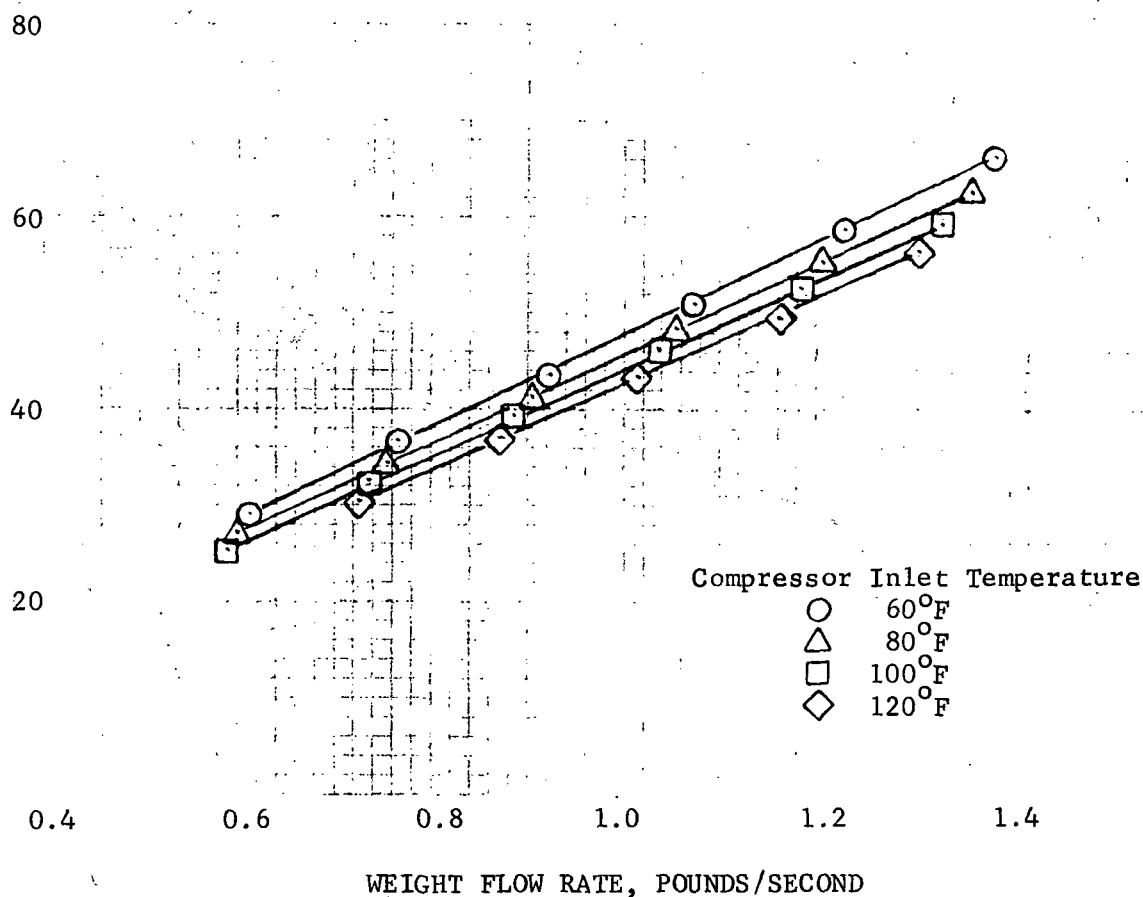
Figure 3 - Variation of Turbine Output Torque with Weight Flow Rate

TURBINE OUTPUT TORQUE, INCH-POUNDS



c) Turbine Inlet Temperature = 1200°F and Shaft Speed = 39,600 RPM

TURBINE OUTPUT TORQUE, INCH-POUNDS

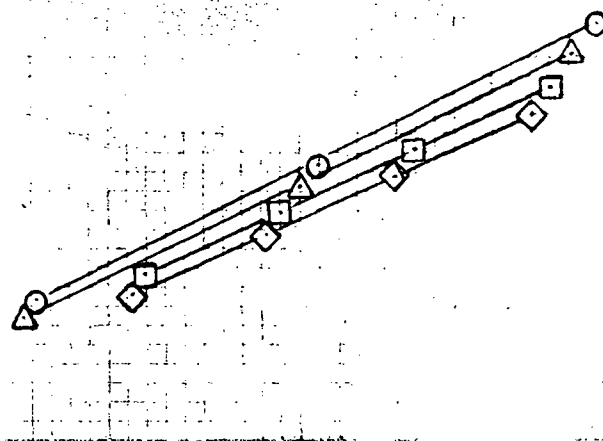


d) Turbine Inlet Temperature = 1300°F and Shaft Speed = 36,000 RPM

Figure 3 - Variation of Turbine Output Torque with Weight Flow Rate

TURBINE OUTPUT TORQUE, INCH-POUNDS

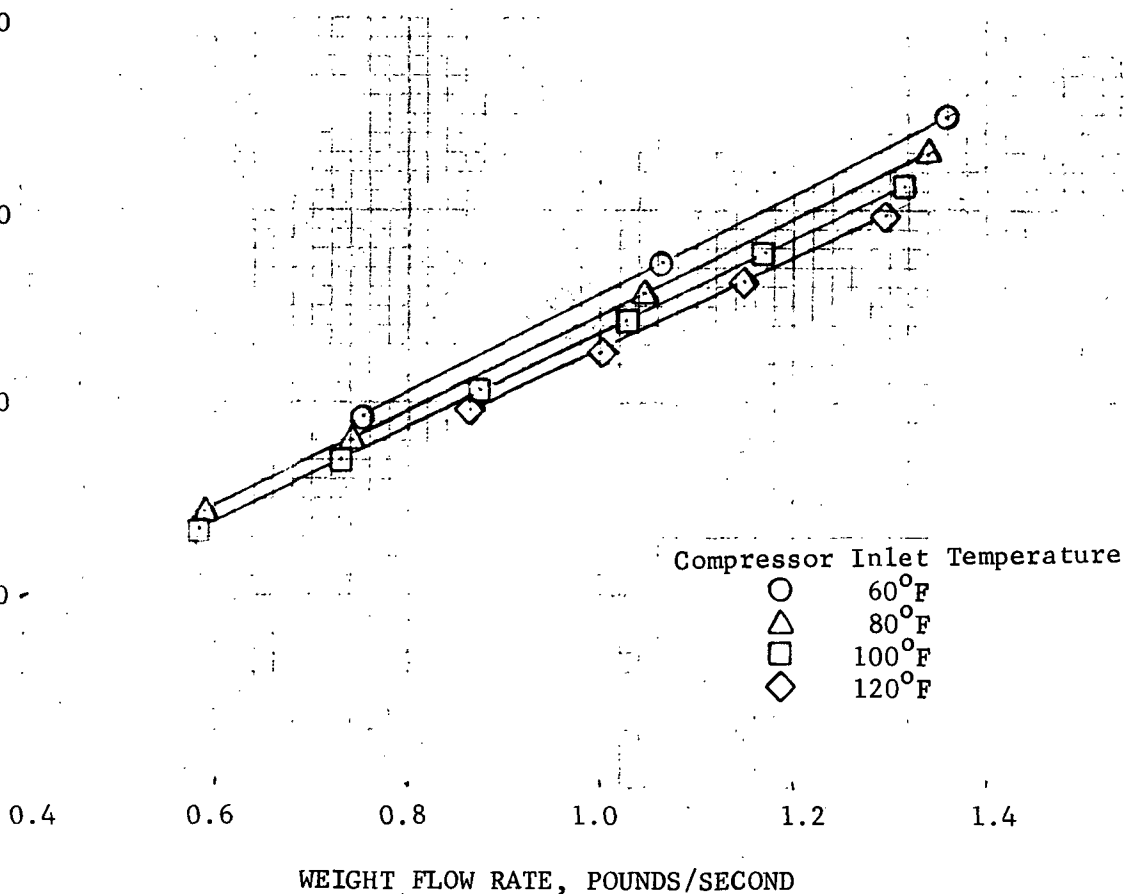
80
60
40
20



e) Turbine Inlet Temperature = 1400°F and Shaft Speed = 32,400 RPM

TURBINE OUTPUT TORQUE, INCH-POUNDS

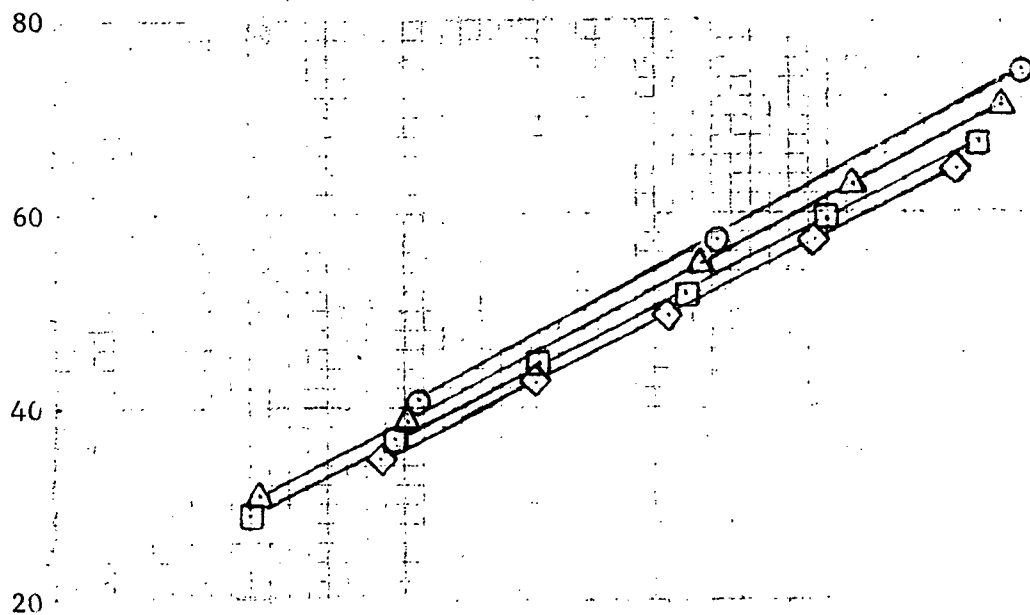
80
60
40
20



f) Turbine Inlet Temperature = 1400°F and Shaft Speed = 36,000 RPM

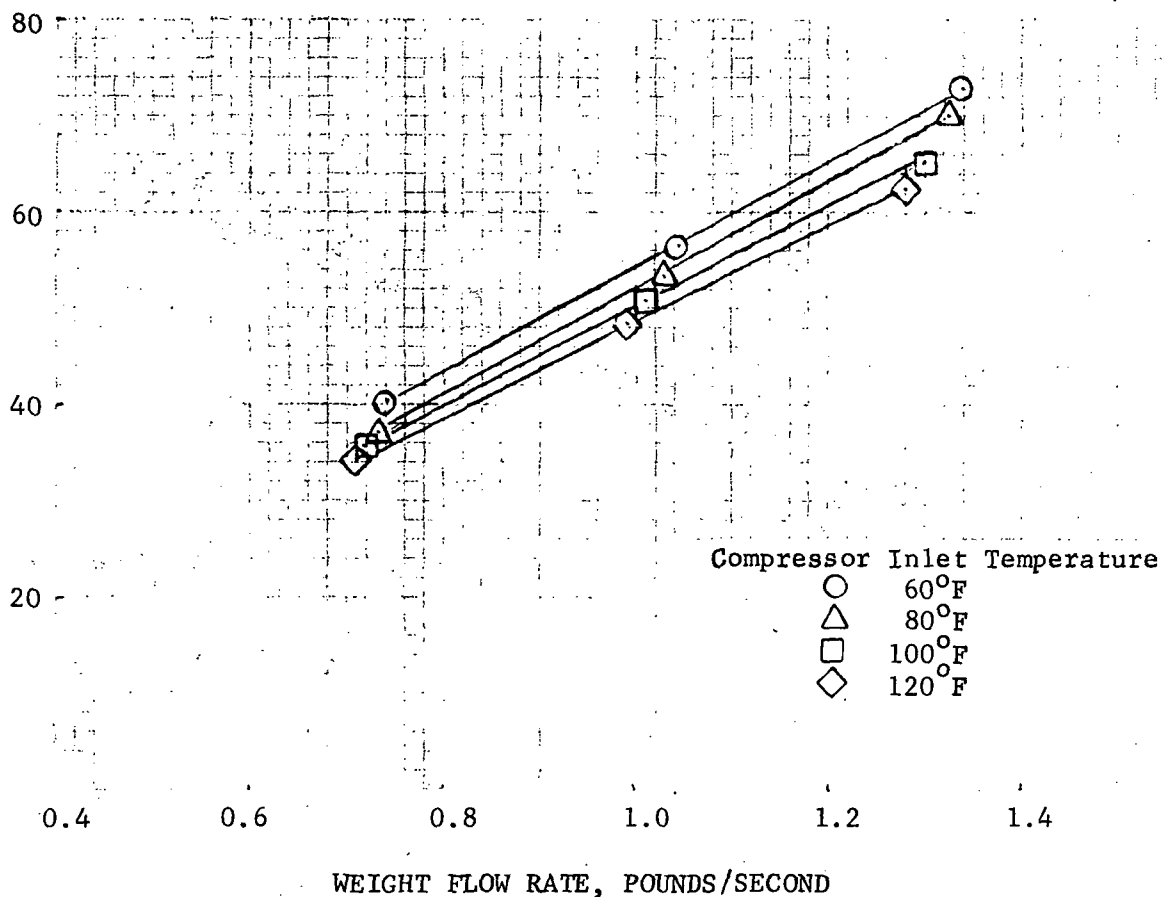
Figure 3 - Variation of Turbine Output Torque with Weight Flow Rate

TURBINE OUTPUT TORQUE, INCH-POUNDS



g) Turbine Inlet Temperature = 1400°F and Shaft Speed = 39,600 RPM

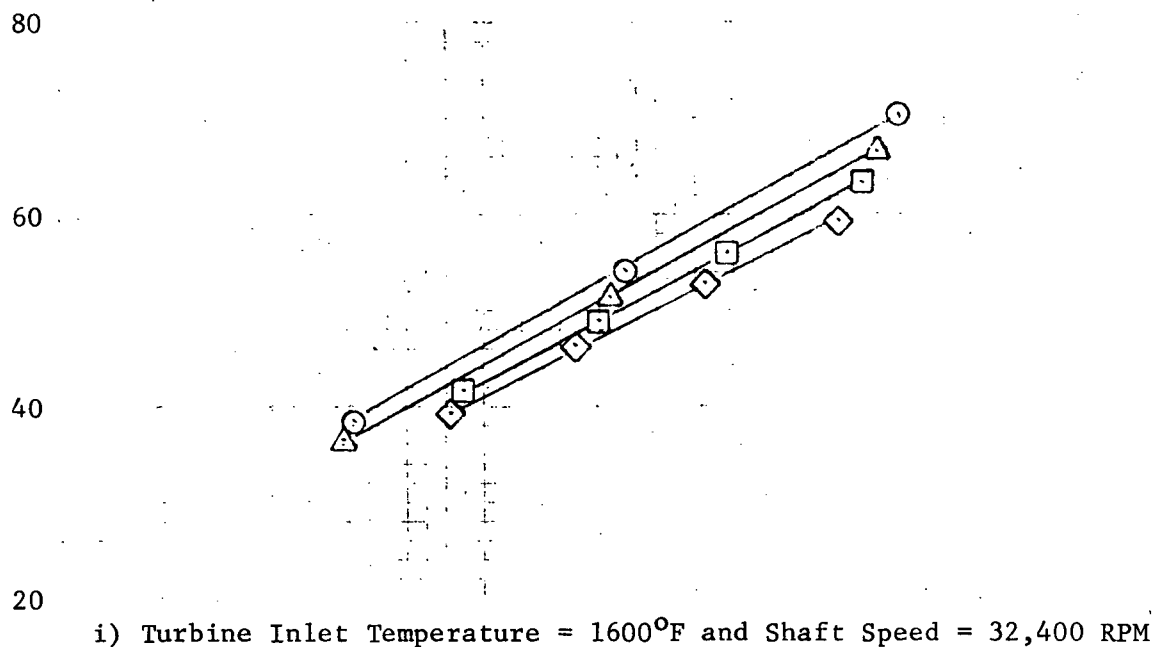
TURBINE OUTPUT TORQUE, INCH-POUNDS



h) Turbine Inlet Temperature = 1500°F and Shaft Speed = 36,000 RPM

Figure 3 - Variation of Turbine Output Torque with Weight Flow Rate

TURBINE OUTPUT TORQUE, INCH-POUNDS



TURBINE OUTPUT TORQUE, INCH-POUNDS

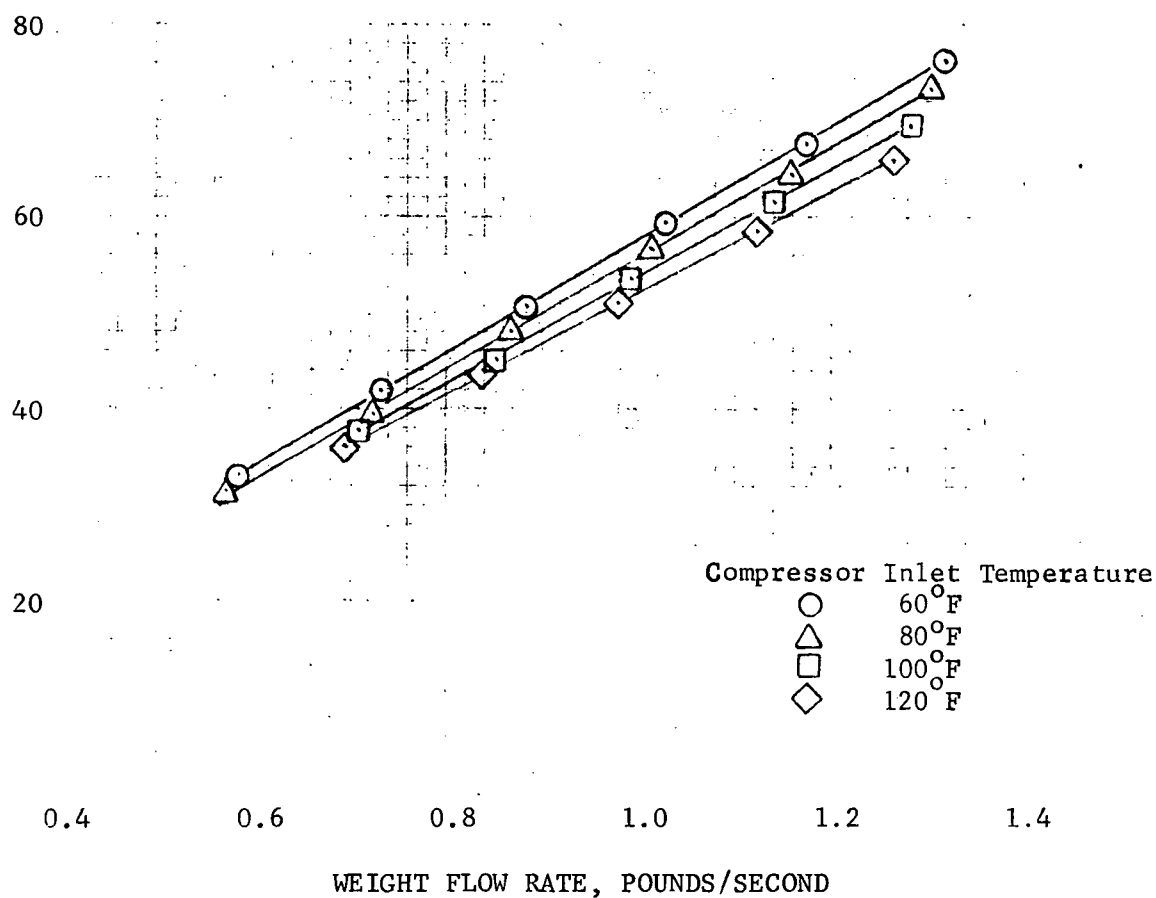
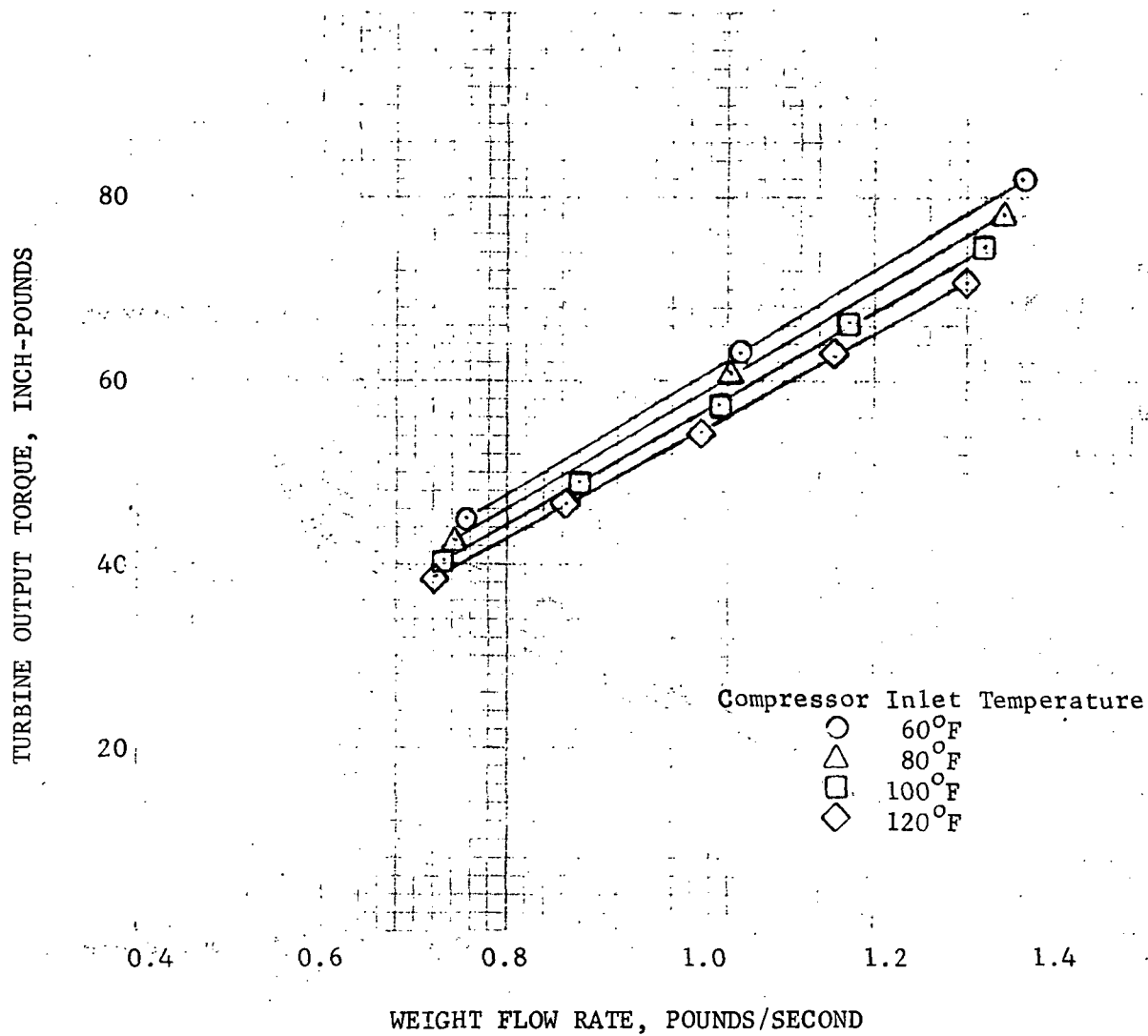


Figure 3 - Variation of Turbine Output Torque with Weight Flow Rate



k) Turbine Inlet Temperature = 1600°F and Shaft Speed = 39,600 RPM

Figure 3 - Variation of Turbine Output Torque with Weight Flow Rate

TURBINE EFFICIENCY - PERCENT

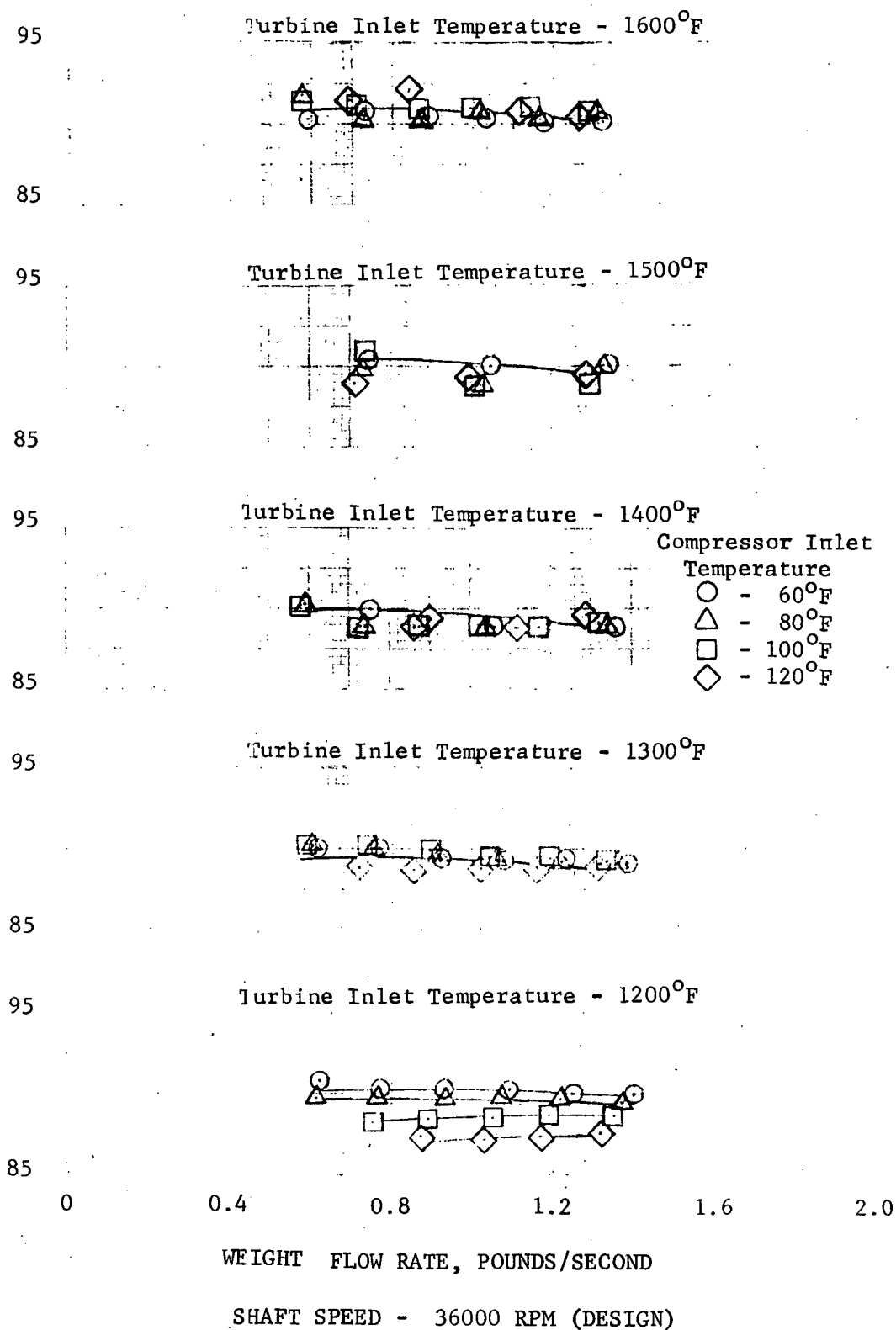


FIGURE 4 - VARIATION OF TURBINE EFFICIENCY WITH WEIGHT FLOW RATE

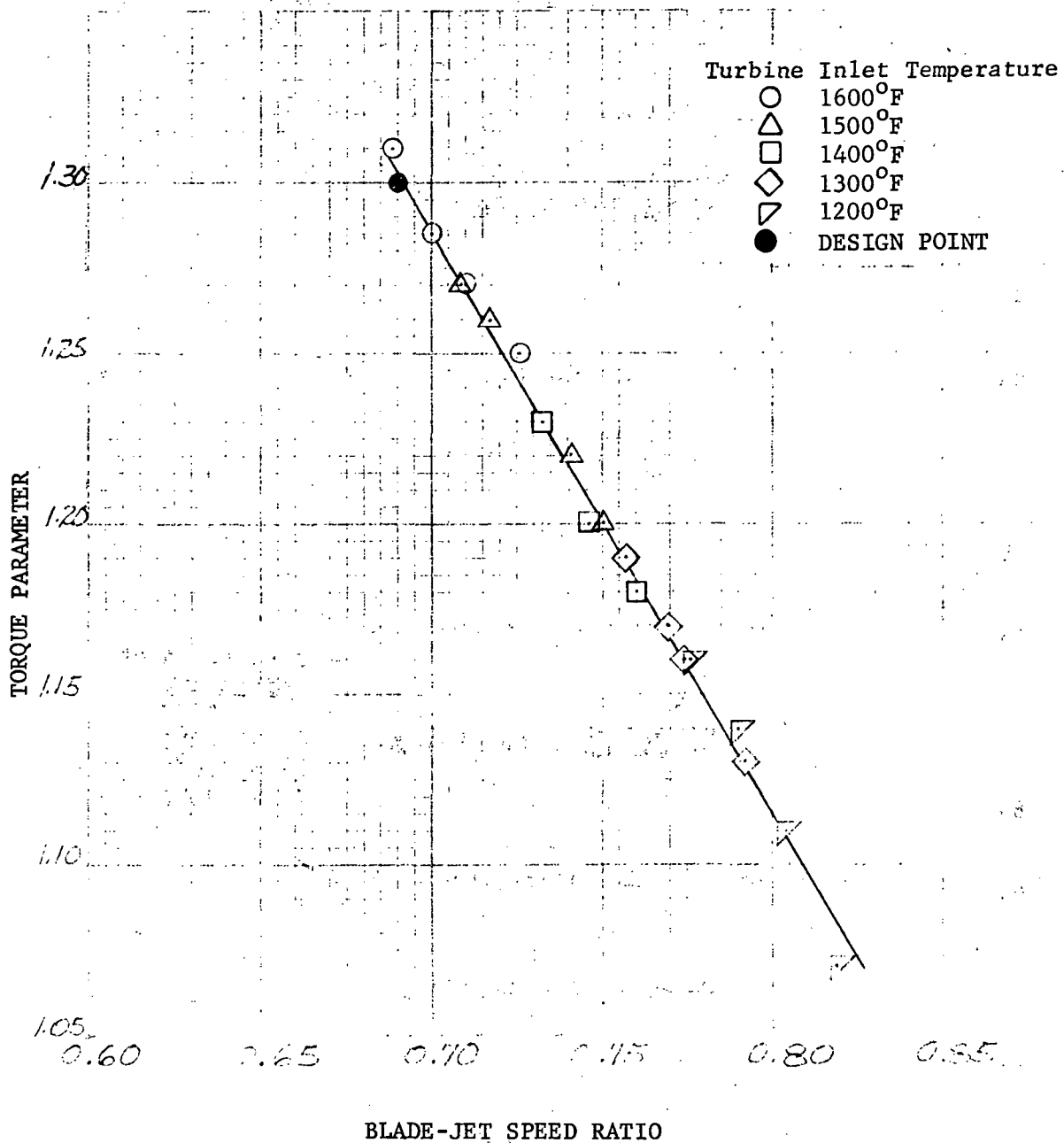


FIGURE 5 - VARIATION OF TORQUE PARAMETER WITH BLADE-JET SPEED RATIO