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# PERFORMANCE OF TWO-STAGE TURBOSUPERCHARGER USING MIXED-FLOW IMPELLERS

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MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

# PERFORMANCE OF TWO-STAGE TURBOSUPERCHARGER USING MIXED-FLOW IMPELLERS

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## SUMMARY

The NACA has investigated the performance of a two-stage turbosupercharger incorporating mixed-flow impellers. Two complete superchargers were tested, the second being the same as the first except for modified vanes in the interstage passage and a somewhat different first-stage diffuser shape. At the maximum pressure ratio of 2.91 the peak efficiency of the modified supercharger was 78 percent at a corrected volume flow of 115 cubic feet per second. The modified supercharger had a maximum efficiency of slightly above 82 percent, an increase of 3 points above that of the original compressor. At the highest common pressure ratio of 2.6, the modified supercharger reached a peak efficiency of 80 percent and the original supercharger, 74 percent. The characteristic curves of both units were fairly flat, which indicated good performance for a wide range of speeds and air flows.

## INTRODUCTION

Because of the demand for higher altitudes for military aircraft, a large amount of research has been directed toward the development of two-stage turbosuperchargers that will provide the desired pressure ratios. A turbosupercharger incorporating an early model mixed-flow impeller showed good performance in the preliminary tests conducted by the manufacturer. The Bureau of Aeronautics, Navy Department, who sponsored the development of this supercharger, requested that NACA to conduct further tests of the unit.

The investigation of the supercharger performance was started by the NACA in March 1942 at the manufacturer's laboratory. An inspection of the unit after completion of the first tests revealed that at some time during the runs the first-stage impeller had been damaged by a loose screw from the inlet throttle valve. Additional tests conducted by the manufacturer revealed that large losses were occurring in the passages between the two stages. The damaged impeller was therefore replaced by a new impeller and the first-stage diffuser and interstage passages were redesigned. Tests of the modified turbosupercharger were made by the NACA at the manufacturer's laboratory in September 1942. The results of the two series of tests are presented in accordance with the recommendations of reference 1.

## SUPERCHARGER

The principal dimensions of the compressors were as follows:

First Stage:

| | |
|---|---|
| Maximum impeller tip diameter, inches | 13.324 |
| Minimum impeller tip diameter, inches | 12.970 |
| Mean impeller diameter, inches | 13.147 |
| Diameter of impeller inlet, inches | 10.000 |
| Number of blades in impeller | 23 |
| Number of blades in diffuser | 17 |
| Mean inside diffuser diameter, inches | 13.629 |
| Outside diffuser diameter, inches | 24.5 |

Second stage:

| | |
|---|---|
| Maximum impeller diameter, inches | 11.360 |
| Minimum impeller diameter, inches | 11.087 |
| Mean impeller diameter, inches | 11.224 |
| Diameter of impeller inlet, inches | 8.250 |
| Number of blades in impeller | 23 |
| Number of blades in diffuser | 16 |
| Mean inside diffuser diameter, inches | 11.375 |
| Outside diffuser diameter, inches | 17 |

| | |
|---|---|
| Impeller frontal clearance, both stages, inch | 0.025 |

The modified supercharger was essentially the same as the original unit. The damaged impeller was replaced by a new impeller of identical design and the only other changes made were the insertion of modified guide vanes in the interstage passage and some modification of the first-stage diffuser.

## TEST SETUP AND INSTRUMENTATION

The compressors used in the tests were driven by the standard exhaust-gas turbine from the supercharger with steam as the working fluid. The supercharger casing and the exhaust duct were lagged with 1 inch of 85-percent magnesia. The arrangement of the inlet and the discharge ducts and the location of the measuring stations are shown in the diagrammatic sketch in figure 1. All measurements conformed to the recommendations of references 1 and 2. Temperatures were indicated with calibrated copper-constantan thermocouples; the difference in potential between the hot junction and the ice bath was measured with a calibrated potentiometer connected to an external spotlight galvanometer. Total pressures were measured with calibrated total-head and pitot-static pressure tubes.

The weight of air entering the supercharger was measured with a Venturi tube. Because air was bled off from the inlet to the second stage for cooling the turbine blades, it was also necessary to measure the air leaving the supercharger. The air was measured by means of an orifice tank and calibrated flow nozzles. Throttling was performed entirely by the valve in the outlet duct.

The speed was set with an indicating tachometer and a tachometer of 60-cycle frequency flashing a neon bulb through a rotating disk with a calculated number of holes. At the desired speed, the disk was "stopped" by the stroboscope. For this reason, it was not possible to test at speeds of even thousands but at the nearest interval where the disk remained "stationary."

## OPERATING PROCEDURES AND COMPUTATIONS

The tests of the original supercharger were made by the manufacturer at 10,864; 12,839; 14,814; and 16,789 rpm. Each run consisted of 8 or 9 points taken at flows from wide-open throttle to surge. At the completion of the tests, preliminary calculations were made and the efficiency at the highest speed was found to be lower than that obtained in the preliminary runs. The supercharger was dismantled for inspection and it was found that the impeller in the first stage had been damaged by a loose screw.

The tests of the modified supercharger consisted of runs at the same low speeds as in the previous tests for determining the best efficiency of the unit, a run at the design speed, and several additional higher speed runs. The top speed was limited by the maximum allowable outlet temperature, which was about 325° F. The test speeds were 10,864; 12,839; 15,802; 16,789; and 17,777 rpm. Because of the modifications in the guide vanes in the interstage passage and the first-stage diffuser shape, the speed required to obtain a given pressure ratio with the modified supercharger was substantially decreased. Each run with the modified supercharger again consisted of 8 or 9 points taken at flows from wide-open throttle to surge. The last point at each speed was in the surge range.

The method of calculating the performance and presenting the characteristics of the supercharger is given in reference 3. The over-all pressure ratio and the adiabatic temperature-rise efficiency are shown as functions of the volume flow corrected to sea-level temperature $Q_{1t}/\sqrt{\theta}$ where $Q_{1t}$ is the volume flow of air at inlet stagnation conditions in cubic feet per second and $\theta$ is the ratio of the inlet-air stagnation temperature to 518.4° F absolute. Different values of tip speed corrected to sea-level temperature $U/\sqrt{\theta}$ are used as a parameter, where $U$ is the tip speed in feet per second of the largest diameter impeller. An auxiliary abscissa for these performance curves gives specific capacity $Q_{1t}/\sqrt{\theta}\, D_2{}^2$ to facilitate comparison with units of different impeller diameters. The term $D_2$ is the largest impeller diameter in feet. The product $(Q_{1t}/\sqrt{\theta})$ $(W_2/W_1)$ is also plotted against corrected volume flow, where $W_1$ is the inlet weight flow and $W_2$ is the outlet wieght flow of air in pounds per second. The percentage air weight flow through the entire supercharger can be determined from this plot; the amount being bled off for cooling the turbine can then be calculated. In the computations of the data for the modified supercharger, corrections were made for humidity; no corrections were made for the original supercharger because the humidity was very low.

## RESULTS AND DISCUSSION

### Original Supercharger

The characteristic curves of the original supercharger (fig. 2) show that the adiabatic efficiency is high throughout the entire operating range. The efficiency is above 70 percent in nearly all cases; the peak efficiency of slightly above 79 percent is obtained at the lowest speed. At the peak pressure ratio of 2.62 the adiabatic efficiency was nearly 74 percent at a corrected volume flow of 110 cubic feet per second.

In figure 3, the product $(Q_{1t}/\sqrt{\theta})$ $(W_2/W_1)$ is plotted as a function of the corrected volume flow. It can be seen that the values for all speeds fall very close to the same curve. This curve can be used for calculating the weight flow leaving the supercharger.

### Improved Supercharger

The characteristic curves of the modified supercharger are fairly flat over most of the range (fig. 4) and the contours show that the efficiency is high for all speeds and throttle settings.

At the lowest speed run a maximum efficiency of over 82 percent was obtained. At the maximum pressure ratio of 2.91 the peak efficiency was 78 percent at a corrected volume flow of 115 cubic feet per second.

The product $(Q_{1t}/\sqrt{\theta})$ $(W_2/W_1)$ is plotted as a function of the corrected volume flow in figure 5. As with the original supercharger all values fall very close to the same curve.

## Comparison of Original and Modified Superchargers

A comparison of the performance characteristics of the original and the modified superchargers shows that the modified supercharger has a maximum efficiency 3 points higher than that of the original supercharger. The peak efficiency of the original supercharger falls off 5 points to 74 percent when the pressure ratio of the original supercharger is increased from 1.6 to 2.6; while the efficiency of the modified supercharger falls off only 2 points to 80 percent with the same increase in pressure. A portion of this improvement in efficiency can probably be attributed to a reduction in pressure losses in the interstage passages because the modified supercharger produces a higher pressure ratio than the original supercharger at the same tip speed. The difference in efficiency between the original and the modified superchargers may also be partly due to the difference in inlet temperature and to heat transfer. The original tests were run with the compressor and most of the ducting in ambient air at room temperature but with the compressor drawing in air from outside the building at 40° F. The final tests were run with the inlet air and the surrounding air at about 80° F. Theoretically a temperature difference should have no effect, but an effect has been observed in other tests and has usually been attributed to heat transfer.

The constant-speed curves of the modified supercharger are somewhat steeper because the modifications increased the pressure ratio more at the peak conditions than at the higher values of corrected volume flow.

Pulsation in the modified supercharger seemed to be more pronounced than in the original. The unit became quite noisy when the surge point was reached and the efficiency and the pressure ratio dropped suddenly at the surge point. The readings, however, were still steady at this point and the unit ran smoothly.

## SUMMARY OF RESULTS

In tests of an original and modified two-stage turbosupercharger the following results were obtained:

1. The modified supercharger had a maximum efficiency of slightly above 82 percent as compared with about 79 percent in the original supercharger.

2. At a pressure ratio of 2.6, the highest available for comparison, the modified supercharger reached a peak efficiency of 80 percent; at this pressure ratio, the original supercharger reached a peak of 74 percent.

3. At the maximum pressure ratio of 2.91 the peak efficiency of the modified supercharger was 78 percent at a corrected volume flow of 115 cubic feet per second.

4. The characteristic curves of the supercharger are fairly flat, showing good performance over a wide operating range of speeds and air flows.

Aircraft Engine Research Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, October 13, 1942.

## REFERENCES

1. Ellerbrock, Herman H., Jr., and Goldstein, Arthur W.: Principles and Methods of Rating and Testing Centrifugal Superchargers. NACA ARR, Feb. 1942.

2. NACA Subcommittee of Supercharger Compressors: Standard Procedures for Rating and Testing Centrifugal Compressors. NACA ARR No. E5F13, 1945.

3. NACA Subcommittee on Supercharger Compressors: Standard Method of Graphical Presentation of Centrifugal Compressor Performance. NACA ARR No. E5F13a, 1945.

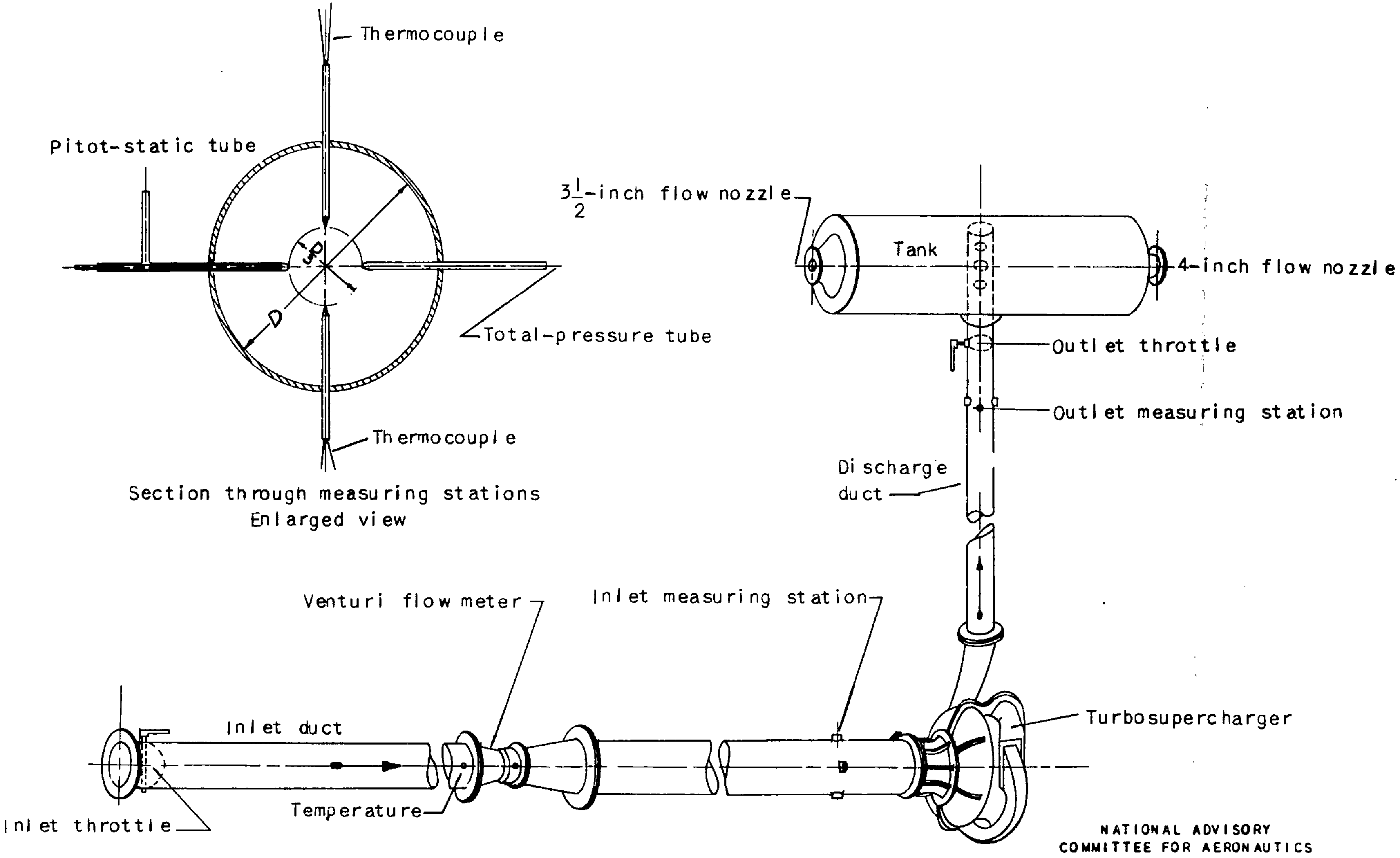

Figure 1. - Instrumentation of two-stage turbosupercharger test rig.

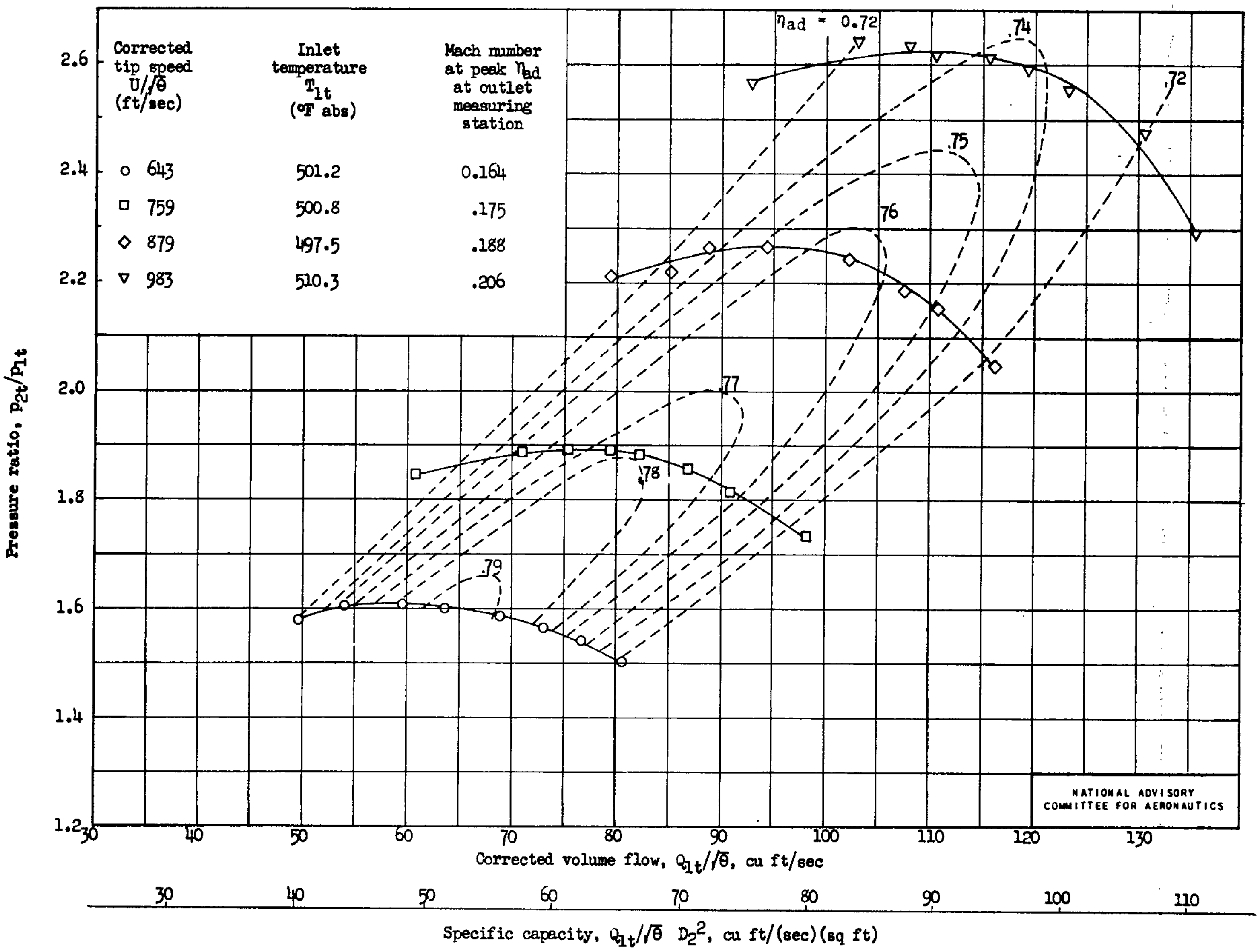

Figure 2. - Performance characteristics of original two-stage turbosupercharger.

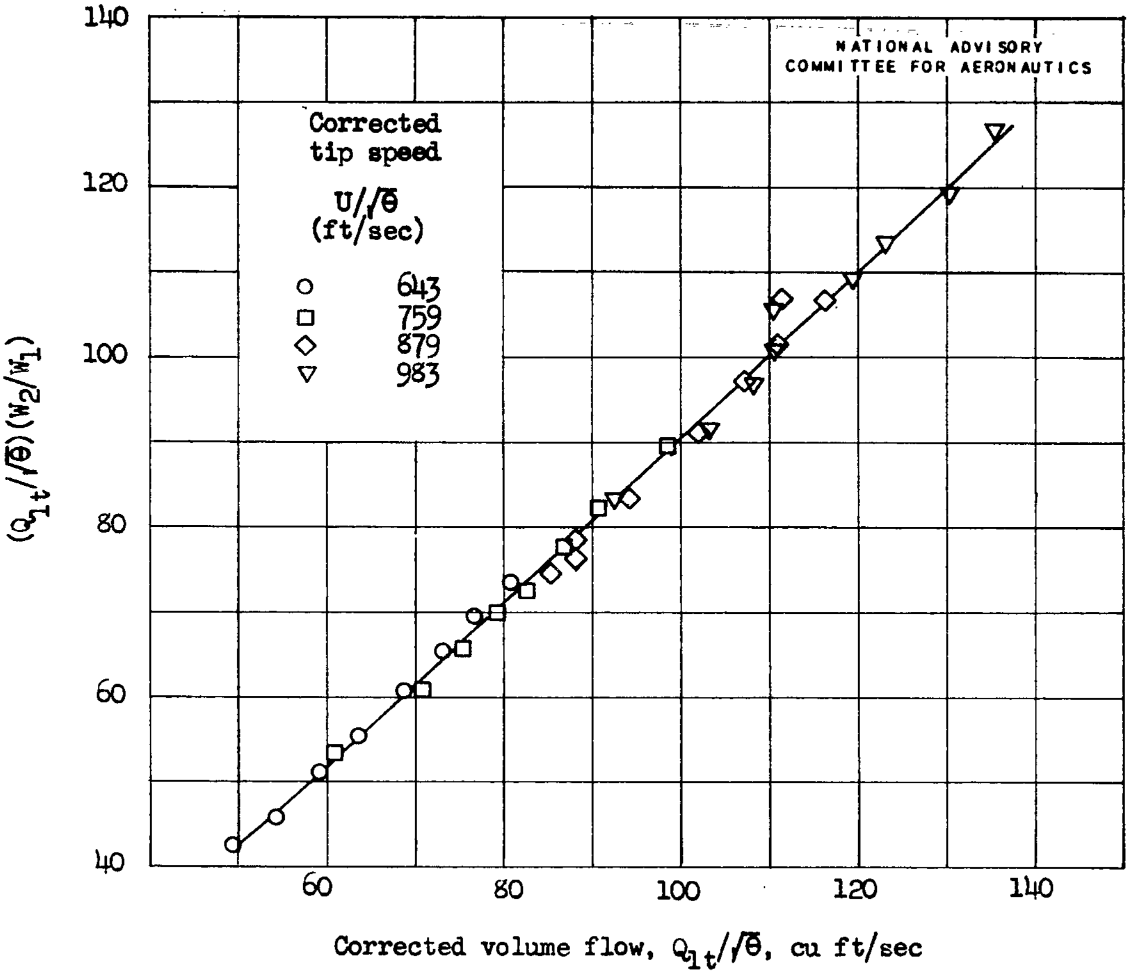

Figure 3. - Variation of $(Q_{1t}/\sqrt{\theta})(W_2/W_1)$ with corrected volume flow for original two-stage turbosupercharger.

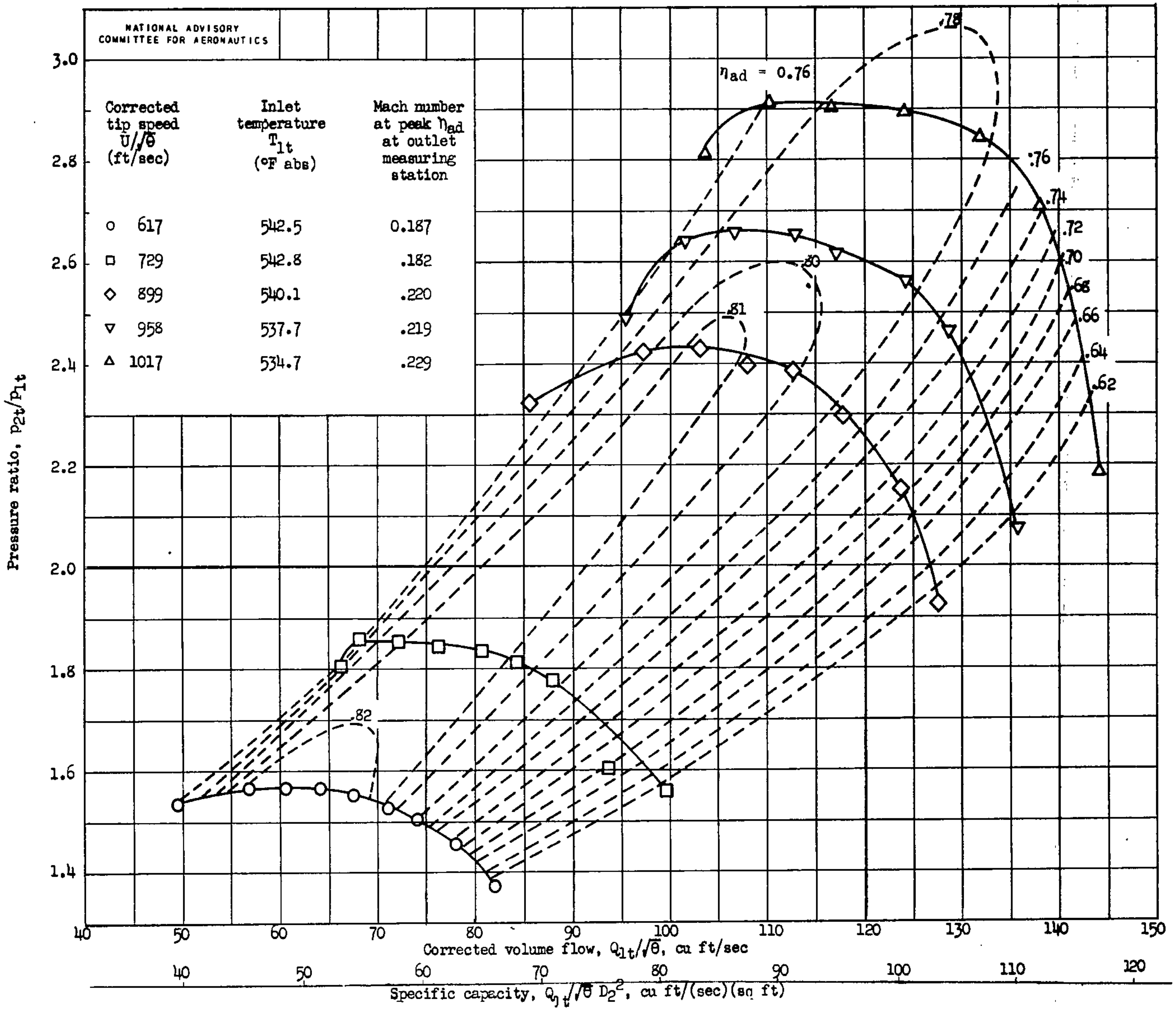

Figure 4. - Performance characteristics of modified two-stage turbosupercharger.

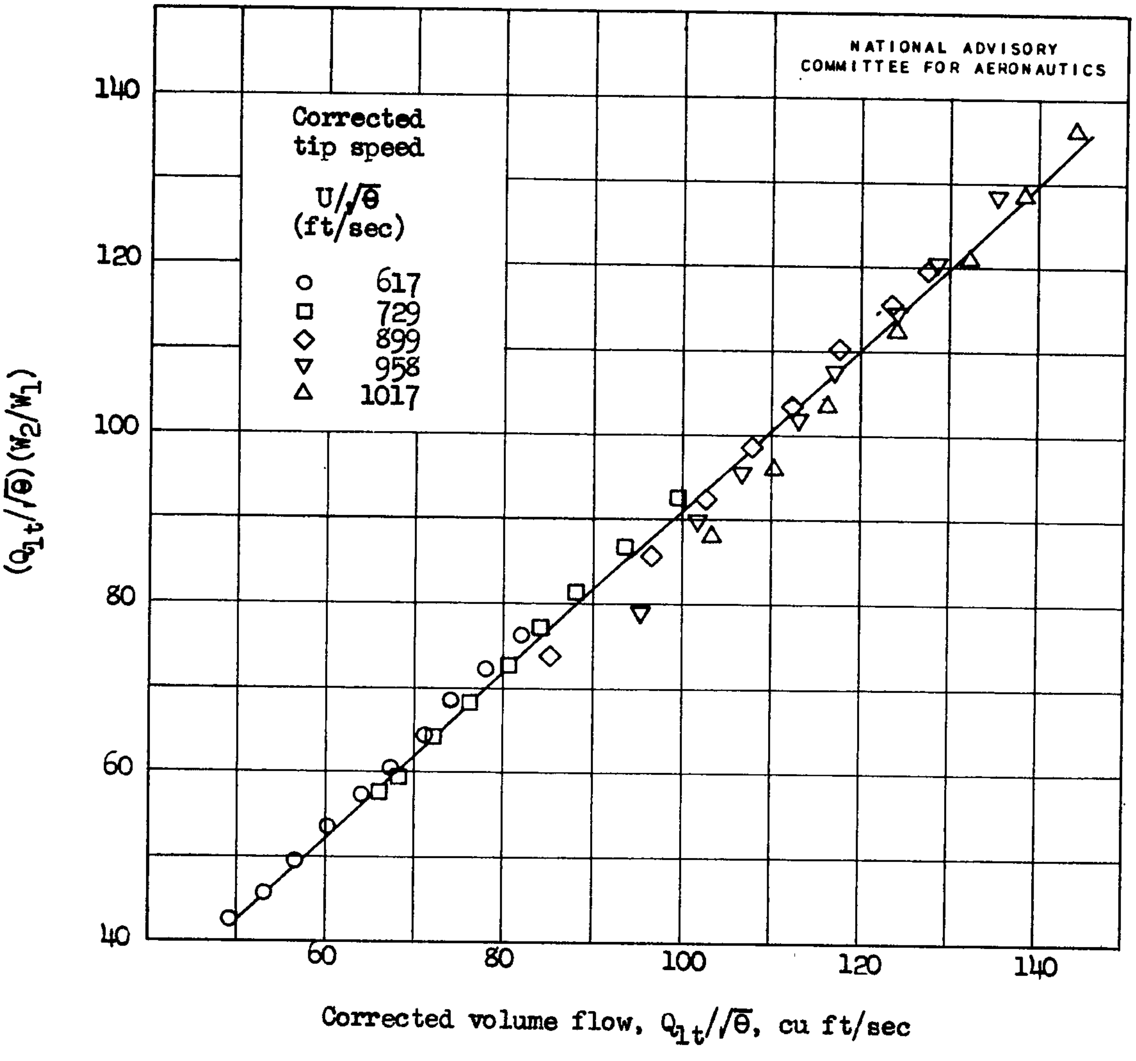

Figure 5. - Variation of $(Q_{1t}/\sqrt{\theta})(W_2/W_1)$ with corrected volume flow for modified two-stage turbosupercharger.