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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

PRELIMINARY ALTITUDE OPERATIONAL CHARACTERISTICS OF A J57-P1 TURBOJET ENGINE

By Lewis E. Wallner and Martin J. Saari

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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SUMMARY

The operational characteristics of a J57-P1 turbojet engine have been investigated at altitudes between 15,000 and 66,000 feet in the Lewis altitude wind tunnel. Included in this study is a discussion of fuel nozzle coking, the altitude operating limits with and without the standard engine control, the compressor surge characteristics, and the engine starting and windmilling characteristics.

Severe circumferential turbine outlet temperature gradients which occurred at high altitude as a result of fuel nozzle coking were alleviated by the manufacturer's change in the fuel flow divider schedule and in a nozzle gasket material. Surge of the outboard compressor in the low engine speed region was eliminated by the use of the air bleeds, incorporated in the engine for this purpose. The maximum altitude at which the engine was operated without the control was about 66,000 feet at 0.8 flight Mach number and at a reduced engine speed to avoid compressor surge; with the engine control in operation, the altitude operating limit is reduced to approximately 59,000 feet. The maximum altitude at which the engine was started was about 40,000 feet.

INTRODUCTION

At the request of the Bureau of Aeronautics, Department of the Navy, the performance and operational characteristics of a J57-P1 engine have been investigated in the Lewis altitude wind tunnel. This investigation covered, in general, a range of engine speeds and exhaust nozzle areas at altitudes between 15,000 and 66,000 feet. Presented herein are data on fuel nozzle coking and associated turbine discharge temperature distribution, the altitude operating limits for the controlled engine and for the uncontrolled engine, both with and without compressor bleed, preliminary data on compressor surge limits of both the inboard and outboard compressors, and the altitude starting limits. In addition, data are presented for the engine in the windmilling condition.

INSTALLATION AND PROCEDURE

The engine was installed in the wind tunnel test section as shown in figure 1. Extensive temperature and pressure instrumentation was placed at the entrance and exit of the engine and each of its major components. The data above an altitude of 50,000 feet were obtained by the use of no-flow ejectors on the engine exhaust pipe and on the compressor bleed ports. These ejectors were designed from the data in reference 1. Surge pressure ratios for the outboard compressor were obtained by injecting air into the bleed ports located between the two compressor rotors. The pressure ratio across the inboard compressor was varied up to the surge value by adjusting the engine exhaust nozzle area.

RESULTS AND DISCUSSION

Fuel nozzle coking. - After approximately 60 hours of engine operation a severe circumferential temperature gradient was encountered at the turbine discharge during high altitude operation. For rated engine operating conditions at an altitude of 50,000 feet, the circumferential variation in turbine discharge temperatures was as high as 1000° F. A check of flow characteristics of the fuel nozzles shown in figure 2 revealed a flow unbalance in the nozzles of both the primary and secondary flow systems. This unbalance was greatest for the primary system, with the nozzles in combustors 1 and 8 receiving about 1/2 of the flow through each of the other 6 nozzles. Disassembly of the nozzles revealed hard coke deposits in the flow passages as shown in figure 3. Damage that was sustained by the first stage turbine nozzle diaphragm (as a result of the nozzle coking) and carbon deposition on the blades is shown in figure 4. A flow check of a clean set of fuel nozzles resulted in relatively small flow deviations between the nozzles as shown in figure 5.

Fuel nozzle coking which had been previously encountered by the engine manufacturer may be attributed to two major causes; oxidation and flaking of a copper gasket in the fuel nozzle assembly and excessive fuel residence heating time in the nozzles under certain operating conditions. To prevent clogging and coking of the nozzles the manufacturer substituted aluminum for the copper gasket and changed the flow schedule in such a manner as to decrease the residence time of the fuel in the nozzles. A comparison of the turbine discharge temperature distributions of the modified system in a clean condition with the original coked nozzles is shown in figures 6 and 7 for two altitudes. At 15,000 feet (fig. 6) both fuel nozzle assemblies produced relatively uniform turbine discharge temperature patterns. (At this flight condition the major portion of the total engine fuel flow is supplied by the secondary fuel system where the flow check of the coked nozzles showed smaller deviations than on the primary fuel system alone.) At an altitude of 50,000 feet the coked and clean fuel nozzle assemblies produced widely different temperature distributions (see fig. 7). The temperature pattern obtained with the improved fuel system after 141 hours of engine operation is also shown in this figure. The relatively uniform temperature distribution after the long period of engine operation attests to the absence of coke deposits in the fuel nozzles, when the modified fuel system is used.

Effect of altitude on engine operation. - The effect of inlet total pressure on engine operating limits is shown in figures 8 to 11. The range of engine operation with the compressor air bleeds closed and without the automatic control is shown in figure 8. In addition to the inlet total pressure scale on the ordinate, an altitude scale is shown for a flight Mach number of 0.8. The inlet air temperature was maintained at approximately the value corresponding to 0.8 flight Mach number. As inlet pressure is reduced, the exhaust-gas temperature limited speed is decreased which is attributed to a decrease in component efficiencies with the decrease in Reynolds number. Surge of the outboard (low pressure) compressor occurred over a relatively narrow range of engine speeds, that increased in extent as altitude was increased. The upper speed limit of this surge region was determined by approaching the surge from a higher speed and conversely, the lower speed limit was determined by accelerating the engine from the surge-free region of low speed. In general the severity of the surge was such as to preclude engine operation within the surge region. The lowest operable inlet pressure was about 200 pounds per square foot absolute at a speed of 8850 rpm; at a flight Mach number of 0.8 this pressure corresponds to an altitude of 63,000 feet.

As a means of avoiding this surge condition of the outboard compressor, air bleed between the two compressor rotors is employed. The engine was equipped with a large and a small bleed port; the single bleed operation presented in this report is with the large bleed port open. Engine operating limits with the large air bleed port open is shown in figure 9. The obvious improvement resulting from compressor bleed is the elimination of the outboard compressor surge region. Surge of the inboard compressor was, however, obtained at high engine speeds at inlet pressures below about 340 pounds per square foot absolute. In order to operate at lower inlet pressures, it is necessary to reduce engine speed. For example, at an inlet pressure of 200 pounds per square foot absolute, the maximum operable engine speed as limited by compressor surge is about 8300 rpm. No operating difficulty was encountered in the low exhaust gas temperature region; acceleration without blowout could easily be made at exhaust temperatures as low as 200° F. (This temperature line is indicated for reference on fig. 9.)

Engine operating limits with both compressor bleeds open are shown in figure 10 and are seen to be generally similar to the limits for operation with one bleed open. With two bleed operation the surge limit is more precisely defined, and it was possible to operate the engine at higher speed in the high altitude region than with only one bleed open; for example at an inlet pressure of 200 pounds per square foot absolute changing from single bleed to double bleed operation increased the maximum operable engine speed limit from 8300 to 8900 rpm. The highest altitude at which the engine was operated was 66,000 feet at an inboard speed of 8100 rpm.

Engine operation with the automatic engine control which modulates fuel flow to maintain a constant temperature limit is presented in figure 11. As inlet pressure was reduced to about 260 pounds per square foot absolute surge was encountered for both idle and military settings of the control, at engine speeds between 8400 and 8700 rpm. With the control at the military setting the engine operates stably down to inlet pressures as low as 260 pounds per square foot absolute, where the temperature limited speed is 9050 rpm. A further slight reduction in pressure resulted in a sudden decrease in speed to 8650 rpm, and surge of the outboard compressor. With the control at the idle setting a reduction in inlet pressure to about 260 pounds per square foot absolute resulted in the closing of the second air bleed at a speed of about 8400 rpm. The closing of the bleed at this operating condition caused surge of the outboard compressor. Thus the operating ceiling of the engine with the automatic control is about 260 pounds per square foot absolute inlet pressure which corresponds to an altitude of 59,000 feet at 0.8 Mach number (assuming 100 percent ram recovery). It should be remembered that small changes in exhaust gas temperature with military control setting are reflected as variations in engine speed and compressor discharge pressure. When operating near the surge limit, slight variations in compressor discharge pressure introduced by the control probably serve to lower the altitude surge limit of the engine.

Compressor surge characteristics. - Surge data for the outboard compressor were obtained over a wide range of rotor speeds by injecting air into the bleed ports, whereby the pressure ratio could be raised to the surge value independently of the engine operating limits. The variation of surge pressure ratio with outboard rotor speed is shown for altitudes between 15,000 and 55,000 feet in figure 12. The steady state operating lines with and without air bleed are also shown on the figure. There was practically no altitude effect on the surge pressure ratios except at speeds above 6500 rpm, where an unexplainable increase in surge limit occurs with an increase in altitude. The need for air bleed in the low speed region is apparent from the intersection of the surge and steady state operating line without bleed in the vicinity of 5000 rpm. Opening the air bleeds resulted in a safe margin between the surge line and the steady state operating line in the low speed region. Rotating stalls were observed prior to surging in the speed region up to about 4000 rpm, as indicated by the cross-hatched region on the figure.

Surge data on the inboard compressor, obtained by decreasing the exhaust nozzle area, are presented in figure 13 for a range of altitudes from 15,000 to 50,000 feet. The compressor surge lines were well defined up to an altitude of 45,000. At 50,000 feet, surge was encountered over a wide range of pressure ratios extending from the surge limit at 45,000 feet to the steady state operating line. Approaching the surge point by changing either engine speed or pressure ratio did not seem to have a consistent effect. The lowest speed shown for the steady state operating line (7150 rpm) is where surge is encountered in the outboard compressor as discussed above. Rotating stall was also obtained at rotor speeds up to 6000 rpm. Although the rotating stall patterns were generally not stable, between one and five stall regions were observed, that rotated at about half compressor speed.

Altitude starting characteristics. - The results of attempted engine ignition and acceleration at various altitudes from 30,000 to 45,000 feet are presented in figure 14. The fuel flow used for the starting attempts was in the vicinity of 600 pounds per hour (as called for by the control). A successful start was arbitrarily defined as ignition and acceleration to 70 percent of rated speed in less than 3 minutes, without exceeding a turbine outlet temperature of 1300° F. The highest altitude at which the engine was started is 40,000 feet. At 35,000 feet, successful starts were obtained over a wide range of windmilling speeds.

Windmilling performance. - Corrected airflow, internal drag and outboard rotor speed in the windmilling condition are presented as functions of corrected inboard rotor speed in figures 15 to 17 for altitudes of 15,000, 35,000, and 50,000 feet. Corrected outboard rotor speed is shown as a function of true air speed in figure 18.

SUMMARY OF RESULTS

1. Surge of the outboard compressor that was encountered at low engine speeds was eliminated by the standard air bleeds provided on the engine. With the use of air bleed it was possible to operate the engine at reduced speed at altitudes as high as 66,000 feet at a Mach number of 0.8.

2. Use of the automatic engine control limited the high altitude operation to about 59,000 feet at 0.8 Mach number.

3. The surge line of the outboard compressor was not appreciably affected by changes in altitude up to 55,000 feet. The surge line of the inboard compressor, however, was considerably reduced at altitudes above 35,000 feet.

4. The highest altitude at which the engine was successfully started was 40,000 feet.

5. A severe turbine discharge temperature gradient was obtained at high altitudes because of fuel nozzle coking. This problem was alleviated by the manufacturer's change in the fuel flow divider schedule and in the material in a fuel nozzle gasket.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, March 26, 1954.

REFERENCE

1. Greathouse, W. K., and Hollister, D. F.: Air-Flow and Thrust Characteristics of Several Cylindrical Cooling-Air Ejectors with a Primary to Secondary Temperature Ratio of 1.0. NACA RM E52L24, 1953.

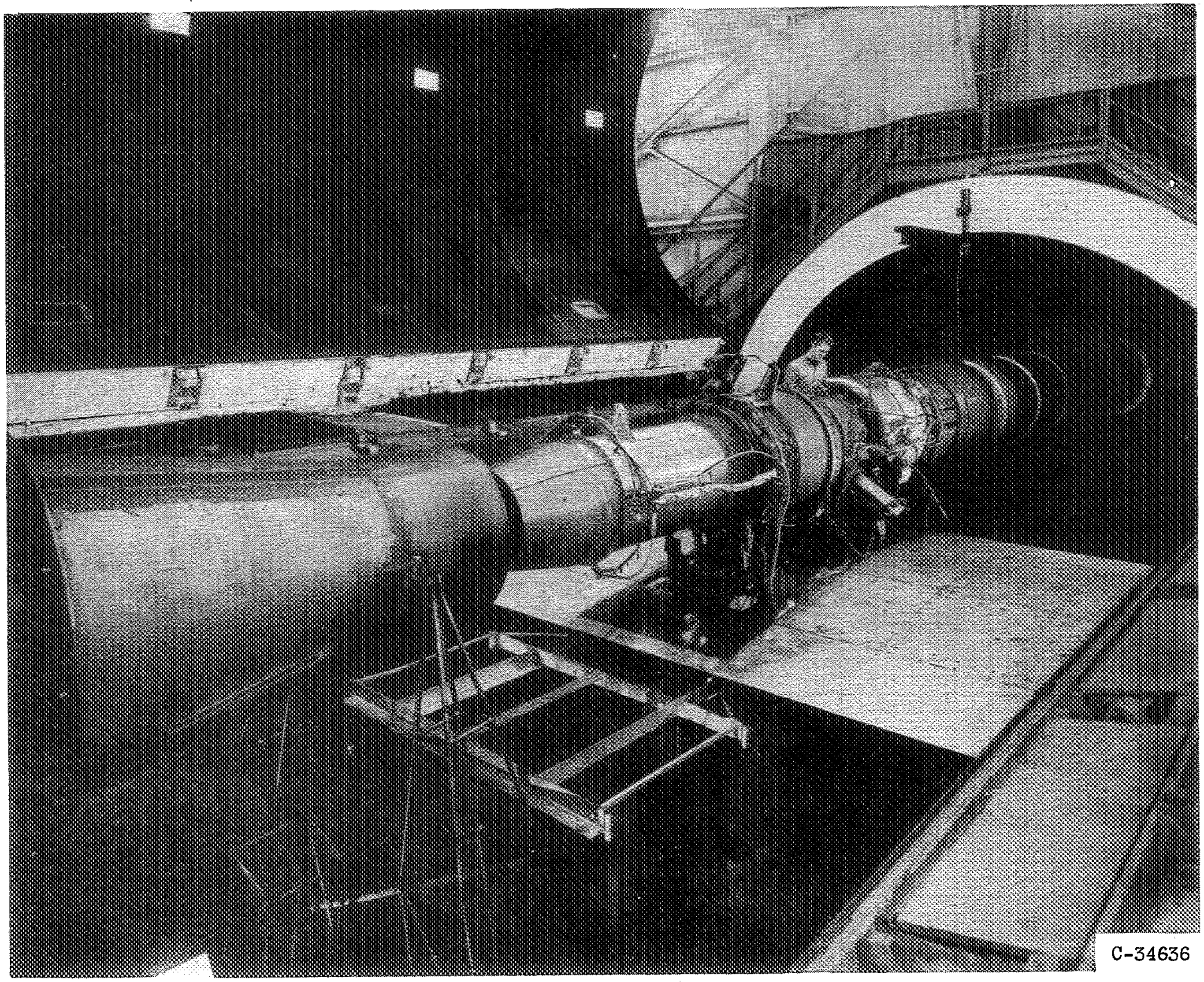

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Figure 1. - A J57-P1 turbojet engine installed in altitude wind tunnel.

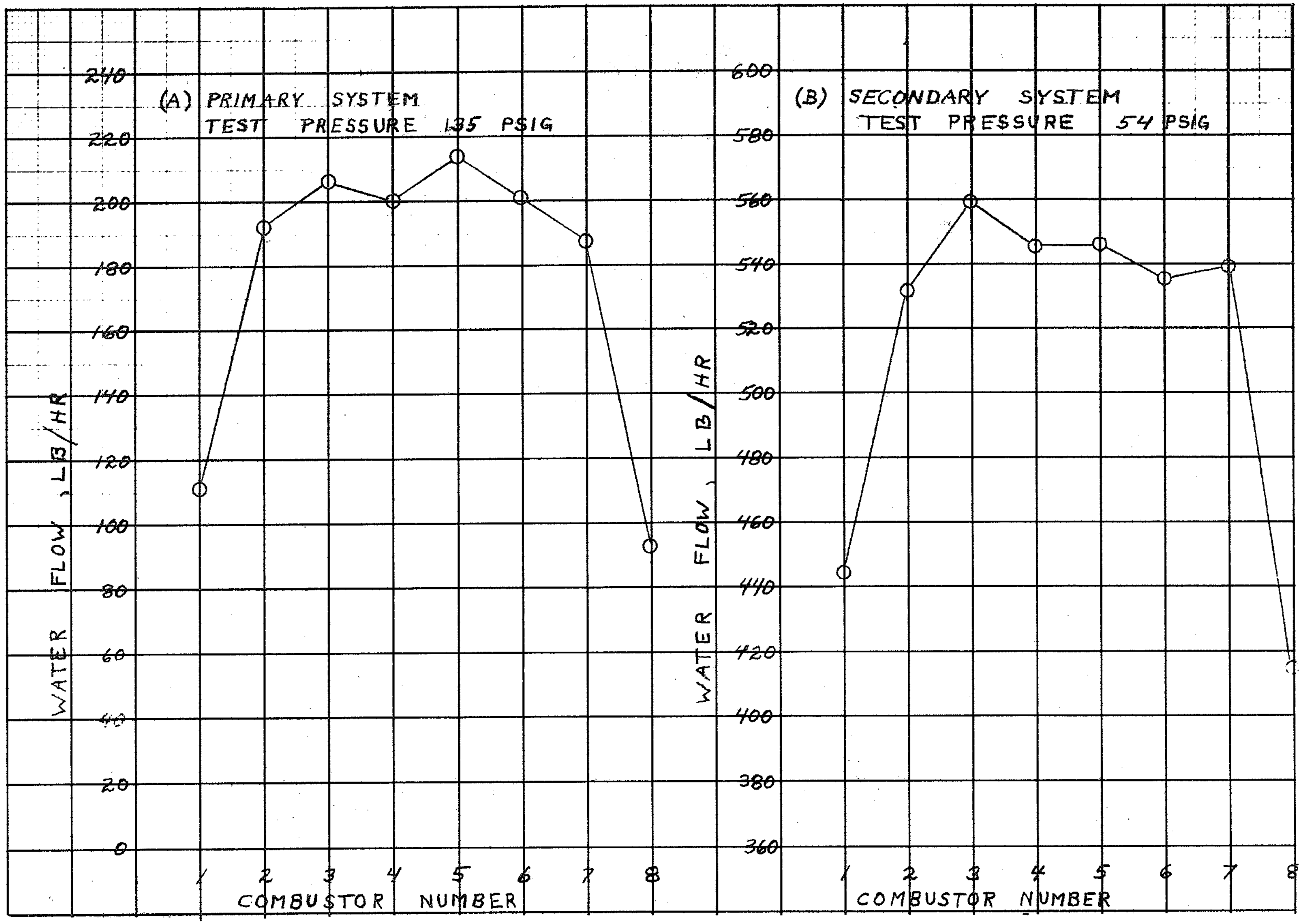

Figure 2. - Fuel nozzle flow balance with coked nozzle assembly.

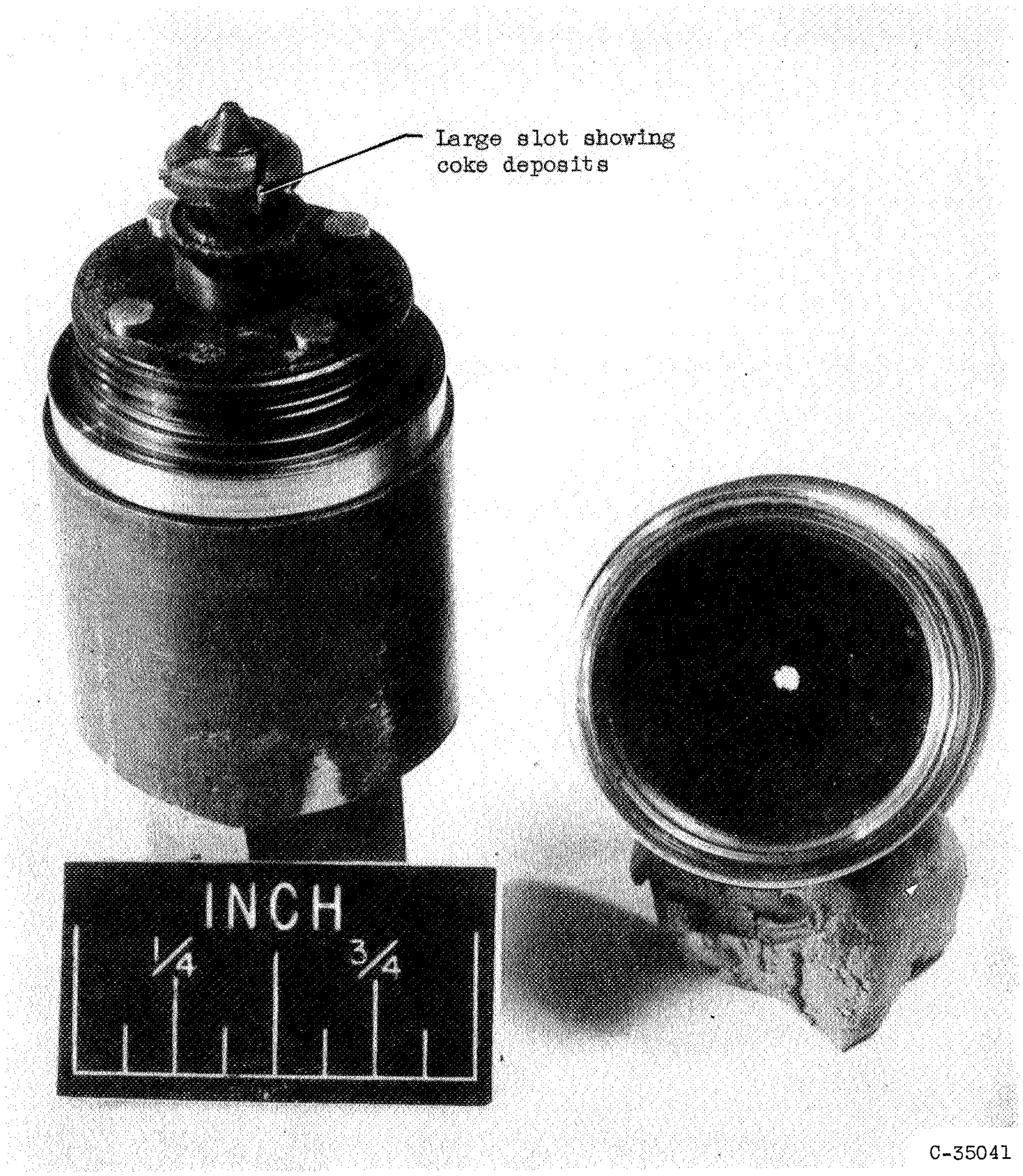

Figure 3. - Fuel nozzle showing coke deposits.

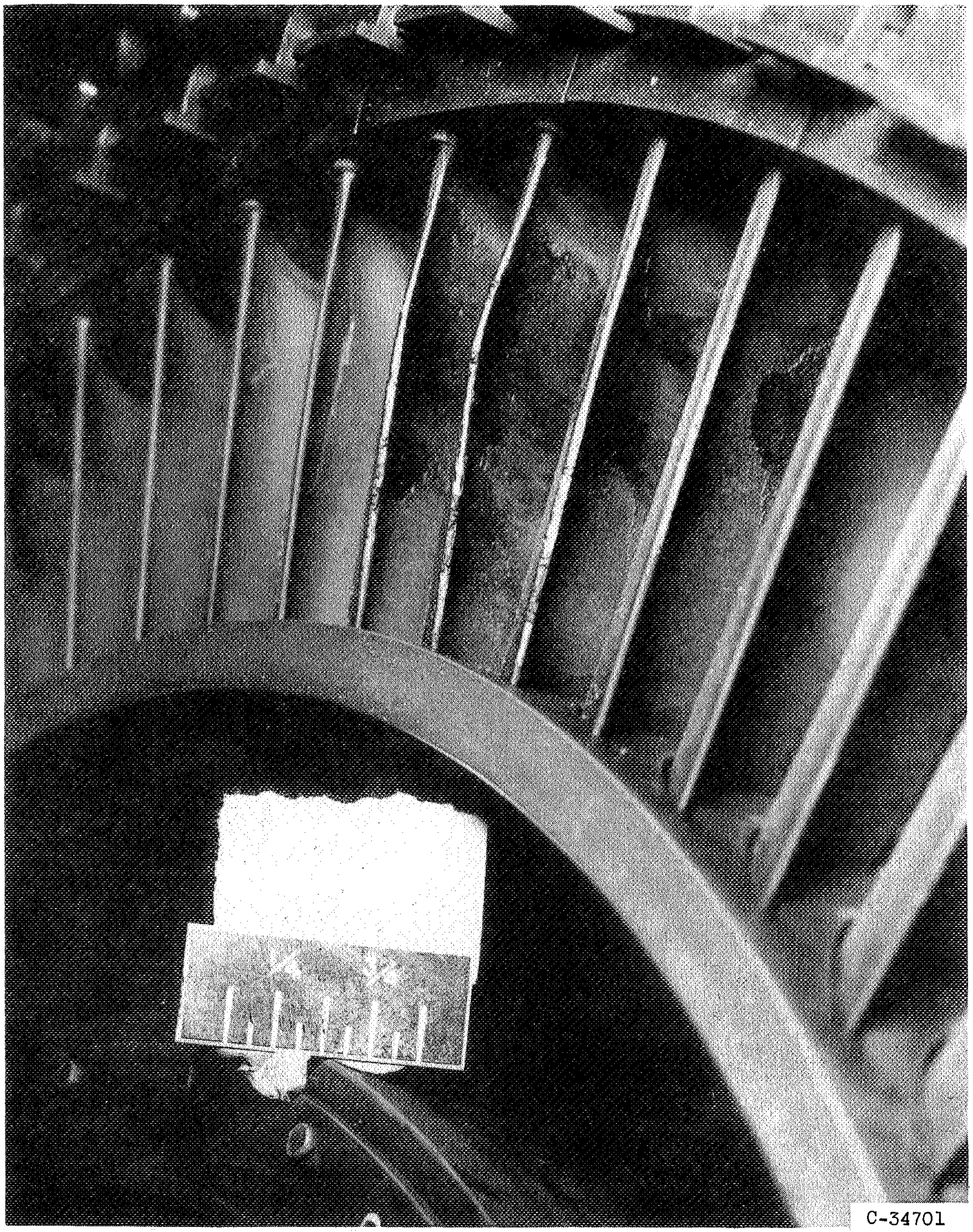

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Figure 4. - Damage sustained to first stage turbine nozzles.

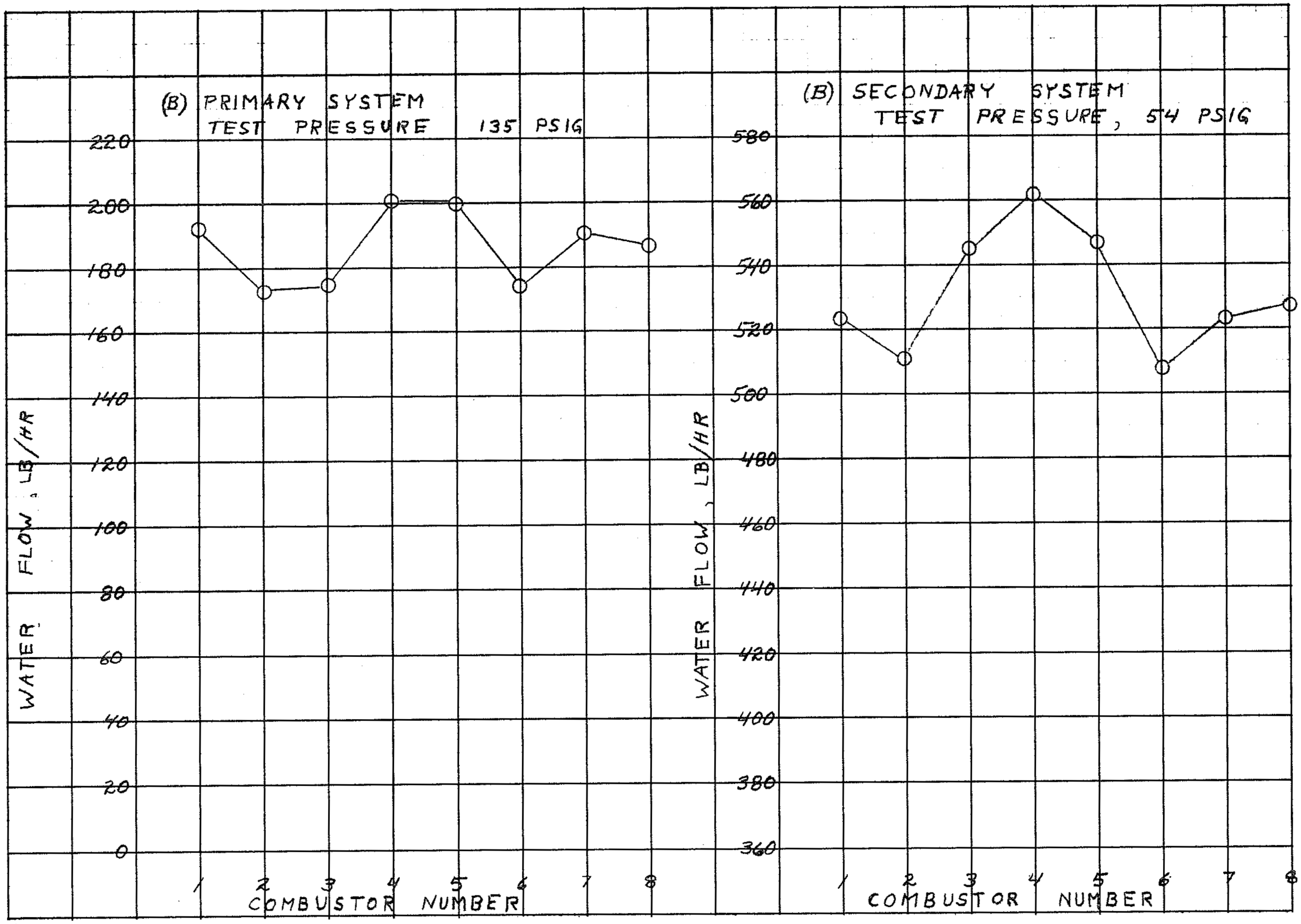

Figure 5. - Fuel nozzle flow balance with clean nozzle assembly.

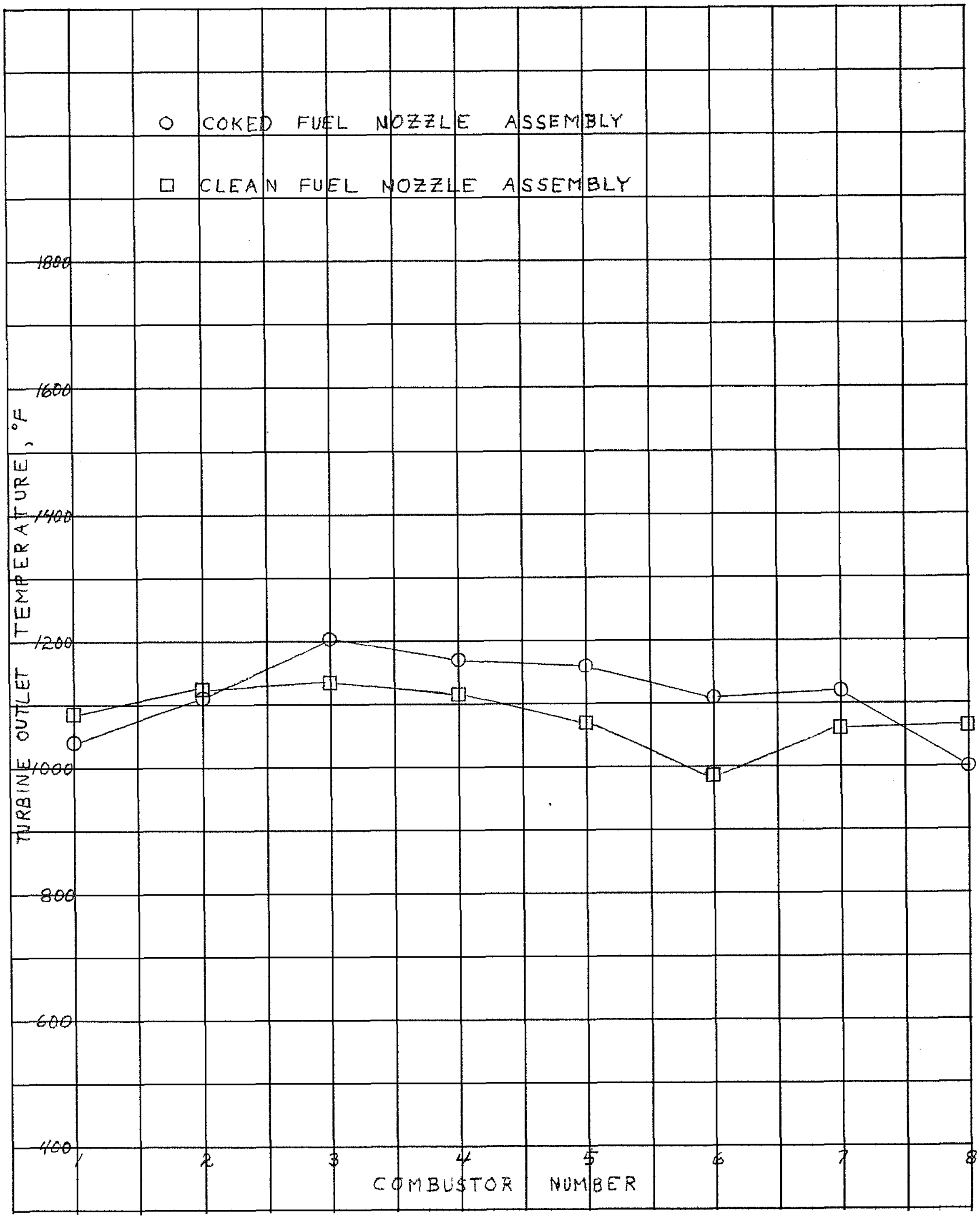

Figure 6. - Effect of coking on turbine outlet temperature distribution. Altitude, 15,000 feet; Mach number, 0.8.

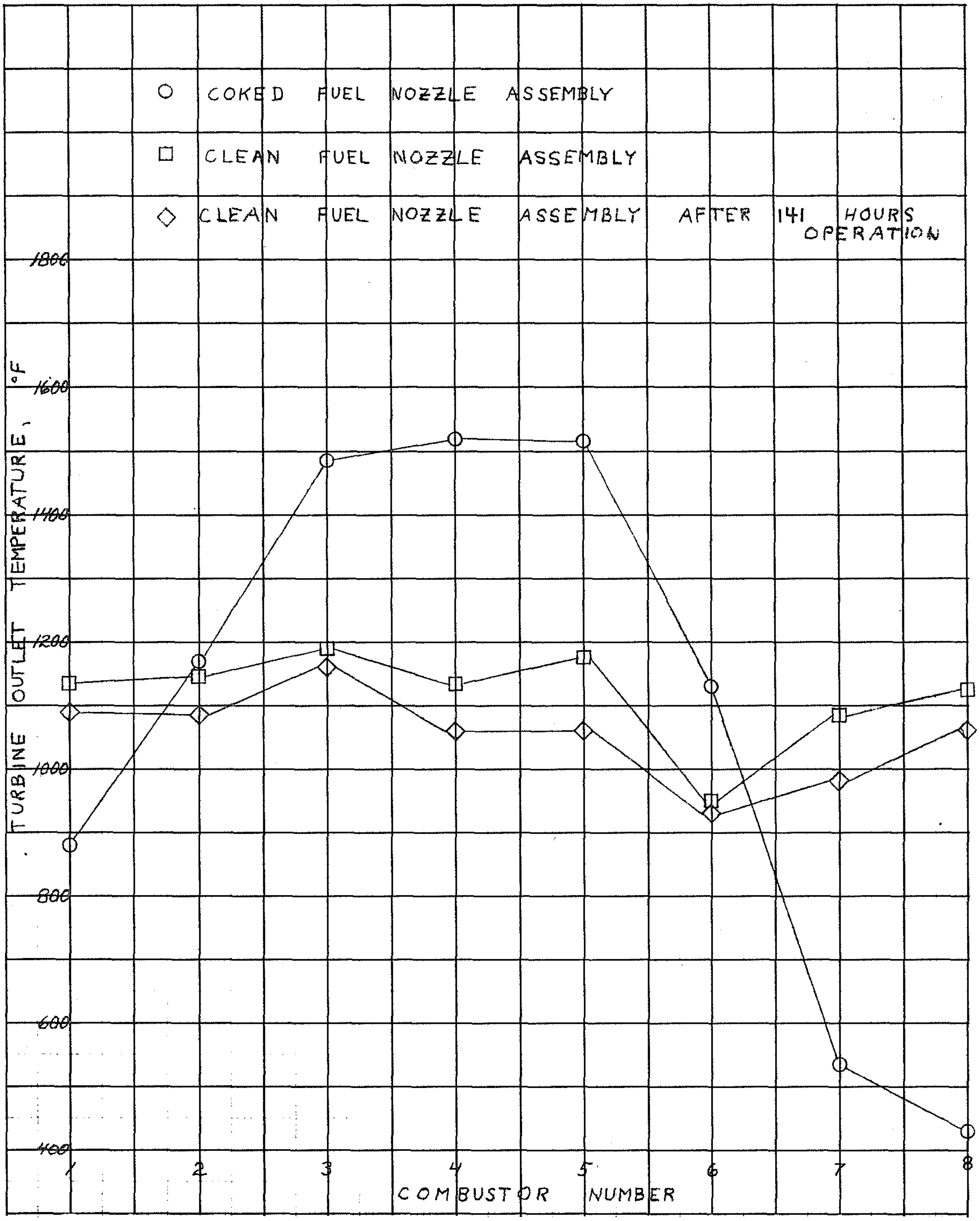

Figure 7. - Effect of coking on turbine outlet temperature distribution. Altitude, 50,000 feet; Mach number, 0.8.

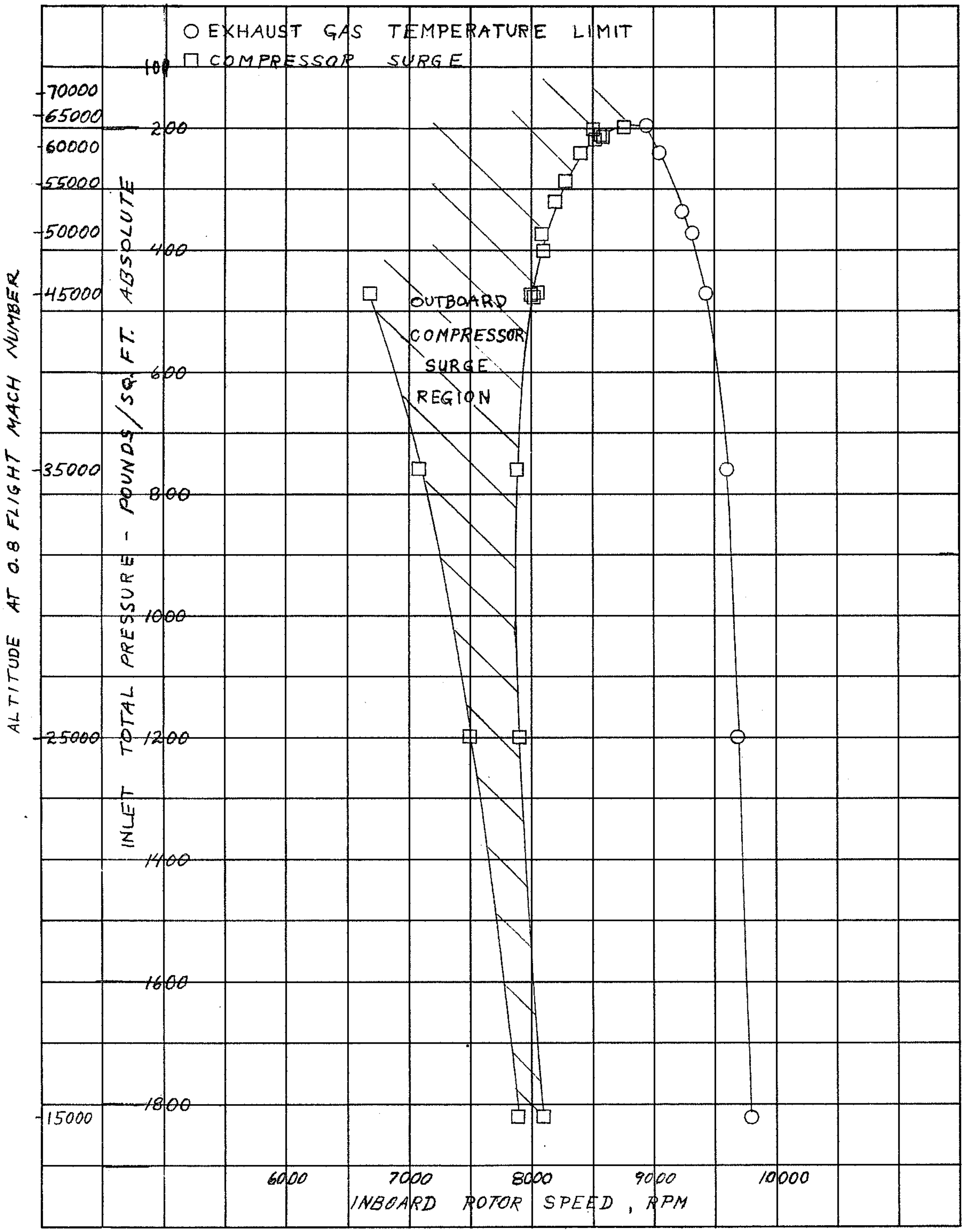

Figure 8. - Effect of altitude on engine operating limits with compressor bleeds closed.

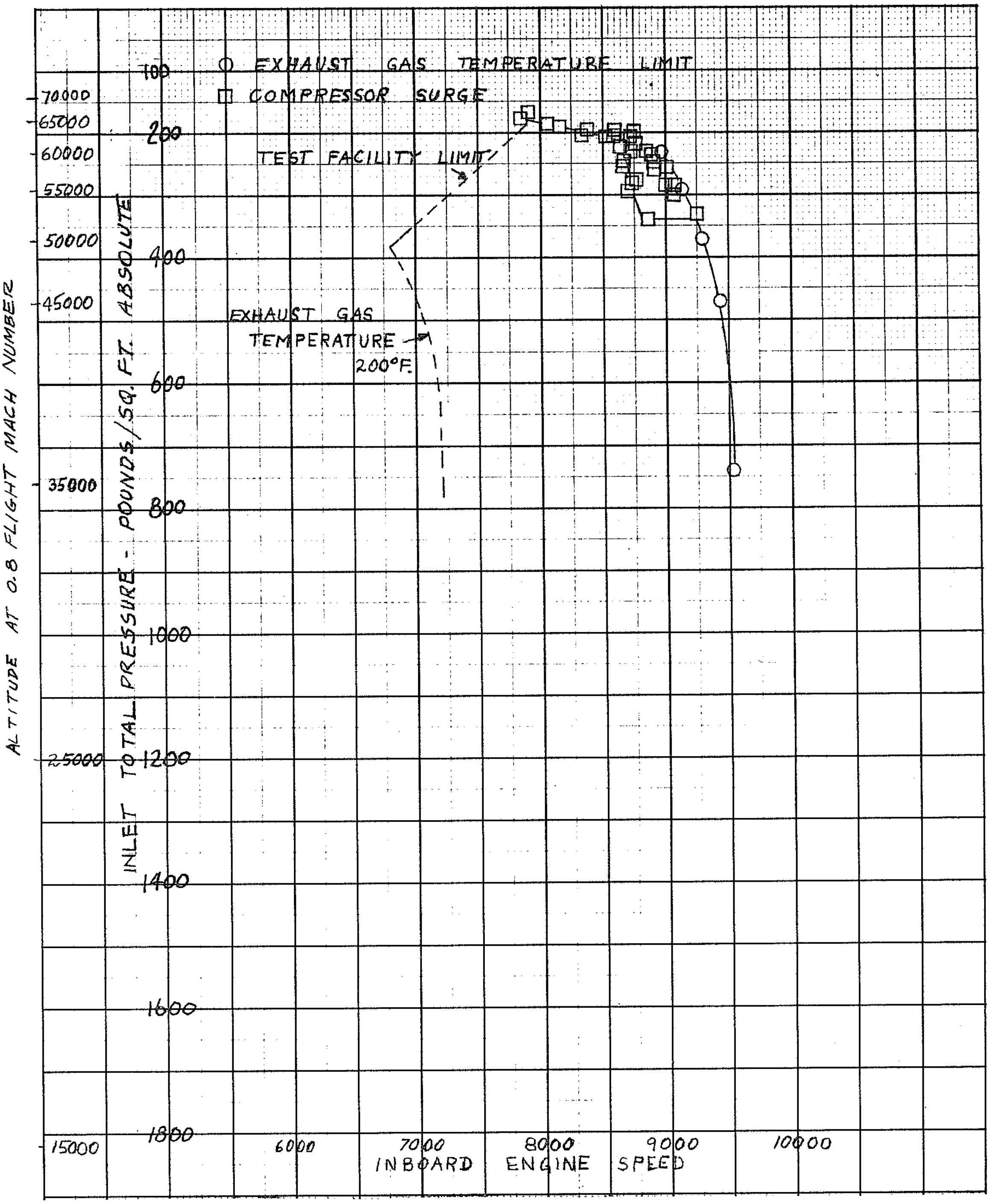

Figure 9. - Effect of altitude on engine operating limits with one compressor bleed open.

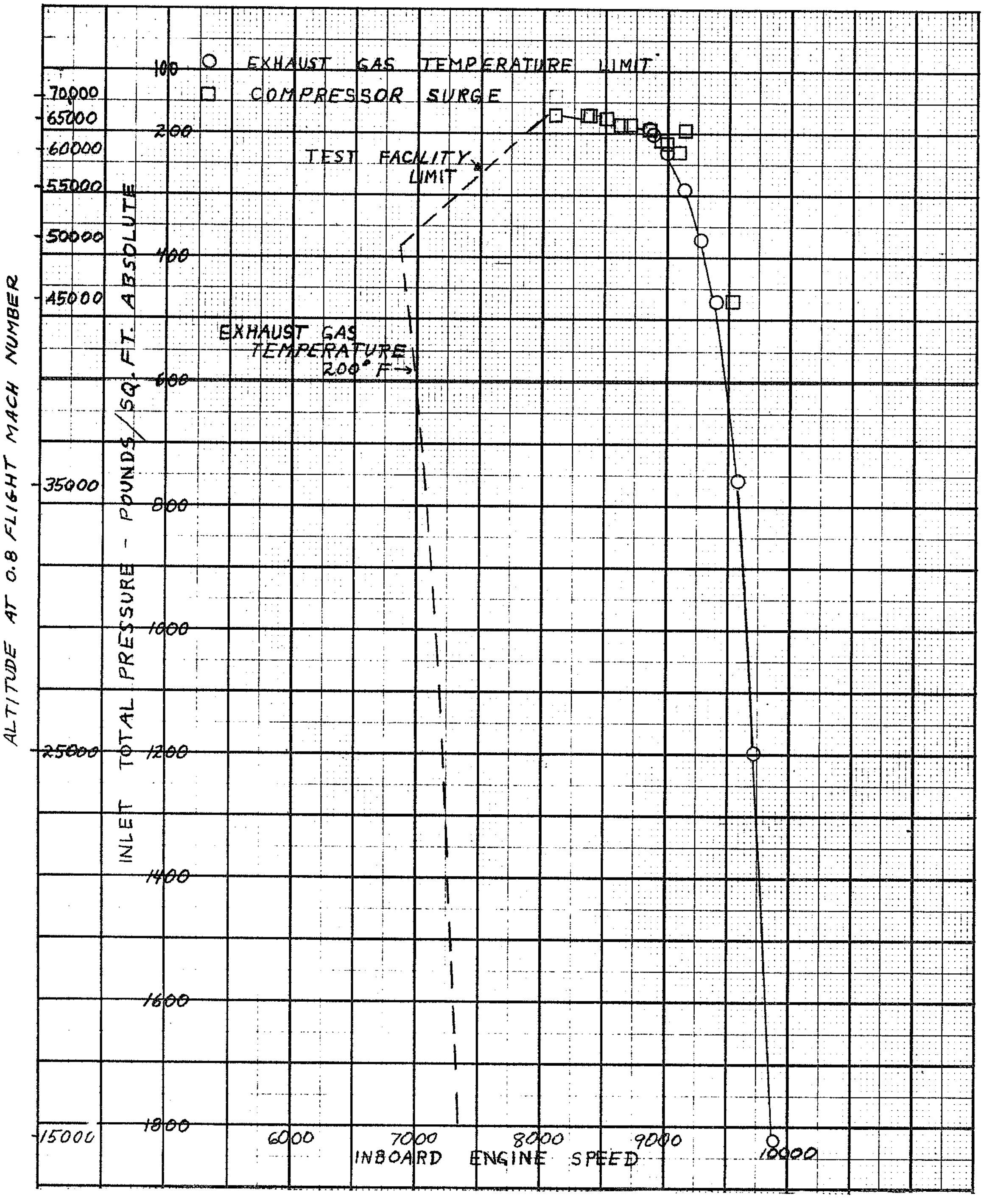

Figure 10. - Effect of altitude on engine operating limits with two compressor bleeds open.

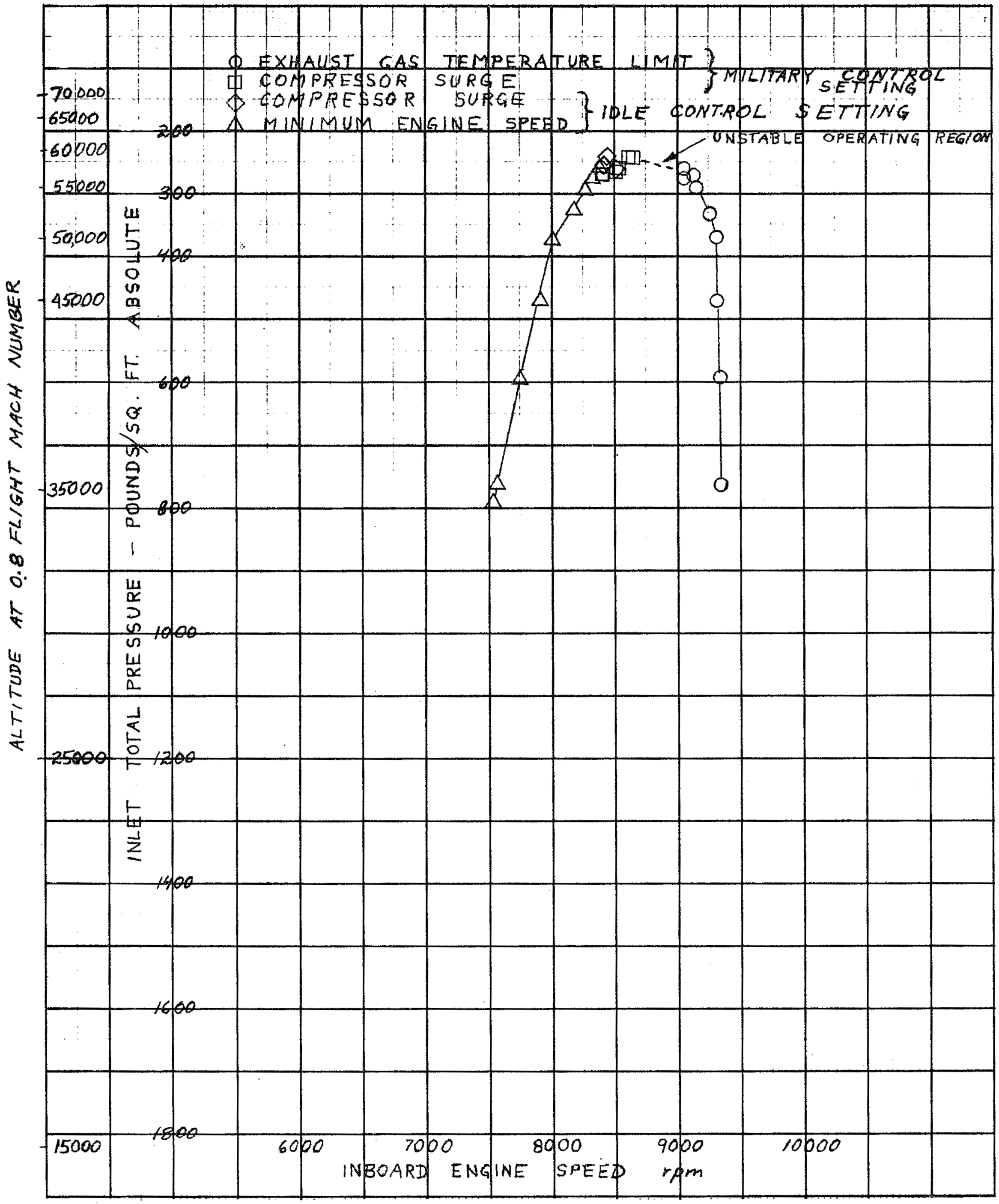

Figure 11. - Effect of altitude on controlled engine operating limits.

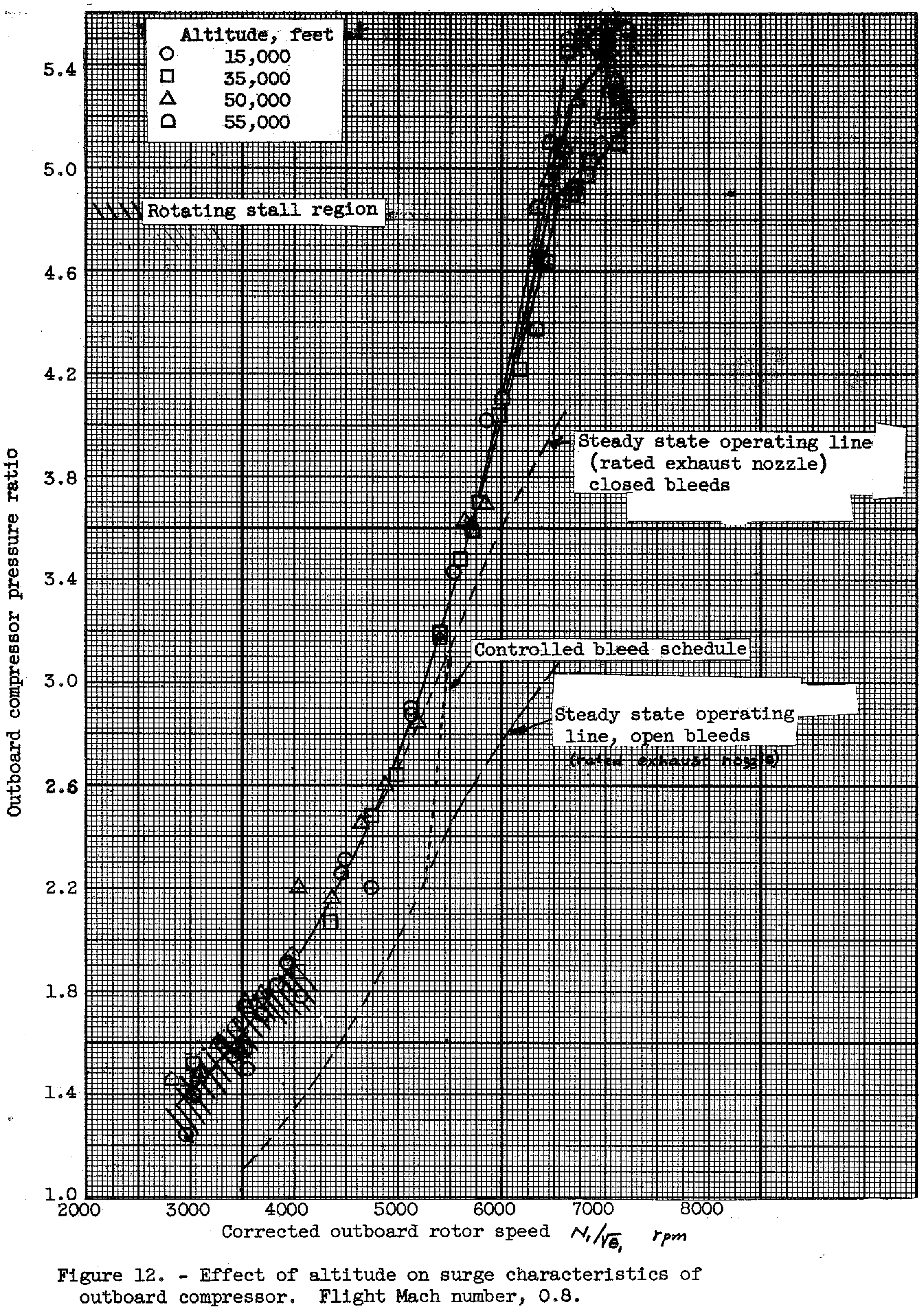

Figure 12. - Effect of altitude on surge characteristics of outboard compressor. Flight Mach number, 0.8.

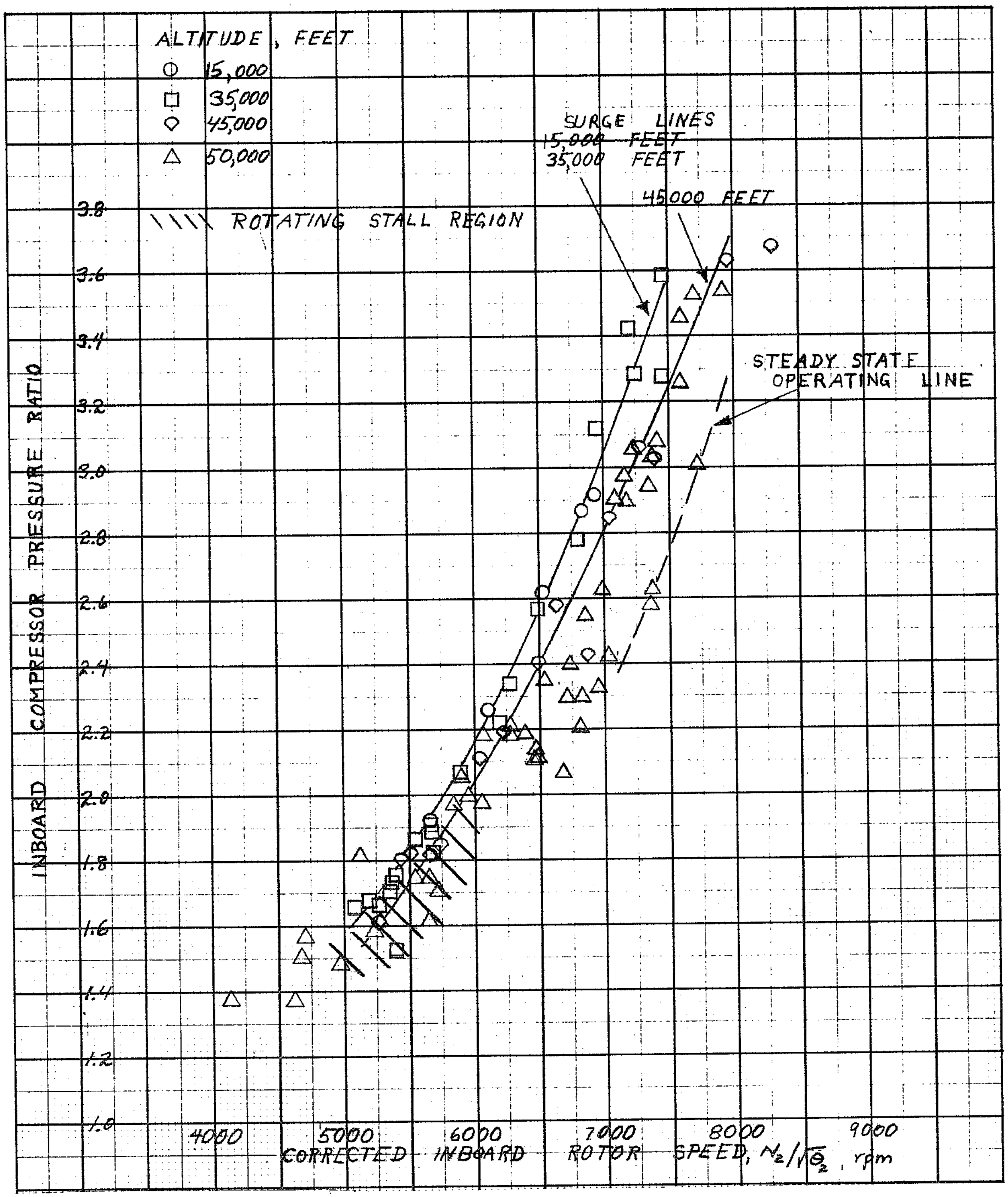

Figure 13. - Effect of altitude on surge characteristics of inboard compressor. Flight Mach number, 0.8.

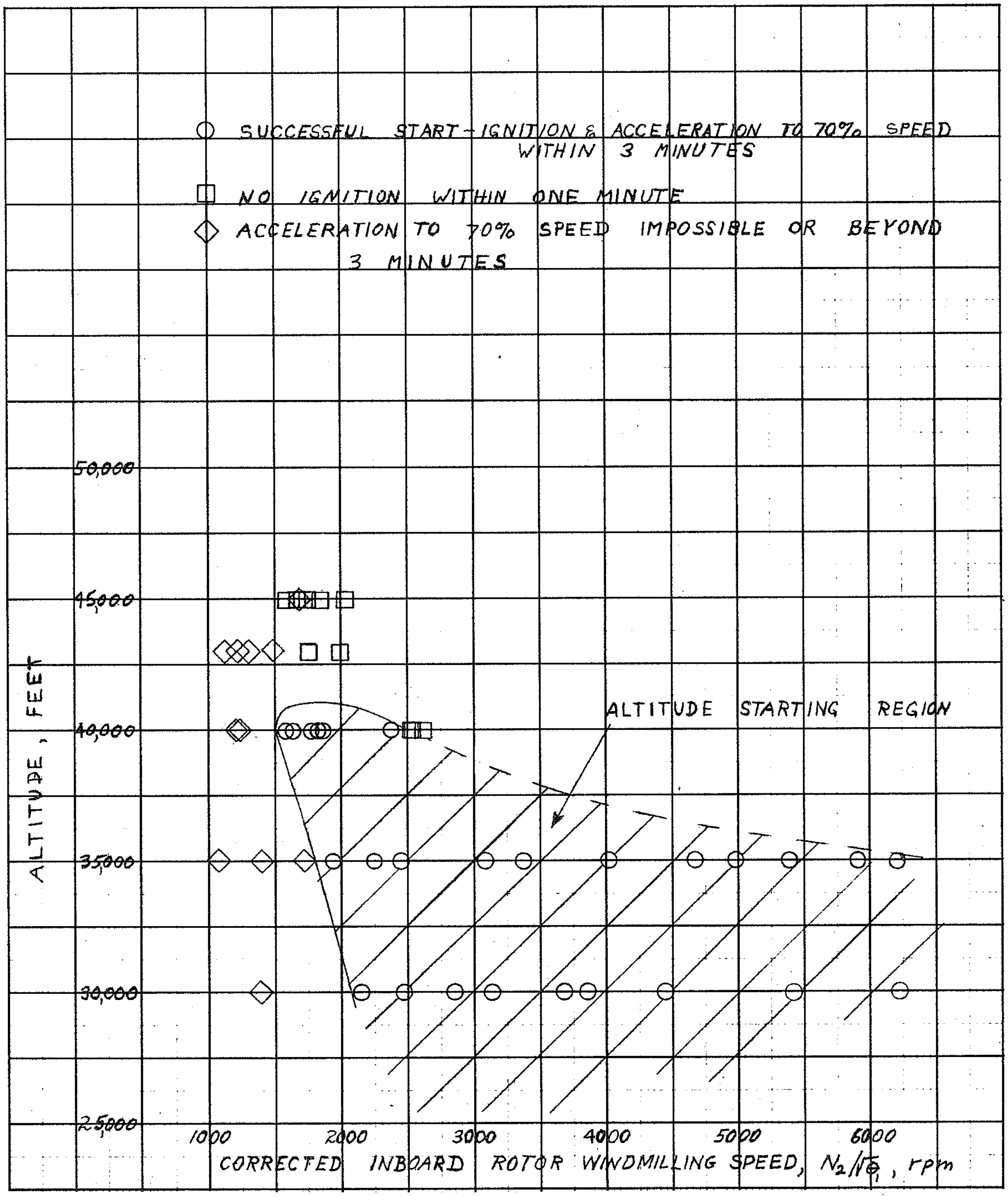

Figure 14. - Effect of altitude on engine starting characteristics.

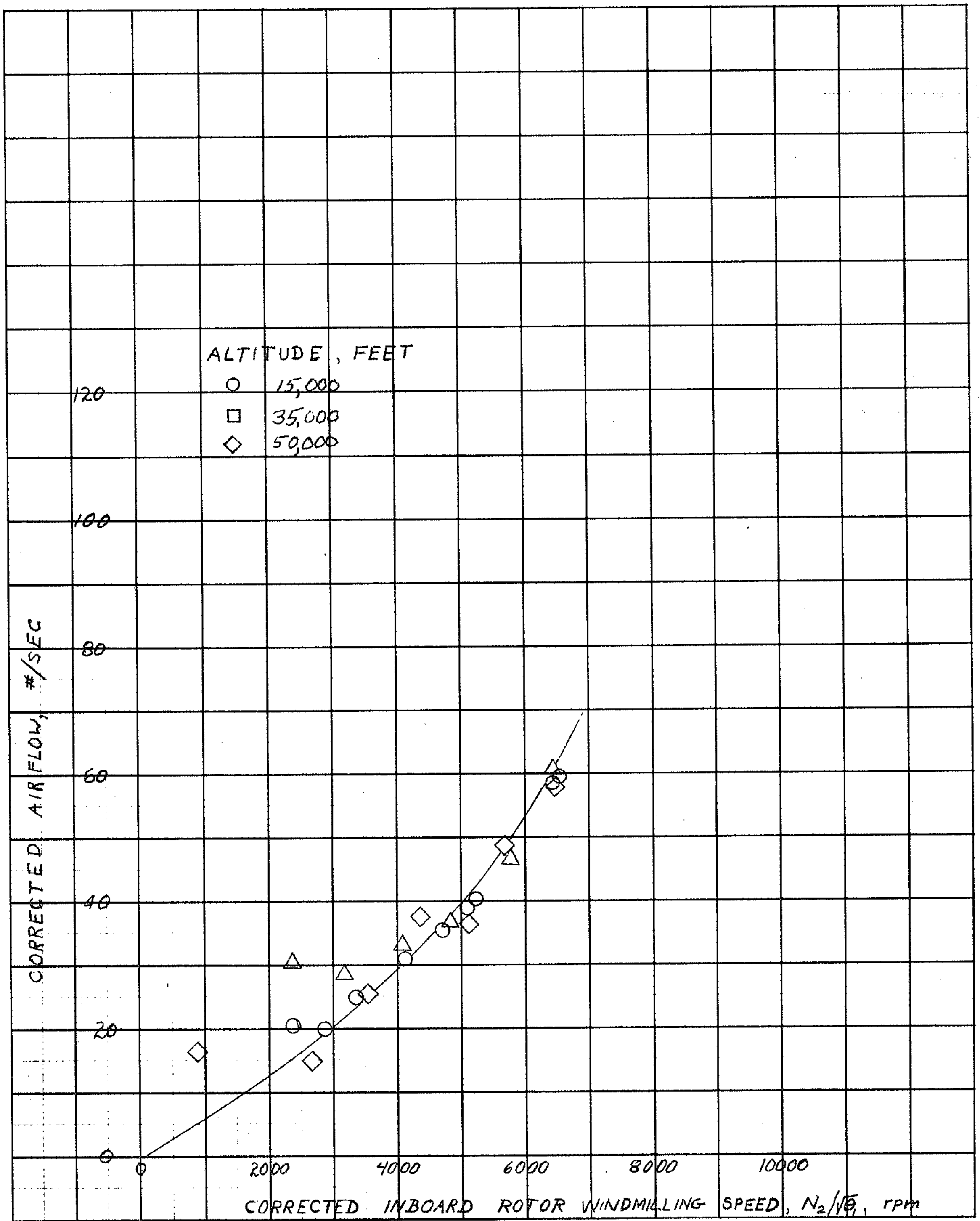

Figure 15. - Variation of windmilling engine air flow with inboard rotor speed.

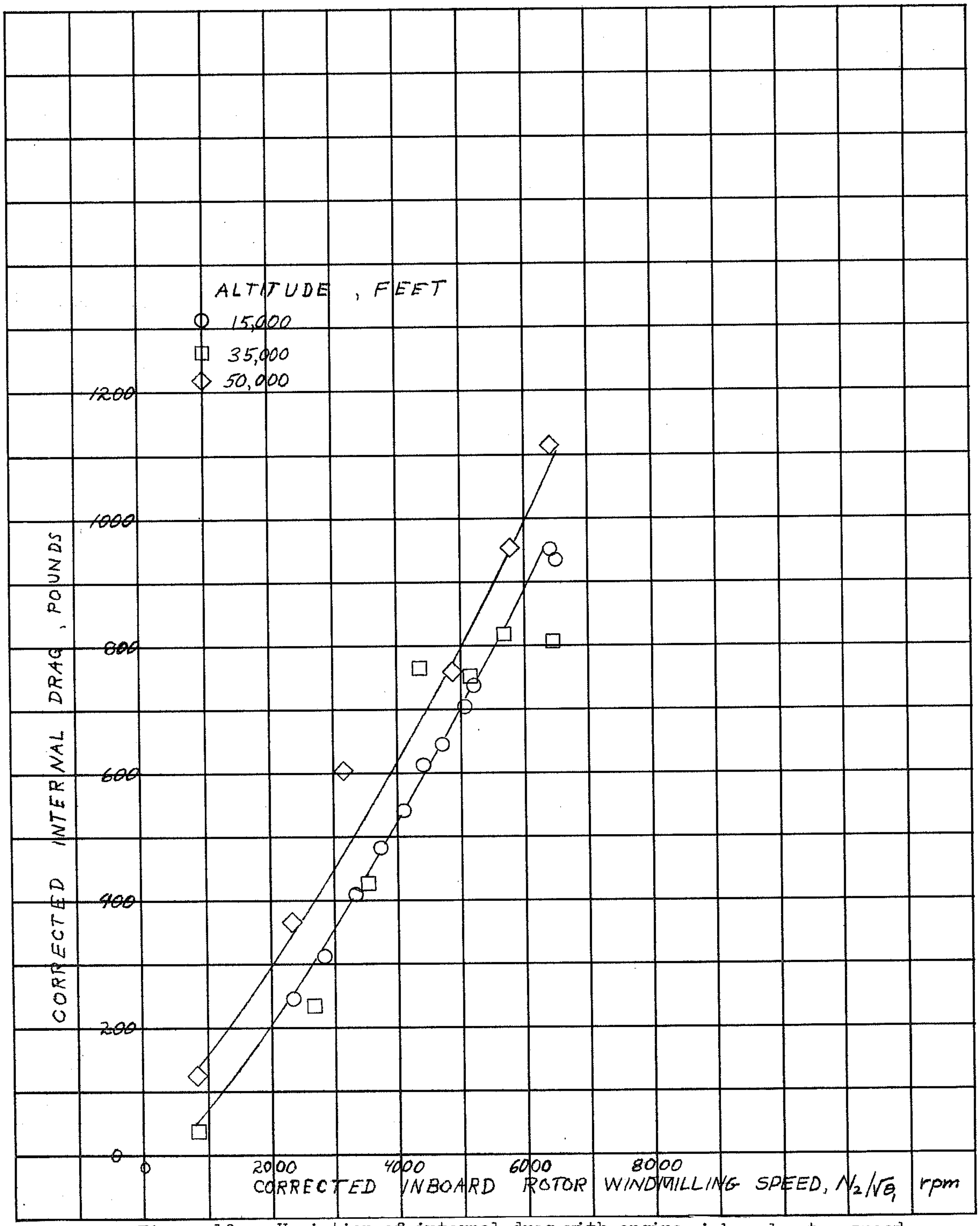

Figure 16. - Variation of internal drag with engine inboard rotor speed.

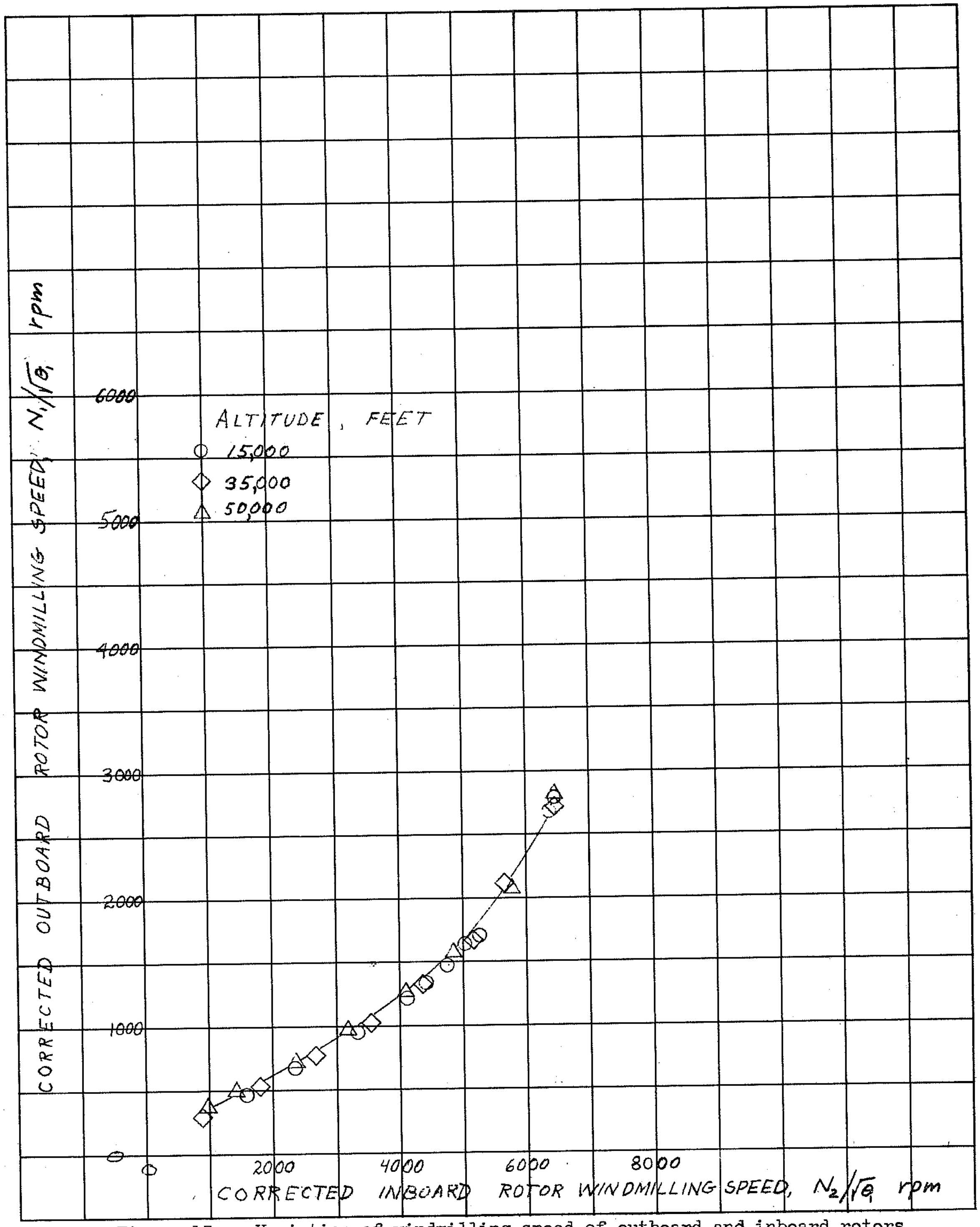

Figure 17. - Variation of windmilling speed of outboard and inboard rotors.

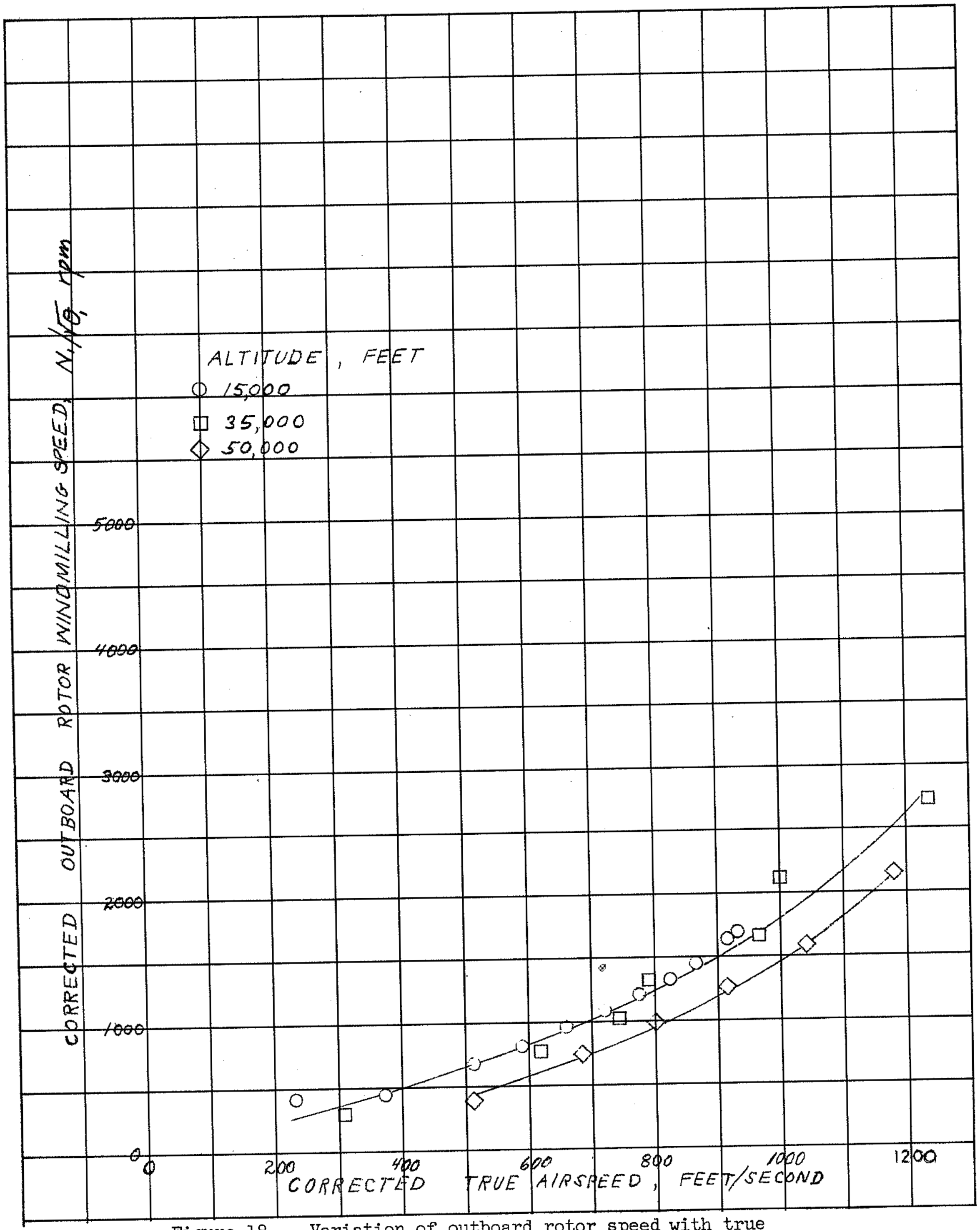

Figure 18. - Variation of outboard rotor speed with true air speed.

PRELIMINARY ALTITUDE OPERATIONAL CHARACTERISTICS OF A J57-P1 TURBOJET ENGINE

Lewis E. Wallner
Lewis E. Wallner
Aeronautical Research Scientist
Propulsion Systems

Martin J. Saari
Martin J. Saari
Aeronautical Research Scientist
Propulsion Systems

Approved:

H. Dean Wilsted
H. Dean Wilsted
Aeronautical Research Scientist
Propulsion Systems

Bruce T. Lundin
Bruce T. Lundin
Chief
Engine Research Division

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Wallner, Lewis E., and Saari, Martin J.

Abstract

The operational characteristics of a J57-P1 turbojet engine have been investigated at altitudes between 15,000 and 66,000 feet in the Lewis altitude wind tunnel. Included in this study is a discussion of fuel nozzle coking, the altitude operating limits with and without the standard engine control, the compressor surge characteristics, and the engine starting and windmilling characteristics.

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