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# RESEARCH MEMORANDUM

for the

Air Research and Development Command, U. S. Air Force

## SOME ALTITUDE OPERATIONAL CHARACTERISTICS OF A PROTOTYPE IROQUOIS TURBOJET ENGINE

COORD. NO. AF-P-6

By Daniel J. Peters and John E. McAulay

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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# SOME ALTITUDE OPERATIONAL CHARACTERISTICS OF A PROTOTYPE IROQUOIS TURBOJET ENGINE*

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## SUMMARY

An investigation of the early developmental Iroquois turbojet engine was conducted in an altitude test chamber. As a part of the overall investigation, the following information was obtained: the engine steady-state windmilling characteristics, engine altitude-ignition limits, high-engine-speed altitude reignition characteristics after simulated combustor blowout, and information pertaining to engine operation at relatively high engine-inlet temperatures.

The steady-state corrected parameters of windmilling drag, rotor speeds, and airflow approach maximum values at a flight Mach number between 1.6 and 1.8. Decreasing the exhaust-nozzle area at a constant flight Mach number results in lower values of corrected rotor windmilling speeds, airflow, and drag. Engine altitude-ignition limits with the standard spark ignition system were markedly affected by variations in exhaust-nozzle area, compressor discharge bleeds, inlet-air temperature, and flight Mach number. With the aid of oxygen enrichment, successful ignition was obtained with all engine variables up to an altitude of 63,000 feet, which was the maximum altitude obtainable with the facility. The investigation of high-speed altitude reignition characteristics demonstrated that reignition of the engine is possible after a simulated combustor blowout. After 64 minutes of continuous engine operation, with inlet temperatures between 235° and 338° F, no operating difficulties or damage to the engine was observed.

## INTRODUCTION

An investigation of the performance and operating characteristics of an early developmental Iroquois twin-spool turbojet engine has been conducted in an NACA Lewis altitude test chamber at the request of the Air Research and Development Command, U.S. Air Force. A discussion of the engine performance and some of the operating characteristics influencing engine performance is presented in reference 1. The engine steady-state windmilling characteristics, ignition characteristics at altitude

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* Title, Unclassified.

windmilling conditions, high-speed altitude reignition characteristics, and information relative to engine operation at relatively high inlet temperatures, all obtained as a part of the over-all investigation, are presented herein.

Steady-state windmilling data were obtained over a range of flight Mach numbers from 0.48 to 1.72 at altitudes of 35,000 and 50,000 feet and are presented in terms of rotor speeds, airflow, compressor pressure ratio, and windmilling drag. Engine ignition characteristics at altitude windmilling conditions were investigated over a range of flight Mach numbers from 0.5 to 1.5; the altitude ignition limits for the spark ignition system with and without an oxygen-boost system are presented. A number of high-engine-speed reignitions were attempted; with the engine operating at near-rated conditions, the fuel flow and ignition were turned off to simulate a combustor blowout, which might occur during armament firing, as discussed in reference 2. After various delay times following fuel cut-off, attempts were made to reignite the engine. A summary of this investigation is presented herein. Finally, a time history is presented for engine-inlet temperature, rotor speed, and ambient test-section temperature during operation of the engine at inlet temperatures up to 348°F.

## APPARATUS

### Installation

The installation of an Iroquois engine in a 14-foot-diameter altitude test chamber is shown in figure 1. A forward bulkhead, which incorporates a labyrinth seal around the engine-inlet air duct, provided a means of maintaining a pressure differential across the engine. The engine was mounted on a bedplate supported by flexure plates. Jet thrust was measured with a calibrated null-type thrust cell after accounting for forces due to the pressure differential across the front bulkhead labyrinth seal. The engine-inlet air temperatures and pressures and ambient exhaust pressures were regulated to simulate the desired altitude flight conditions.

### Engine

The prototype Iroquois engines used in this investigation have a sea-level static thrust rating of approximately 18,000 pounds. The Iroquois engine is a twin-spool turbojet engine that includes a three-state, transonic, axial flow, low-pressure compressor driven by a single-stage turbine; a seven-stage, axial-flow, high-pressure compressor driven by a two-stage turbine; an annular vaporizing combustion chamber; and an afterburner with a fully modulated convergent exhaust nozzle. The maximum low- and high-pressure rotor speeds are 5740 and 7800 rpm, respectively. The rated turbine-discharge gas temperature is 1275° F (1735° R) as indicated by 25 Chromel-Alumel thermocouples located at the turbine discharge. The maximum and minimum exhaust-nozzle areas are 1020 and 649 square inches, respectively. The engine had two high-pressure compressor discharge bleed valves, each 3.75 inches in diameter, which could be opened to permit acceleration of the engine through the part-speed compressor stall region.

The high-energy capacitor-type standard engine ignition system employed two ignitor plugs, firing separately at an average rate of 1.8 sparks per second. Two pilot fuel nozzles, each having two concentric passages, were located in the vicinity of the ignitor plugs. Pilot fuel was fed through the center passage and oxygen (when used) through the annulus. An oxygen boost system was employed for a portion of the engine altitude ignition investigation and a number of the high-engine-speed reignitions. Oxygen was supplied and controlled manually from outside the test section and fed through the annulus of the pilot fuel nozzles at a pressure of 40 pounds per square inch gage.

A main engine-fuel-line purge system was incorporated for the high-engine-speed reignition investigation as an aid toward obtaining complete combustor blowout. When the fuel valve was closed to simulate blowout, pressurized air purged the remaining fuel from the line between the fuel valve and the main engine fuel nozzles.

The steady-state engine windmilling characteristics were evaluated with the AX 103/1 engine and the altitude ignition and high-speed altitude reignition characteristics were evaluated with the AX 102/2A engine; both engines were models of the "original" configurations of reference 1. The high inlet-temperature investigation was evaluated with the AX 102/3C engine, which is termed the "Modified B" configuration in reference 1. This engine (AX 102/3C) incorporated several modifications of engines of the "original" configuration. These modifications included increased turbine-stator areas, variable guide vanes between the low- and high-pressure compressors, and minor compressor changes. Engine AX 102/3C was operated with the compressor bleed valves in the closed position.

## Instrumentation

Instrumentation for measuring steady-state pressures and temperatures was installed at various stations throughout the engine. A schematic cross-section of the engine showing station locations is presented in figure 2. Steady-state engine speeds were recorded with tachometer-generators and electronic pulse counters. Engine fuel flow was measured with a calibrated Potter flowmeter.

Transient recordings of pressures, engine speeds, and turbine-discharge temperature were obtained with a multichannel oscillograph. Pressures were recorded with differential type transducers, the turbine-discharge temperature with a single bare-wire Chromel-Alumel thermocouple, and engine speeds with tachometer generators.

## PROCEDURE

### Steady-State Engine Windmilling Characteristics

Steady-state windmilling data were obtained at simulated altitudes of 35,000 and 50,000 feet over a range of flight Mach numbers from 0.48 to 1.72 with various combinations of exhaust-nozzle areas and compressor bleed valve positions. At each altitude and engine configuration setting, steady-state windmilling data were obtained while increasing the flight Mach number.

### Altitude Ignition Characteristics

Altitude ignition data were obtained from steady-state windmilling conditions with the standard spark ignition system over a range of flight Mach numbers from 0.5 to 1.5. At each desired flight Mach number, the altitude was varied until it was possible to determine an altitude increment above which ignition did not occur and below which ignition was successful. Fuel flow was preset according to the manufacturer's ignition fuel-flow schedule given in figure 3. The fuel valve was then opened and the ignition was energized simultaneously. The time allowed for ignition was 10 seconds, and upon starting, the engine was immediately shut down. The engine acceleration characteristics were not investigated because of the critical stall characteristics of the engine (ref. 1). The altitude ignition characteristics were then re-evaluated to determine the effects of oxygen enrichment to the combustor. Oxygen was introduced in the combustor simultaneously with the opening of the fuel valve and the energizing of the ignition system.

### High-Engine-Speed Reignition Characteristics

A number of high-engine-speed reignitions were attempted at various altitudes and flight Mach numbers. With the engine operating at near-rated speed, the fuel flow was turned off and the fuel manifold purge system was activated to simulate a combustor blowout such as might occur during armament firing (ref. 2). Then, after short periods of delay time (0.20 to 2.04 sec), attempts were made to reignite the engine by energizing the ignition system and by opening the fuel valve with the fuel flow regulated to a reduced value. This reduced fuel-flow value corresponded to the predetermined steady-state fuel-flow rate for the engine speed to which the engine had decayed at the time reignition was initiated. The reason for this fuel-flow reduction was to attempt to avoid compressor stall upon reignition. As it was, stall occurred frequently during the reignition investigation.

Because of the low firing frequency of the ignitor plugs (1.8 sparks/sec), a spark would not always be present at the same instant reignition was initiated, thus further delaying reignition. Consequently, some attempts were made in which fuel was fed through two pilot fuel nozzles to maintain a constant source of ignition when reignition was initiated. However, the nozzles became clogged with carbon from the combustor and this method of obtaining a constant source of ignition was abandoned.

Oxygen was introduced into the combustor through the annulus of the pilot fuel nozzles, during a number of the reignition attempts, as an aid to obtaining successful reignition. The same oxygen boost system was used for evaluating both the altitude ignition characteristics and the high-engine-speed reignition characteristics.

### High Inlet-Temperature Operation

The engine was operated for a period of 64 minutes with engine-inlet temperatures between 235° and 338° F. Of this 64 minutes the engine was operated 34 minutes at 235° F, 22 minutes while the temperature was increased to 338° F, 4 minutes at 338° F, and 4 minutes while reducing the temperature back to 235° F.

## RESULTS AND DISCUSSION

### Steady-State Engine Windmilling Characteristics

The steady-state engine windmilling data are presented in table I and figures 4 to 8. Corrected parameters of engine-windmilling drag and low-pressure rotor windmilling speed are presented in figures 4 and 5, respectively, as functions of flight Mach number. Corrected parameters of high-pressure rotor windmilling speed and engine-inlet airflow and compressor pressure ratio are presented in figures 6, 7, and 8, respectively, as functions of corrected low-pressure rotor windmilling speed. Because these latter parameters more nearly generalize as functions of corrected low-pressure rotor windmilling speed, they are presented in this manner rather than as functions of flight Mach number.

It is estimated from their trends that the corrected parameters of windmilling drag, rotor speeds, and airflow would reach maximum values at a flight Mach number between 1.6 and 1.8, because of choking in the compressor. By decreasing the nozzle area at a constant flight Mach number, the flow is restricted so that corrected engine windmilling speeds are reduced with an accompanying reduction in corrected airflow and drag. In the event of combustor blowout at supersonic Mach numbers, closing the exhaust nozzle results in a reduction in internal engine drag of as much as 35 percent.

## Altitude Ignition Characteristics

The engine altitude ignition characteristics with and without oxygen enrichment are summarized in figure 9 for various combinations of exhaust-nozzle areas and compressor bleeds and for two engine-inlet air temperatures. Altitude ignition with the standard spark ignition system was markedly affected by variations in flight Mach number, exhaust-nozzle area, compressor discharge bleed, and inlet temperature. With the aid of oxygen enrichment, successful ignition was obtained up to an altitude of 63,000 feet, which was the maximum altitude obtainable with the facility. The engine acceleration characteristics were not investigated because of the critical stall characteristics of the engine (ref. 1).

## High-Engine-Speed Reignition Characteristics

The high speed reignition characteristics were investigated to determine whether ignition was possible after a simulated combustor blowout. Figure 10 illustrates the change in several engine variables during a representative high-speed reignition. Ignition and fuel were turned off at zero time and a high-pressure rotor speed of 7434 rpm. The initial rise in the curves is the result of the short burst of fuel being purged out of the line. The slight oscillation in the compressor- and turbine-discharge total pressures is caused by a mild stall that occurred because of the additional short burst of fuel. At 1.25 seconds, ignition was turned on along with a fuel flow corresponding to the engine fuel requirements at a high-pressure rotor speed of 6500 rpm. The engine relit at approximately 1.8 seconds as indicated by the sudden increase in compressor-discharge total pressure. The lag in the turbine-discharge total-temperature trace in figure 10 is due to the slow response of the thermocouple used. Table II summarizes the high-speed reignitions that were attempted during this investigation. This investigation was only of a preliminary nature and was conducted primarily to determine whether or not high-speed altitude reignition was feasible.

## High Inlet-Temperature Operation

Figure 11 presents the time history of the high inlet-temperature test and shows the variation of engine-inlet temperature, approximate ambient test section temperature, and high-pressure rotor speed. For a period of time of 64 minutes, the engine was operated at engine inlet temperatures of 235° F (695° R) or higher. Of this 64 minutes, 34 minutes of operation were at a temperature of 235° F, 22 minutes during an increase in the temperature to 338° F, and 4 minutes at a temperature of 338° F. The temperature then was reduced rather quickly. No difficulties were encountered in the operation of the engine during the investigation and no apparent damage resulted from it. Steady-state performance data are presented in reference 1.

## SUMMARY OF RESULTS

From an investigation of the engine steady-state windmilling characteristics, ignition characteristics at altitude windmilling conditions, high-speed altitude reignition characteristics, and high inlet-temperature operation the following results were obtained:

1. The steady-state corrected parameters of windmilling drag, rotor speeds, and airflow approached maximum values at a flight Mach number between 1.6 and 1.8. Decreasing the nozzle area at a constant flight Mach number results in a reduction in corrected rotor speeds, airflow, and drag. In the event of combustor blowout at supersonic Mach numbers, closing the exhaust nozzle will result in a reduction in internal engine drag of as much as 35 percent.

2. Engine altitude ignition limits obtained with the standard spark ignition system were markedly affected by variations in flight Mach number, exhaust-nozzle area, compressor discharge bleeds, and engine-inlet temperature. With the aid of oxygen enrichment, successful ignition was obtained with all engine variables up to an altitude of 63,000 feet, which was the maximum altitude obtainable with the facility.

3. The brief investigation of high-speed reignition characteristics shows that reignition at high speeds is possible after simulating combustor blowout due to armament firing.

4. After 34 minutes of operation with engine-inlet temperatures of 235° F, 22 minutes with temperatures from 235° to 338° F, 4 minutes at 338° F, and 4 minutes from 338° to 235° F no operating difficulties or visual damage to the engine occurred.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, June 30, 1958

## APPENDIX - SYMBOLS

| | |
|---|---|
| $A$ | area, sq in. |
| $D_w$ | windmilling drag, or negative net thrust $D_w = -F_N = F_{JS} - \frac{w_{a_1}}{g} V_1$, lb |
| $F_N$ | net thrust, lb |
| $F_{JS}$ | jet scale thrust measured by null balance thrust cell |
| $g$ | acceleration due to gravity at sea level, 32.172 ft/sec$^2$ |
| $M$ | flight Mach number |
| $N$ | rotor speed, rpm |
| $P$ | total pressure, lb/sq ft abs |
| $p$ | static pressure, lb/sq ft abs |
| $R$ | gas constant for air, 53.3 ft/$^\circ$R |
| $T$ | total temperature, $^\circ$F or $^\circ$R |
| $V$ | velocity, obtained from velocity parameter, $V/\sqrt{gRT}$ (ref. 3) |
| $w$ | weight flow, lb/sec |
| $\delta$ | ratio of absolute total pressure to absolute static pressure of standard NACA atmosphere at sea level |
| $\theta$ | ratio of absolute total temperature to absolute static temperature of standard NACA atmosphere at sea level |

Subscripts:

| | |
|---|---|
| a | air |
| f | fuel |
| HP | high-pressure rotor |
| LP | low-pressure rotor |
| N | nozzle |
| w | windmilling |

| | |
|---|---|
| 0 | free stream |
| 1 | low-pressure compressor inlet |
| 2 | low-pressure compressor discharge |
| 3 | high-pressure compressor discharge |
| 4 | high-pressure turbine inlet |
| 5 | low-pressure turbine inlet |
| 6 | low-pressure turbine discharge |
| 9 | tailpipe |
| 10 | exhaust-nozzle outlet |

## REFERENCES

1. McAulay, John E., and Groesbeck, Donald E.: Investigation of a Prototype Iroquois Turbojet Engine in an Altitude Test Chamber. NACA RM SE58E26, 1958.

2. Anon.: Proceedings of Symposium on Effects of Armament Firing Upon Turbojet Engines. NOTS 1850, Naval Ord. Test Station, China Lake (Calif.), 1957.

3. Turner, L. Richard, Addie, Albert N., and Zimmerman, Richard H.: Charts for the Analysis of One-Dimensional Steady Compressible Flow. NACA TN 1419, 1948.

TABLE I. - STEADY-STATE ENGINE WINDMILLING DATA

| Simulated altitude, ft | Simulated flight Mach number, $M_0$ | Bleed valves | Exhaust nozzle | Corrected low-pressure rotor speed, $\frac{N_{LP}}{\sqrt{\theta_1}}$, rpm | Corrected high-pressure rotor speed, $\frac{N_{HP}}{\sqrt{\theta_1}}$, rpm | Corrected engine-inlet airflow, $\frac{w_{a,1}\sqrt{\theta_1}}{\delta_1}$, pps | Corrected engine windmilling drag, $D_w/\delta_1$, lb | Low-pressure compressor-inlet total pressure, $P_1$, lb/sq ft abs | Low-pressure compressor-discharge total pressure, $P_2$, lb/sq ft abs | High-pressure compressor-discharge total pressure, $P_3$, lb/sq ft abs | Turbine-discharge total pressure, $P_6$, lb/sq ft abs | Exhaust-nozzle exit total pressure, $P_9$, lb/sq ft abs | Altitude static pressure, $P_0$, lb/sq ft abs | Low-pressure compressor inlet total temperature, $T_1$, °R | Compressor pressure ratio, $P_3/P_1$ | Turbine-inlet total pressure, $P_4$, lb/sq ft abs | Exhaust nozzle outlet static pressure, $P_{10}$, lb/sq ft abs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35,000 | 1.46 | Open | Closed | 2460 | 4460 | 101.8 | 1738 | 1769 | 2065 | 2877 | 856 | 828 | 509 | 474 | 1.626 | 2371 | 507 |
| | .89 | | | 1035 | 2762 | 58.0 | 1409 | 837 | 858 | 811 | 527 | 524 | 501 | 474 | .9687 | 714 | 499 |
| | .69 | | | 715 | 2042 | 45.6 | 1089 | 688 | 694 | 632 | 512 | 510 | 502 | 475 | .9194 | 586 | 501 |
| | .48 | | | 475 | 1402 | 34.4 | 750 | 589 | 590 | 552 | 506 | 506 | 503 | 475 | .9371 | 533 | 502 |
| | .48 | Closed | | 496 | 1431 | 32.8 | 738 | 587 | 588 | 558 | 506 | 506 | 502 | 475 | .9504 | 538 | 502 |
| | .69 | | | 765 | 2135 | 47.1 | 1051 | 689 | 697 | 651 | 514 | 512 | 501 | 474 | .9443 | 601 | 501 |
| | .89 | | | 1138 | 2933 | 60.4 | 1343 | 843 | 869 | 874 | 536 | 533 | 503 | 473 | 1.037 | 762 | 503 |
| | 1.43 | | | 2561 | 4552 | 104.9 | 1514 | 1674 | 1977 | 2912 | 867 | 839 | 504 | 472 | 1.740 | 2416 | 502 |
| | .49 | Open | Open | 488 | 1434 | 31.8 | 749 | 591 | 592 | 553 | 504 | 503 | 502 | 475 | .9367 | 534 | 502 |
| | .69 | | | 730 | 2079 | 45.0 | 1147 | 689 | 695 | 630 | 506 | 504 | 501 | 475 | .9156 | 585 | 501 |
| | .89 | | | 1104 | 2902 | 61.9 | 1641 | 838 | 862 | 832 | 514 | 510 | 503 | 472 | .9926 | 725 | 503 |
| | 1.24 | | | 2715 | 4514 | 103.3 | 2675 | 1283 | 1525 | 2141 | 587 | 562 | 503 | 471 | 1.669 | 1766 | 503 |
| | .49 | Closed | | 502 | 1451 | 32.8 | 768 | 586 | 587 | 556 | 503 | 503 | 502 | 475 | .9500 | 536 | 501 |
| | .69 | | | 788 | 2191 | 48.6 | 1215 | 688 | 697 | 654 | 506 | 505 | 501 | 475 | .9497 | 601 | 501 |
| | .89 | | | 1253 | 2136 | 66.3 | 1685 | 842 | 875 | 913 | 517 | 513 | 503 | 471 | 1.084 | 785 | 502 |
| | 1.20 | | | 2930 | 4627 | 106.9 | 2541 | 1215 | 1478 | 2225 | 593 | 566 | 502 | 471 | 1.831 | 1845 | 501 |
| 50,000 | 1.53 | Open | Open | 3331 | 4591 | 109.8 | 2800 | 943 | 1204 | 1721 | 384 | 325 | 246 | 459 | 1.826 | 1402 | 245 |
| | .69 | | | 742 | 2098 | 51.8 | 1545 | 334 | 336 | 304 | 244 | 243 | 243 | 485 | .9122 | 281 | 242 |
| | .79 | | | 898 | 2458 | 52.7 | 1543 | 370 | 376 | 343 | 248 | 247 | 246 | 486 | .9271 | 308 | 244 |
| | .88 | | | 1082 | 2843 | 58.3 | 1741 | 409 | 419 | 398 | 251 | 248 | 246 | 484 | .9734 | 345 | 244 |
| | .99 | | | 1381 | 3367 | 68.8 | 2060 | 461 | 483 | 507 | 254 | 251 | 245 | 483 | 1.099 | 425 | 244 |
| | 1.09 | | | 1786 | 3875 | 80.5 | 2352 | 517 | 560 | 665 | 261 | 256 | 244 | 488 | 1.285 | 549 | 243 |
| | 1.19 | | | 2380 | 4342 | 98.7 | 2674 | 586 | 676 | 917 | 276 | 267 | 246 | 485 | 1.565 | 750 | 244 |
| | 1.29 | | | 2875 | 4517 | 104.6 | 2799 | 668 | 807 | 1132 | 293 | 278 | 245 | 480 | 1.694 | 926 | 244 |
| | 1.72 | | Closed | 2653 | 4500 | 103.9 | ---- | 1228 | 1456 | 2047 | 572 | 550 | 241 | 478 | 1.666 | 1689 | 240 |
| | .68 | | | 715 | 2032 | 49.7 | 1307 | 336 | 339 | 309 | 250 | 249 | 246 | 481 | .9173 | 287 | 245 |
| | .89 | | | 1012 | 2710 | 57.6 | 1558 | 410 | 418 | 359 | 256 | 255 | 244 | 480 | .9490 | 342 | 243 |
| | 1.09 | | | 1472 | 3501 | 71.1 | 1813 | 515 | 543 | 586 | 277 | 273 | 244 | 480 | 1.137 | 489 | 243 |
| | 1.30 | | | 2081 | 4160 | 90.2 | 1866 | 673 | 750 | 961 | 329 | 321 | 242 | 478 | 1.429 | 789 | 241 |
| | 1.30 | Closed | | 2283 | 4334 | 95.9 | 1740 | 673 | 767 | 1072 | 350 | 340 | 244 | 476 | 1.593 | 885 | 243 |
| | 1.10 | | | 1688 | 3763 | 78.6 | 1730 | 517 | 555 | 664 | 286 | 281 | 243 | 475 | 1.285 | 553 | 241 |
| | .88 | | | 1114 | 2877 | 62.8 | 1627 | 411 | 423 | 419 | 261 | 259 | 247 | 475 | 1.020 | 365 | 246 |
| | .69 | | | 757 | 2108 | 45.5 | 1183 | 336 | 339 | 313 | 249 | 249 | 244 | 476 | .9316 | 289 | 244 |
| | .69 | | Open | 784 | 2173 | 44.4 | 1251 | 338 | 341 | 316 | 247 | 246 | 245 | 476 | .9351 | 290 | 244 |
| | .90 | | | 1189 | 3020 | 61.6 | 1762 | 409 | 422 | 428 | 250 | 248 | 243 | 476 | 1.046 | 367 | 243 |
| | 1.09 | | | 2095 | 4176 | 89.2 | 2356 | 516 | 576 | 765 | 267 | 261 | 245 | 475 | 1.483 | 633 | 244 |
| | 1.30 | | | 3222 | 4649 | 109.7 | 2698 | 672 | 844 | 1262 | 306 | 286 | 244 | 477 | 1.880 | 1041 | 243 |

TABLE II. - HIGH-ENGINE-SPEED REIGNITION DATA

| Ignition system | Simulated altitude, ft | Simulated flight Mach number, $M_0$ | Engine-inlet total temperature, $T_1$, $^{\circ}F$ | Exhaust-nozzle area, $A_N$, sq in. | Compressor bleed valves | Initial high pressure rotor speed, $N_{NP}$, rpm | High pressure rotor speed corresponding to fuel flow preset for reignition | High pressure rotor speed (at reignition), $N_{HP}$, rpm | Delay time, sec | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| None | 25,000 | 0.9 | 115 | 692 | Closed | 7514 | 7000 | 7110 | 0.51 | Reignition |
| | 25,000 | .9 | 260 | 678 | ↓ | 7527 | 6690 | ---- | .75 | No reignition |
| | 25,000 | .9 | 260 | 678 | ↓ | 7578 | 6520 | ---- | 1.00 | No reignition |
| | 35,000 | .9 | 122 | 682 | ↓ | 7524 | 7190 | 7300 | .20 | Reignition |
| Standard ignition system | 35,000 | .9 | 107 | 683 | ↓ | 7713 | 6420 | 6350 | .65 | Reignition |
| | 35,000 | .9 | 107 | 683 | ↓ | 7757 | 6412 | 5700 | .65 | ↓ |
| | 50,000 | .9 | 104 | 663 | Open | 7485 | 6390 | 6540 | .65 | ↓ |
| | 50,000 | .9 | 110 | 684 | ↓ | 7434 | 6400 | 6480 | 1.25 | ↓ |
| | 55,000 | .9 | 108 | 684 | ↓ | 6990 | 6200 | 6620 | .65 | ↓ |
| | 56,000 | 1.55 | 110 | 680 | ↓ | 7530 | 6250 | 6500 | 1.21 | ↓ |
| | 56,000 | 1.55 | 110 | 673 | ↓ | 7450 | 6453 | ---- | 2.05 | No reignition |
| Standard ignition system and oxygen enrichment | 50,000 | .9 | 104 | 663 | ↓ | 7420 | 6408 | 6650 | .65 | Reignition |
| | 50,000 | .9 | 110 | 683 | ↓ | 7455 | 6408 | 6600 | 1.25 | ↓ |
| | 55,000 | .9 | 108 | 684 | ↓ | 6970 | 6270 | 6500 | .65 | ↓ |
| Pilot fuel | 35,000 | .9 | --- | 683 | Closed | 7800 | 7590 | ---- | .60 | No reignition |
| | 45,000 | 1.0 | --- | 679 | Closed | 7771 | 6600 | ---- | 1.11 | No reignition |

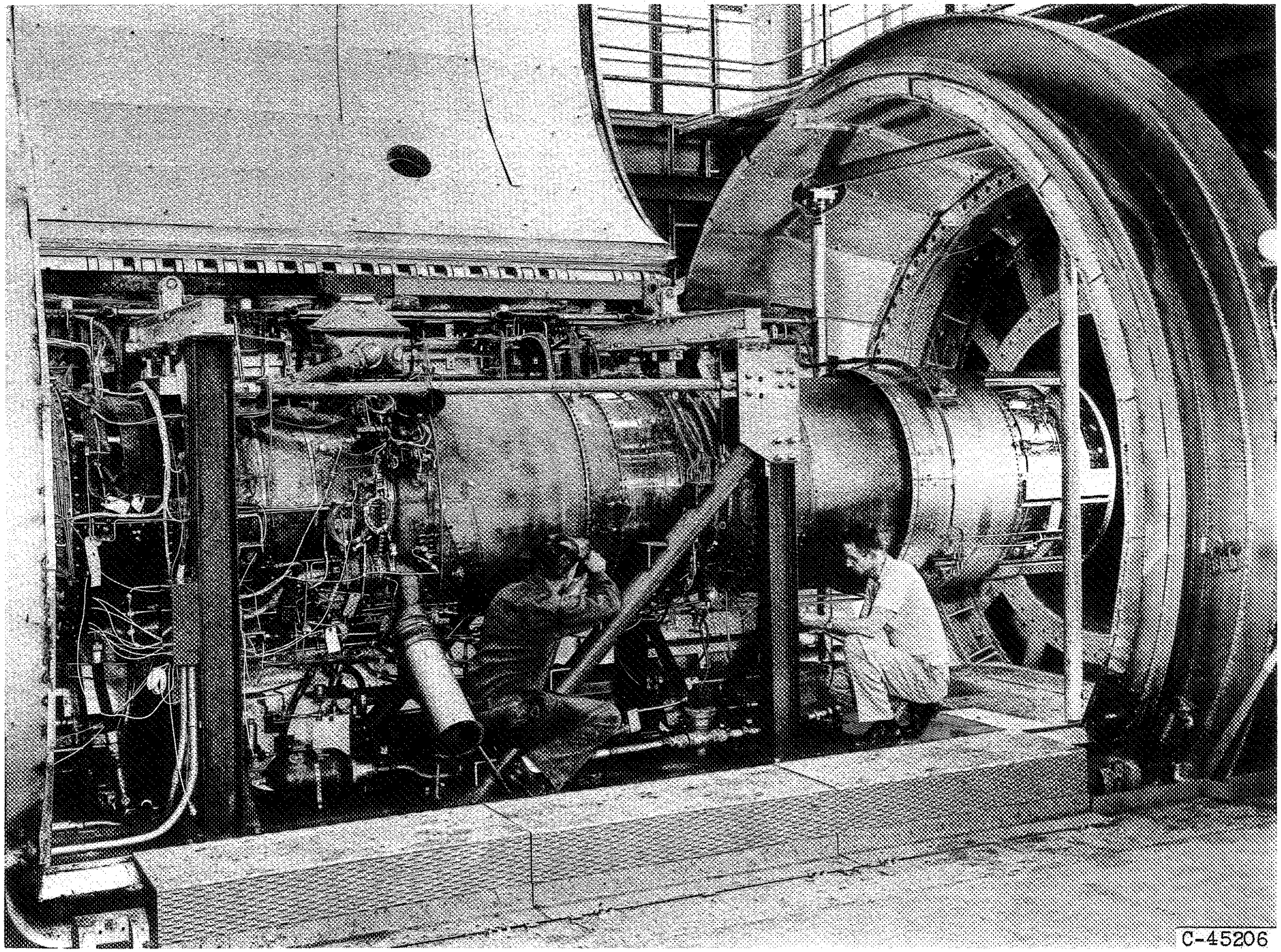
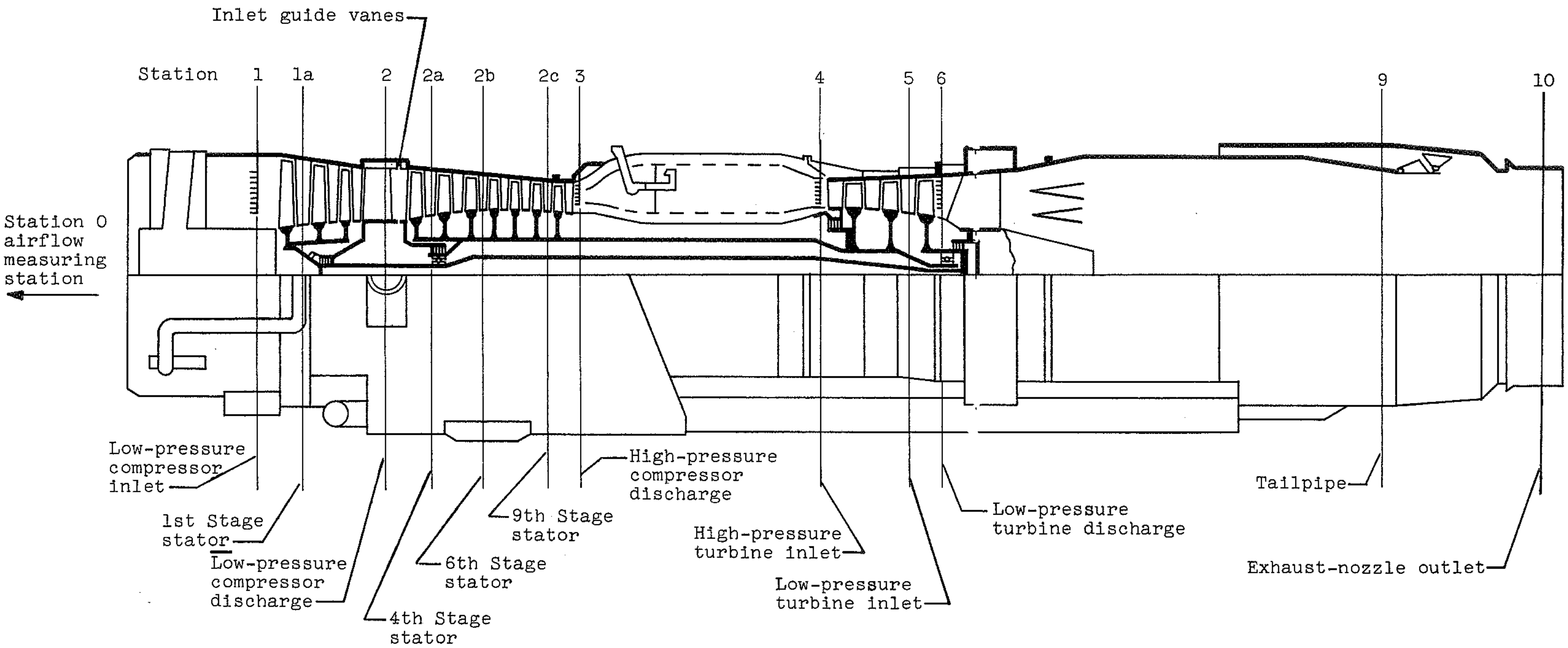


Figure 1. - Iroquois turbojet engine installed in altitude test chamber.



| Station | Measurements | | |
|---|---|---|---|
| | Total pressure | Static pressure | Total temperature |
| 0 | 20 | 8 | |
| 1 | 20 | 4 | 10 |
| 2 | 20 | 4 | 20 |
| 3 | 20 | | 20 |
| 4 | 10 | | |
| 5 | 10 | | |
| 6 | 25 | | 25 |
| 9 | 20 | 4 | 20 |
| 10 | | 4 | |

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Figure 2. - Schematic diagram of Iroquois turbojet engine showing steady-state instrumentation stations.

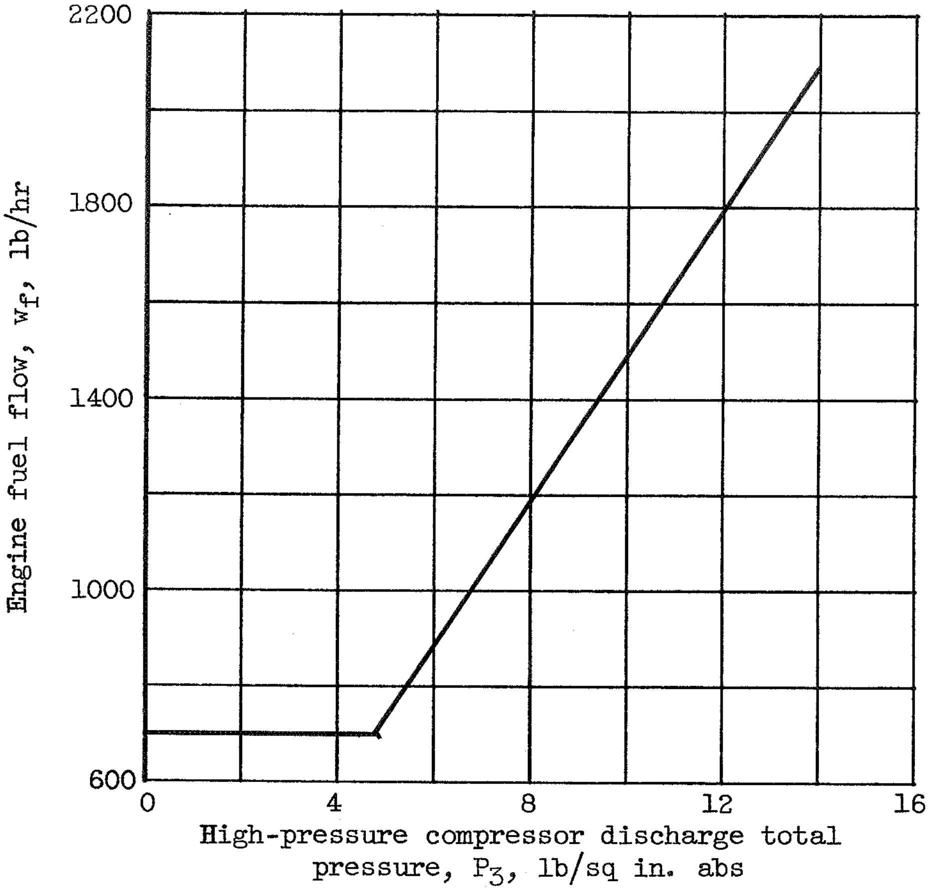


Figure 3. - Fuel flow schedule for altitude ignition investigation.

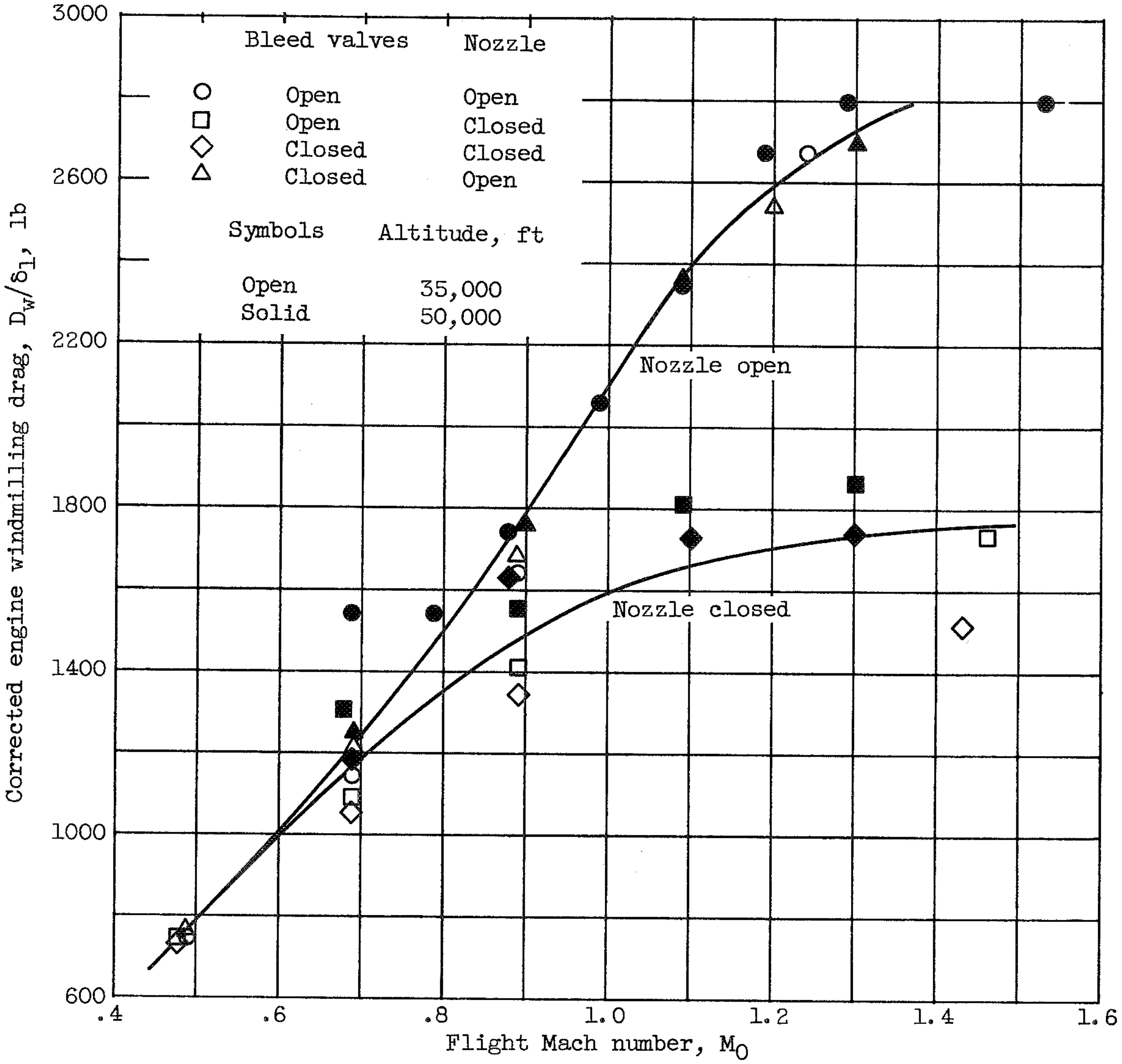


Figure 4. - Variation of corrected engine windmilling drag with flight Mach number.

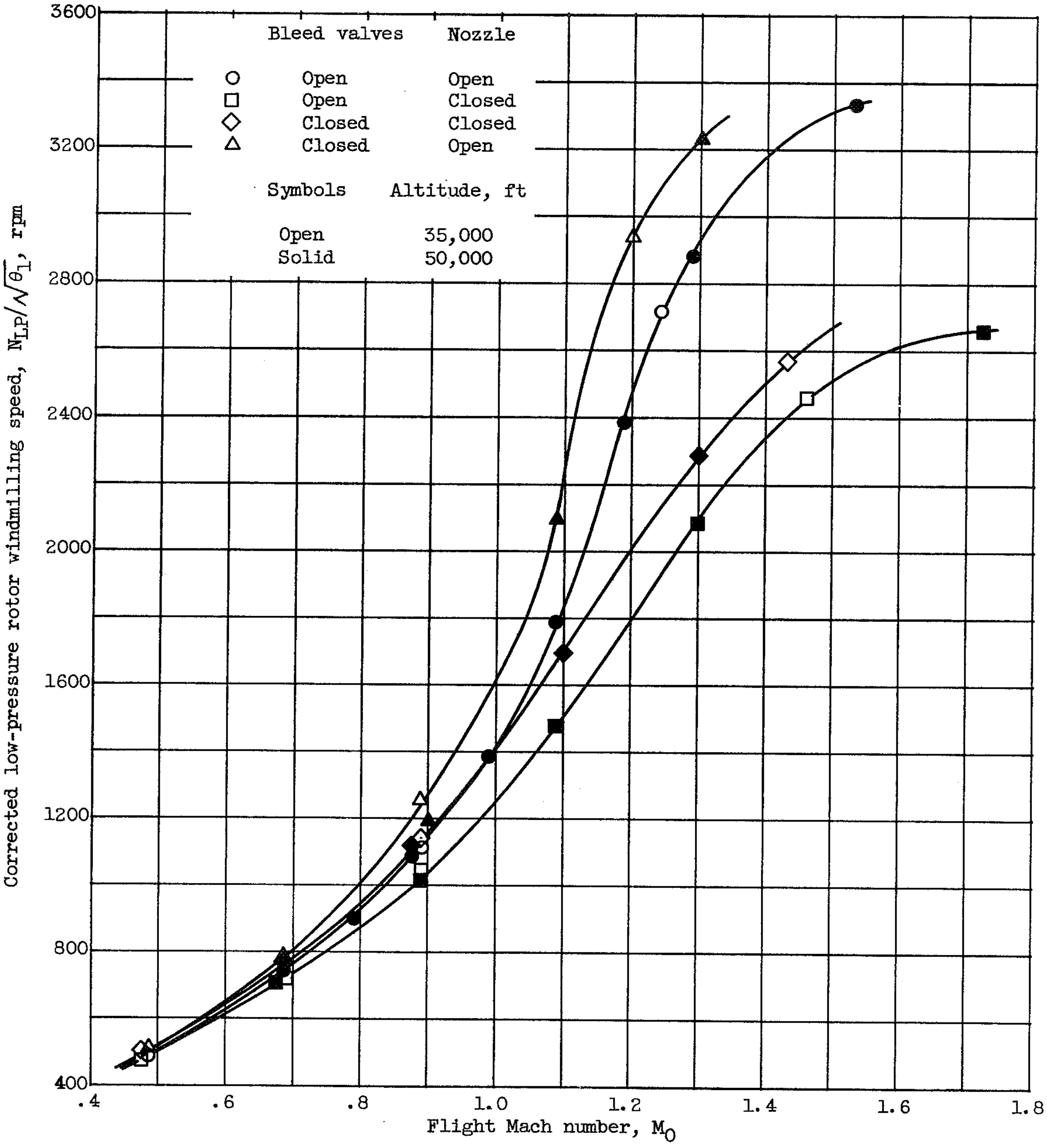


Figure 5. - Variation of corrected low-pressure rotor windmilling speed with flight Mach number.

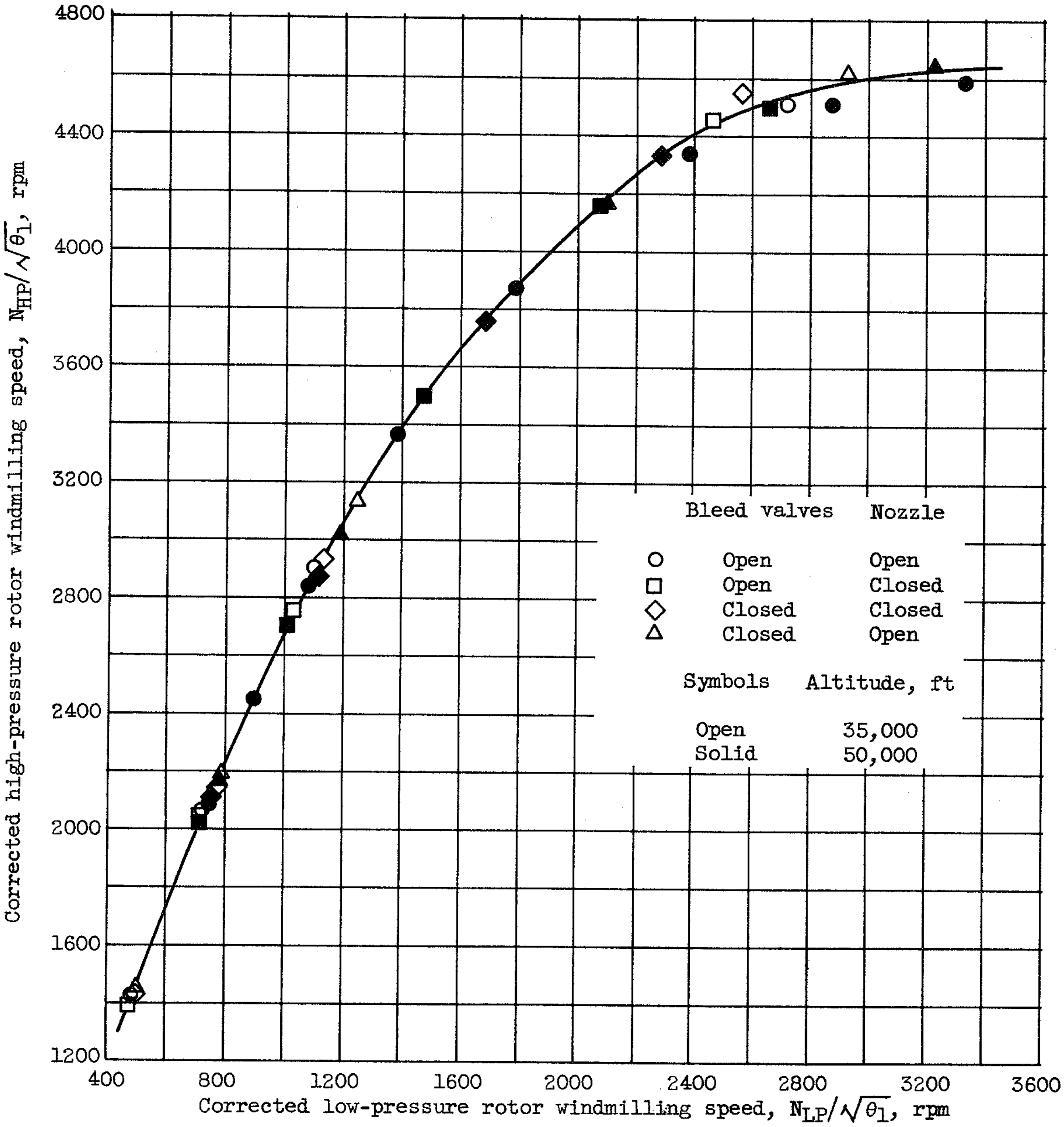


Figure 6. - Variation of corrected high-pressure rotor windmilling speed with corrected low-pressure rotor windmilling speed.

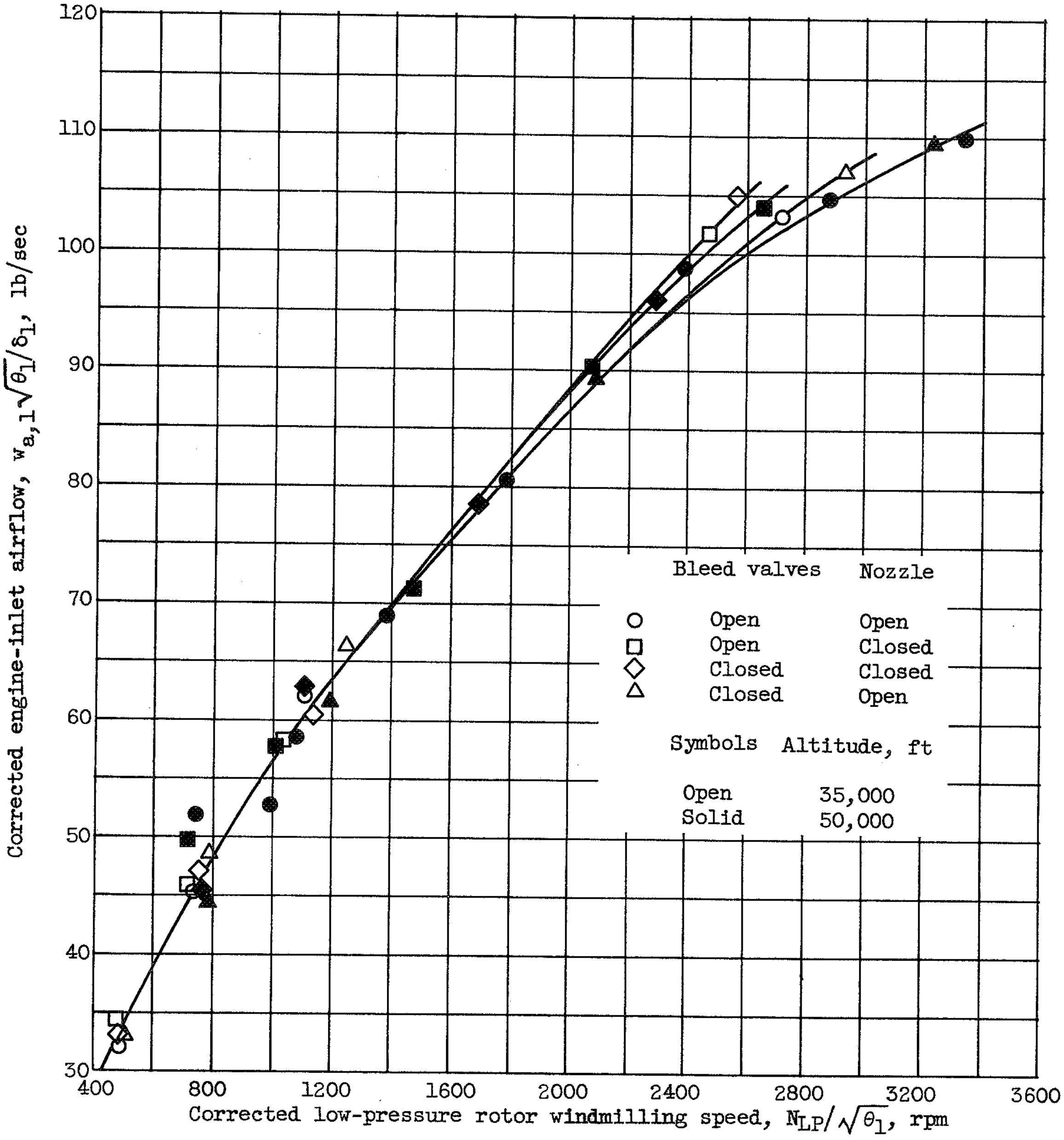


Figure 7. - Variation of corrected engine-inlet airflow with corrected low-pressure rotor windmilling speed.

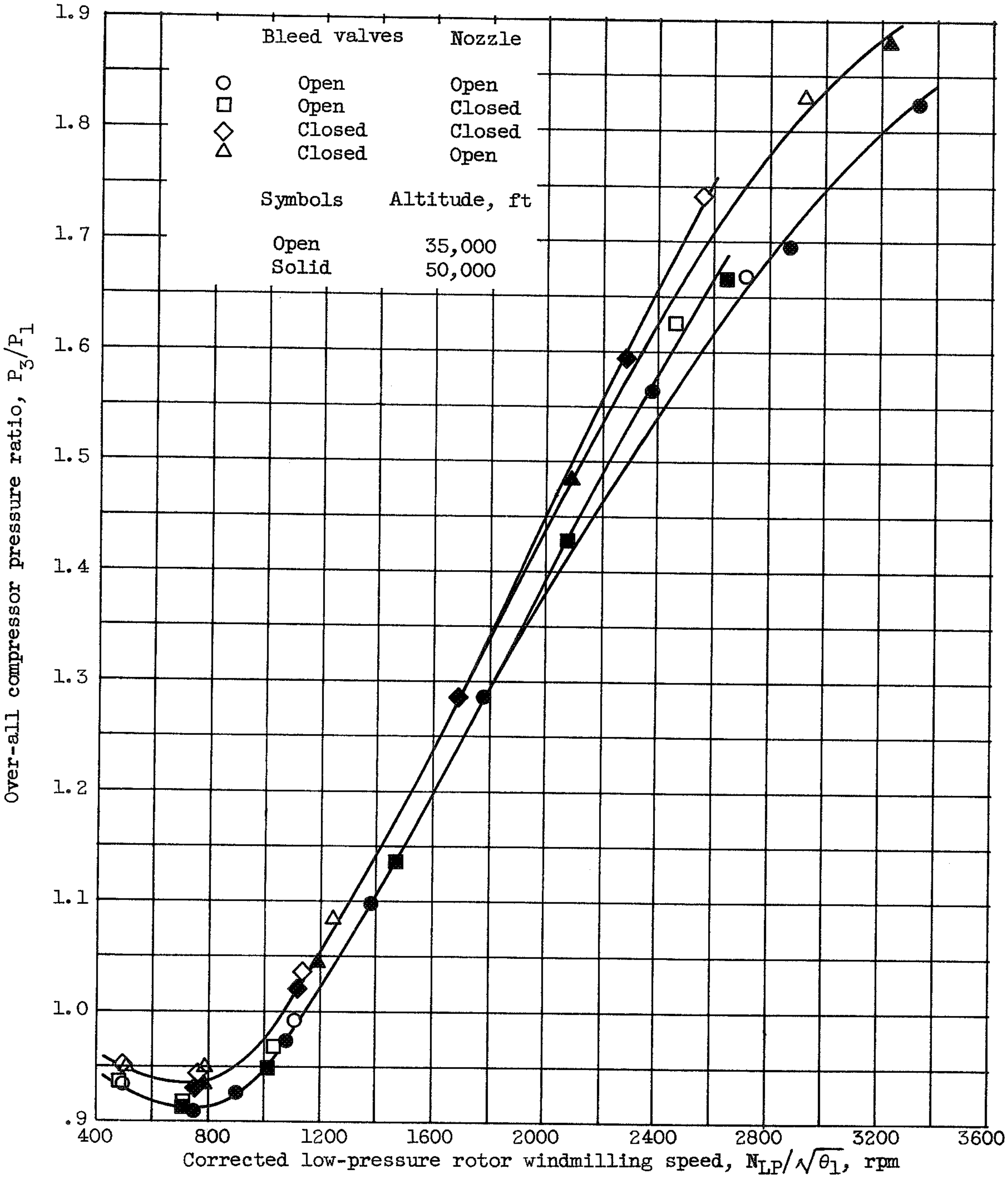
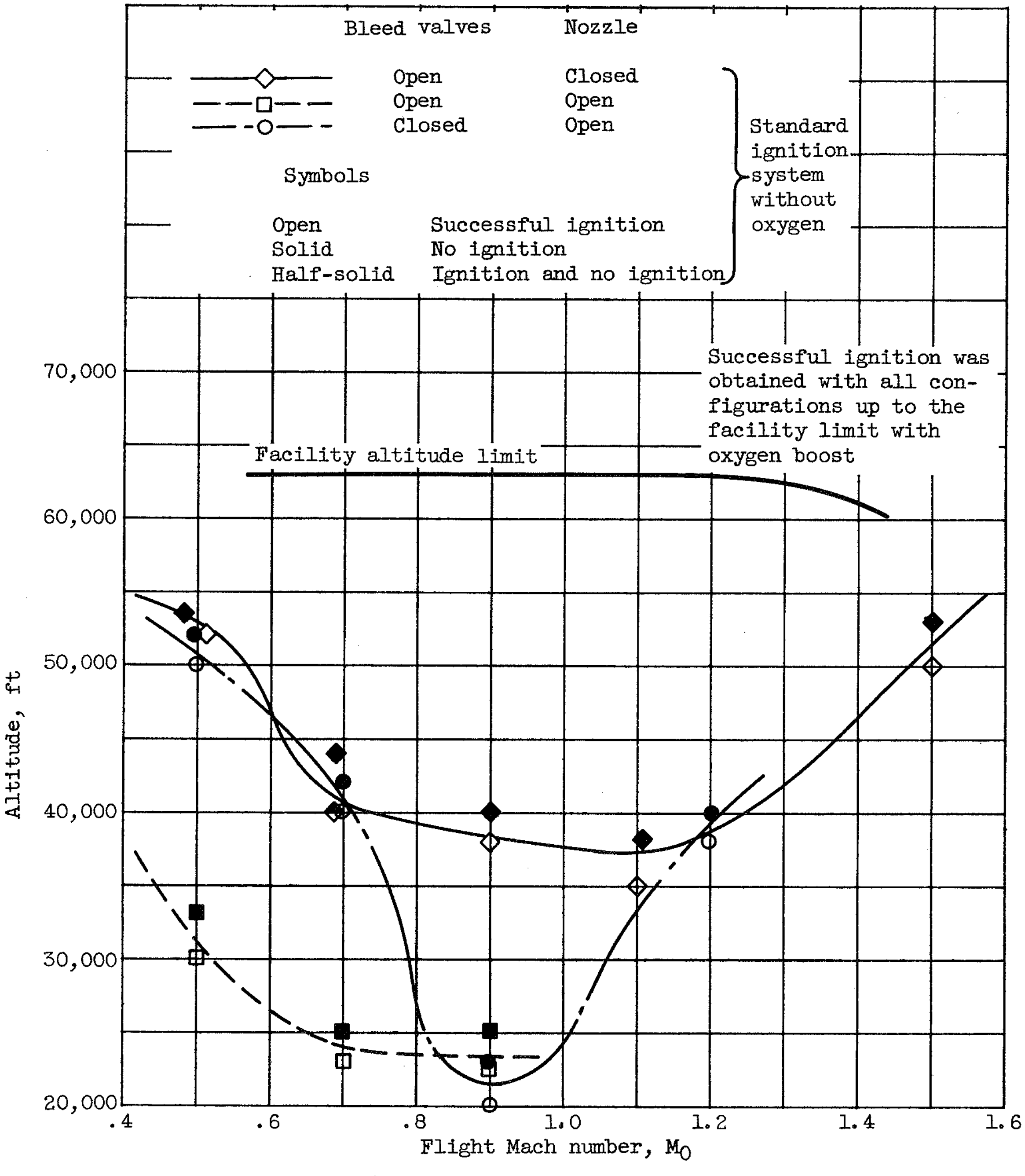
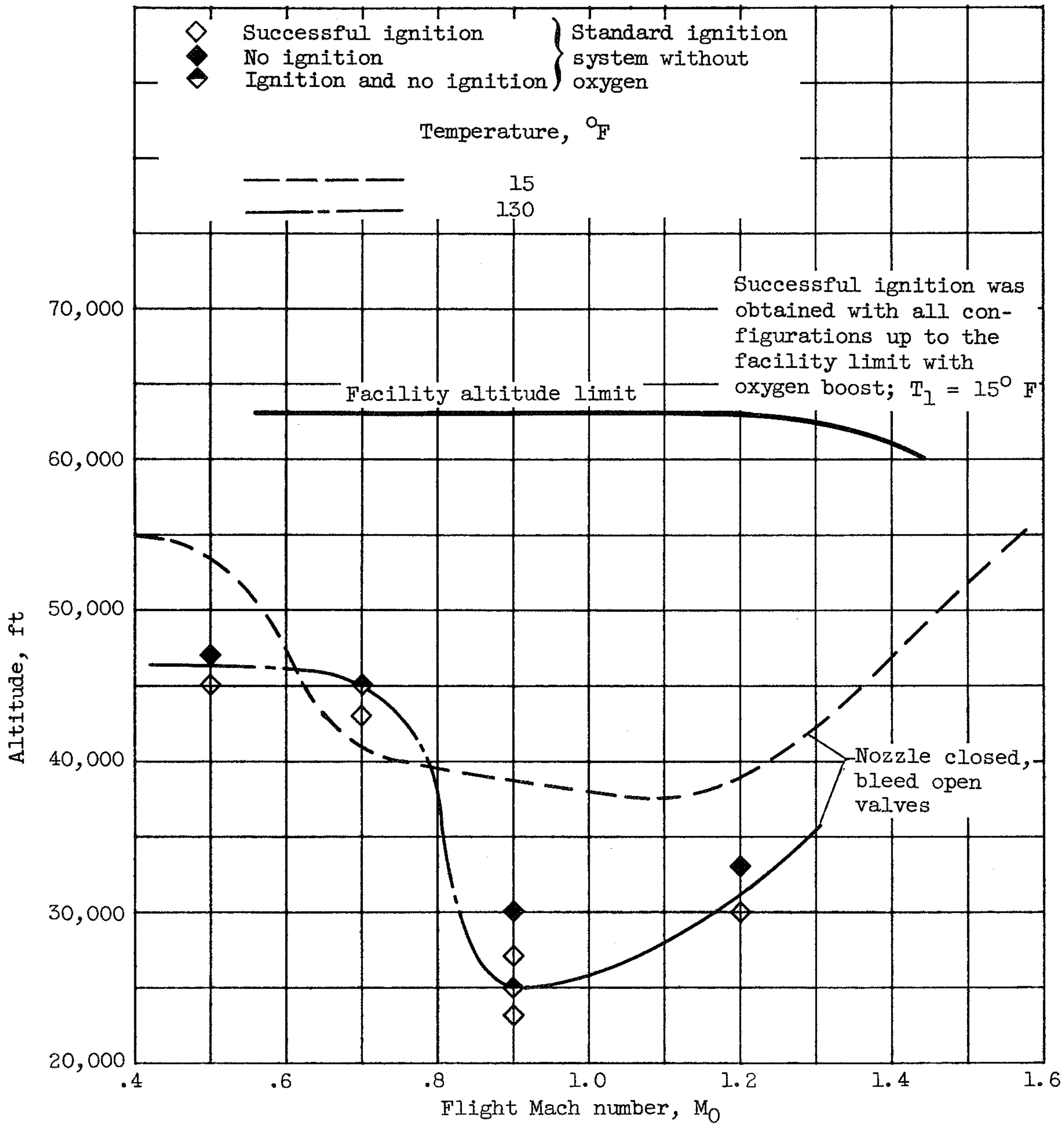


Figure 8. - Variation of over-all compressor pressure ratio with corrected low-pressure rotor windmilling speed.



(a) Effect of nozzle area and bleed valves; inlet temperature, $T_1$, 15° F.

Figure 9. - Altitude ignition characteristics.



(b) Effect of engine-inlet temperature, $T_1$

Figure 9. - Concluded. Altitude ignition characteristics.

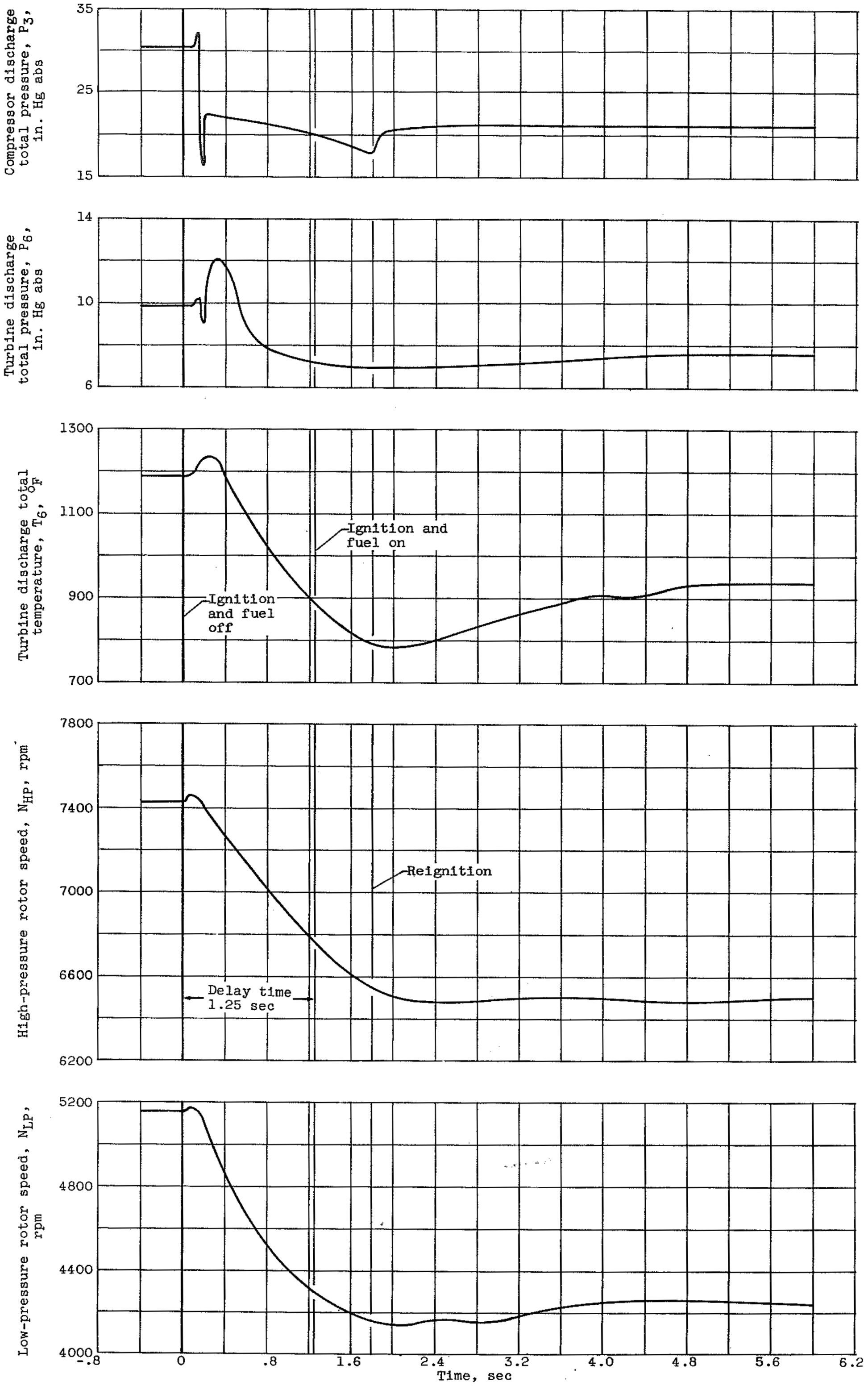


Figure 10. - Variation of engine speeds, compressor discharge total pressure, and turbine discharge total temperature and pressure during typical high-speed reignition. Engine, AX 102/2A; bleed valves, open; nozzle area, 684 square inches (90.6% closed); engine-inlet temperature, 105° F; altitude, 50,000 feet; flight Mach number, 0.90.

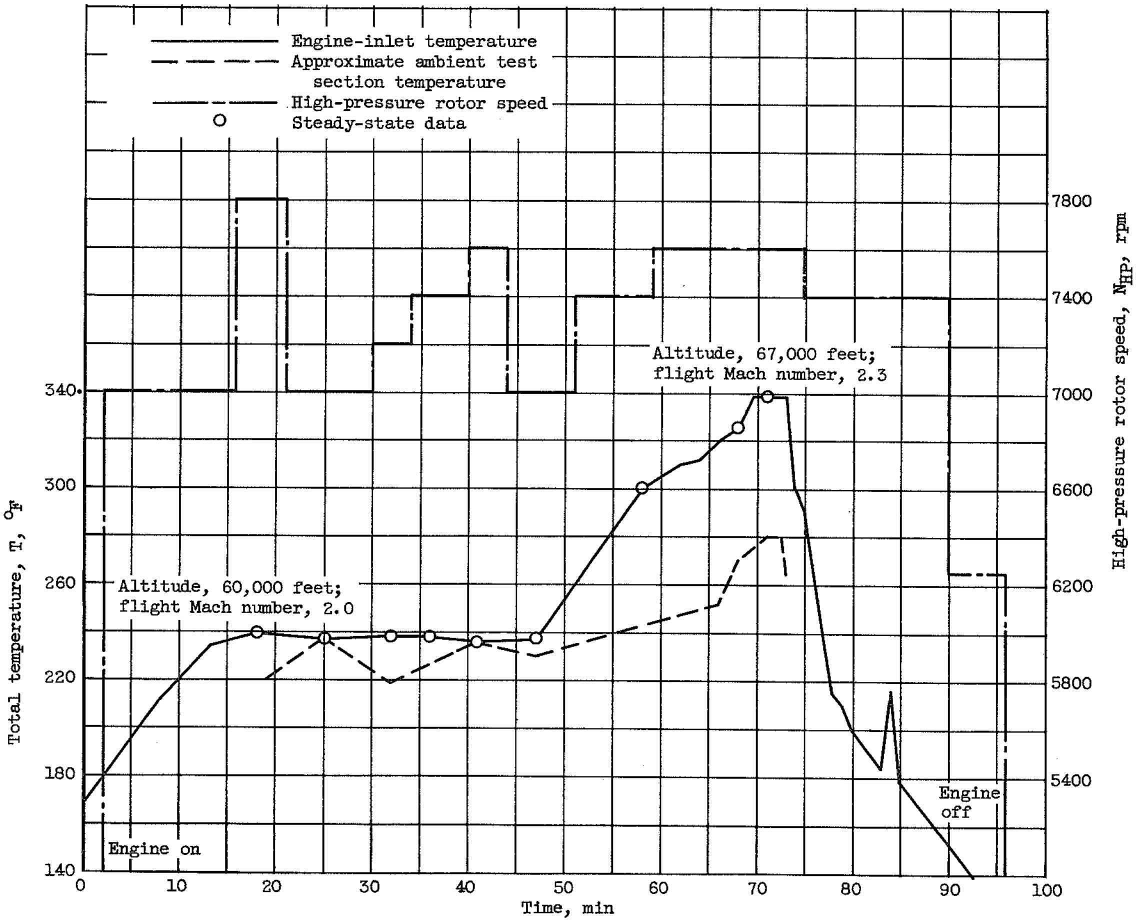


Figure 11. - Variation of high-pressure rotor speed, engine-inlet temperatures, and approximate ambient temperature during high-temperature test.

# SOME ALTITUDE OPERATIONAL CHARACTERISTICS OF A PROTOTYPE IROQUOIS TURBOJET ENGINE

By Daniel J. Peters and John E. McAulay

## ABSTRACT

The evaluation of the altitude operational characteristics was part of the over-all investigation of the early developmental Iroquois engine. Engine steady-state windmilling characteristics were evaluated over a range of flight Mach numbers from 0.48 to 1.72 at altitudes of 35,000 and 50,000 feet. Engine altitude ignition limits were obtained over a range of flight Mach numbers from 0.5 to 1.5 with the standard engine ignition system and also with an oxygen boost system. A short investigation of high-speed altitude reignition following combustor blowout was conducted.

## INDEX HEADINGS

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|---|---|
| Engines, Turbojet | 3.1.3 |
| Combustion, Turbine Engines | 3.5.2.2 |
| Ignition Systems | 3.12.2 |

(Title, Unclassified)

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