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RESEARCH MEMORANDUM

INVESTIGATION OF A SUPERSONIC-INLET - TURBOJET-ENGINE COMBINATION AT MACH 2.0 AND ANGLES OF ATTACK UP TO 6°

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Data were obtained on a supersonic-inlet - turbojet-engine combination at a free-stream Mach number of 2.0 and angles of attack from 0° to 6°. Performance of the engine, which operated over a wide range of compressor-face distortions and during unstable inlet flow, is presented. In addition, the effect of the engine on the inlet performance is discussed.

Although the engine did not influence inlet pressure recovery, data indicate that the engine may have increased the compressor-face distortions at angle of attack. Insofar as could be determined, neither very high compressor-face distortions nor unstable inlet flow resulted in engine surge or in a reduction in engine performance. However, a crack was observed in the front-bearing support strut after 19.2 hours of operation at Mach 2.0. Unstable inlet flow existed for about 1.6 hours of this running time.

INTRODUCTION

Investigations of supersonic inlet configurations usually are made with a throttling exit plug in place of the turbojet engine (e.g., refs. 1 and 2) because of tunnel size and ease of operation. Thus, interaction between the inlet and the engine is rarely observed except in flight. To study the interaction problems, a J34 turbojet engine was operated behind a supersonic inlet in the Lewis 8- by 6-foot supersonic wind tunnel (refs. 3 to 5). These tests indicated a definite effect of the engine on the inlet stability characteristics but showed little effect of the inlet on engine performance.

Presented herein are the results of an investigation made at the NACA Lewis laboratory on an inlet-engine combination for a proposed supersonic airplane. Tests also were made with the engine removed from the nacelle, wherein an exit plug was used to vary airflow (ref. 2). The present study was conducted in the 10- by 10-foot supersonic wind tunnel at a Mach number of 2.0 and at angles of attack from 0° to 6°. This report presents data showing the effect of the engine on inlet performance as well as the performance of the engine behind a supersonic inlet. Effects of the engine on the inlet stability characteristics for this same configuration are presented in reference 6.

SYMBOLS

The following symbols are used in this report:

N	engine speed, rpm
N^*	rated engine speed, 7460 rpm
P	total pressure, lb/sq ft
p	static pressure, lb/sq ft
Re	Reynolds number index, $\delta/\varphi\sqrt{\theta}$
r	radius, ft
T	total temperature, $^{\circ}R$
w	weight flow, lb/sec
α	angle of attack, deg
β	compressor-stator position, deg
δ	ratio of total pressure to NACA standard sea-level pressure of 2116 lb/sq ft
η_e	compressor adiabatic efficiency
θ	ratio of total temperature to NACA standard sea-level temperature of 518.7° R
θ_l	cowl-position parameter (angle between diffuser axis and line joining cone apex to cowl lip), deg
φ	ratio of absolute viscosity at engine-face conditions to absolute viscosity at NACA standard sea-level conditions

Subscripts:

av	average
f	fuel
max	maximum
min	minimum

0 free stream

2 compressor face

5 turbine discharge

APPARATUS AND PROCEDURE

The turbojet engine (fig. 1) investigated in this study had a seventeen-stage axial-flow compressor and a three-stage turbine. Although the engine was equipped with an afterburner, the tests were conducted without afterburning. The first seven stator stages in the compressor were variable and are scheduled by engine speed plus compressor-inlet temperature. The variable exhaust nozzle is scheduled by power-level position and biased by exhaust-gas temperature. The flow area at the compressor face was 4.52 square feet.

The engine was installed in a production nacelle for a current supersonic airplane. Figures 2 and 3 show that the nacelle had a bulge on the bottom to provide space for engine accessories. The maximum diameter of the nacelle was about 51 inches. The engine was started by allowing it to windmill until the tunnel was at the test condition and then lighting it; generally, little difficulty was encountered in engine lightoff.

The nacelle configuration consisted of a translating-spike inlet (ref. 2) and a convergent ejector exhaust nozzle whose secondary airflow was supplied by subinlets in the main inlet. A larger ejector than the flight model was used, in order to assure pumping ability high enough to choke the subinlets (fig. 3). The secondary flow was used in oil coolers before it was discharged into the annulus around the engine upstream of the ejector. About 8 to 10 percent of the main inlet flow was bypassed to the ejector in this manner.

Inlet tests were made with both the engine and cold-pipe configurations shown in figure 3. The performance of the engine and a comparison of the inlet performance for the cold-pipe and engine configurations are presented herein. For supercritical inlet operation, the engine airflow was calculated from the known mass-flow ratio (from exit-plug data) and the measured static pressure at station 75.4 (fig. 3). When the inlet was subcritical, engine airflow was obtained from the manufacturer's airflow curve. Total pressure at the compressor face was calculated from the measured static pressure and the engine airflow. Engine performance was computed (in the normal manner) from data recorded by the instrumentation shown in figure 3.

The inlet-engine combination was tested at a free-stream Mach number of 2.0 at a pressure altitude of about 56,000 feet. The compressor-face total temperature was about 540° ±10° R because of the method of facility operation. Thus, the engine was tested at a Reynolds number index of 0.43 to 0.56. On a standard day in flight (free-stream static temperature, 392° R), the Reynolds number index Re would range from 0.31 to 0.40.

RESULTS AND DISCUSSION

Figure 4 presents the inlet performance for various spike positions, measured with the cold-pipe configuration and with the engine operating. The total-pressure recovery characteristics were the same for both cases at all angles of attack. The comparison of the compressor-face distortions shown in the upper part of figure 4 is not exact because of instrumentation differences between the cold-pipe and engine configurations. The distortion values presented for the cold-pipe case were computed from the six rakes noted in figure 3. However, these rakes were not installed during the engine tests; instead, flush total-pressure probes were installed in the horizontal support struts at the compressor face. As shown in figures 4(b) and (c), the horizontal distortions with the engine were, in some cases, considerably higher than those measured with the cold pipe. This difference increased with angle of attack and with spike extension (decreasing cowl-position parameter, θ_l). The investigation reported in reference 4 did not show an adverse effect of the engine on distortion, possibly because that test was restricted to zero angle of attack.

The source of the high distortion with the engine is shown in figure 5. Profiles at the compressor face with the same inlet operating condition are presented for the engine and cold-pipe configurations at angles of attack of 0°, 3°, and 6°. As shown in figure 5, the cold-pipe data were not exactly on the horizontal centerline, as were the engine data. Thus, only trends may be surmised from this figure. Even at zero angle of attack the profiles appear different, although the distortion value was the same. Whether this is an effect of the engine or of the circumferential location is not clear. In any event, as angle of attack is increased to 6°, low pressures developed around the hub with the engine operating. It would appear that the engine induced swirl around the hub that resulted in flow separation. This conclusion is indicated by the relative level of the static pressures measured 6 inches upstream of the total-pressure survey.

Total-pressure profiles at the turbine discharge are presented in figure 6 for distortions of 14 and 48 percent at the compressor face at practically the same engine speed. It is interesting to note that the profiles at the turbine discharge are approximately the same for such different amounts of compressor-face distortion.

The range of compressor-face distortion imposed on the engine at the various angles of attack is shown in figure 7. Duration of operation at the various angles of attack is summarized in table I. In addition to operation with these severe distortions, the engine was operated during unstable inlet flow (table I). The engine was operated for a short while with static-pressure amplitudes as high as 48 percent of the compressor value. A more complete discussion of these data and the amount of pulse propagation through the engine is included in reference 6.

The measured engine performance is presented in figure 8, which shows various degrees of compressor-face distortion and includes operation with unstable inlet conditions. These data indicate that, for the particular engine investigated, high compressor-face distortion and inlet pulsations did not reduce engine performance (e.g., fig. 8(d)). In addition, observations made during the test indicated no tendency of the engine to surge under these conditions. Whether the high distortions or inlet buzz reduced the surge margin, as may have been the case, was not determined. In addition, the possible development of hot spots in the engine could not be observed with the instrumentation available.

During the last run of this investigation, severe inlet pulsing was imposed on the engine for about 12 minutes, and vibrations in excess of 50 mils (about 10 mils was the allowable maximum) were recorded. Immediately after the severe buzz condition was imposed on the engine, the engine was restarted in the tunnel and operated at rated power. Engine vibrations were observed to be normal. After this run the engine was removed from the nacelle and was thoroughly inspected. In addition to a few broken mounting brackets around the engine, a paper-thin crack was observed in the horizontal front-bearing support strut close to the hub (fig. 9). Whether the severe inlet pulsing caused this damage is not certain, since, prior to the last run, the engine had been operated for over 19 hours at a free-stream Mach number of 2.0 without close inspection of this region.

The performance of the engine during windmilling (zero fuel flow) is shown in figure 8. A set of windmilling speed data obtained with Mach numbers up to 2.5 and presented in figure 10 indicates higher windmilling speeds than those reported for the J34 engine in reference 5.

SUMMARY OF RESULTS

The following results were noted in an investigation of a supersonic-inlet - turbojet-engine combination at a free-stream Mach number of 2.0 and angles of attack from 0° to 6°:

1. Inlet pressure recovery with the engine was the same as that with an exit plug. However, the trend of the data indicates that compressor-face distortion may have been increased at angle of attack by the engine.

2. Unstable inlet flow and large compressor-face distortion were imposed on the engine apparently without reducing engine performance or inducing engine surge.

3. The engine was operated for over 19 hours (including about 12 min of violent inlet buzz), after which a paper-thin crack was observed in the front-bearing support. In addition, engine vibrations of about 50 mils, which were much higher than the maximum allowable, were recorded during severe inlet buzz. After this severe operating condition, the engine was restarted and operated at rated power. Vibrations were observed to be normal.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, May 20, 1957

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TABLE I. - SUMMARY OF ENGINE OPERATION

Type of operation	Free-stream Mach number	Angle of attack, deg	Time, hr (a)
Stable inlet	2.0	0 3 6	12.4 3.0 2.3
Unstable inlet $\Delta p_2 \leqq 0.07\ P_0$	2.0	0 3 6	0.6 .3 .5
Unstable inlet $\Delta p_2 \geqq 0.07\ P_0$	2.0	0	0.2
Tunnel, subsonic	<1.0	0	3.1

[a]Total time, 22.4 hr.

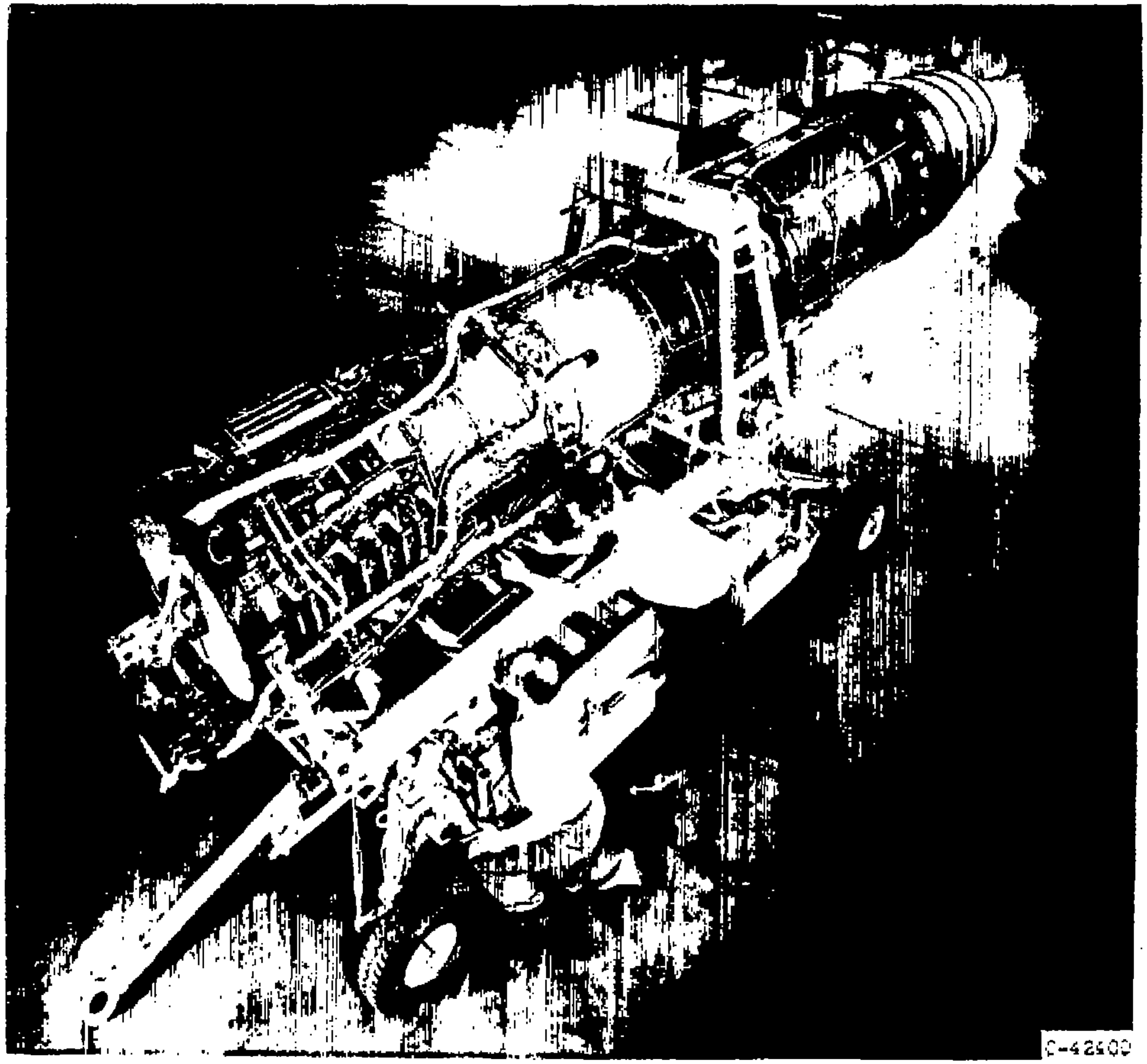


Figure 1. - Turbojet engine.

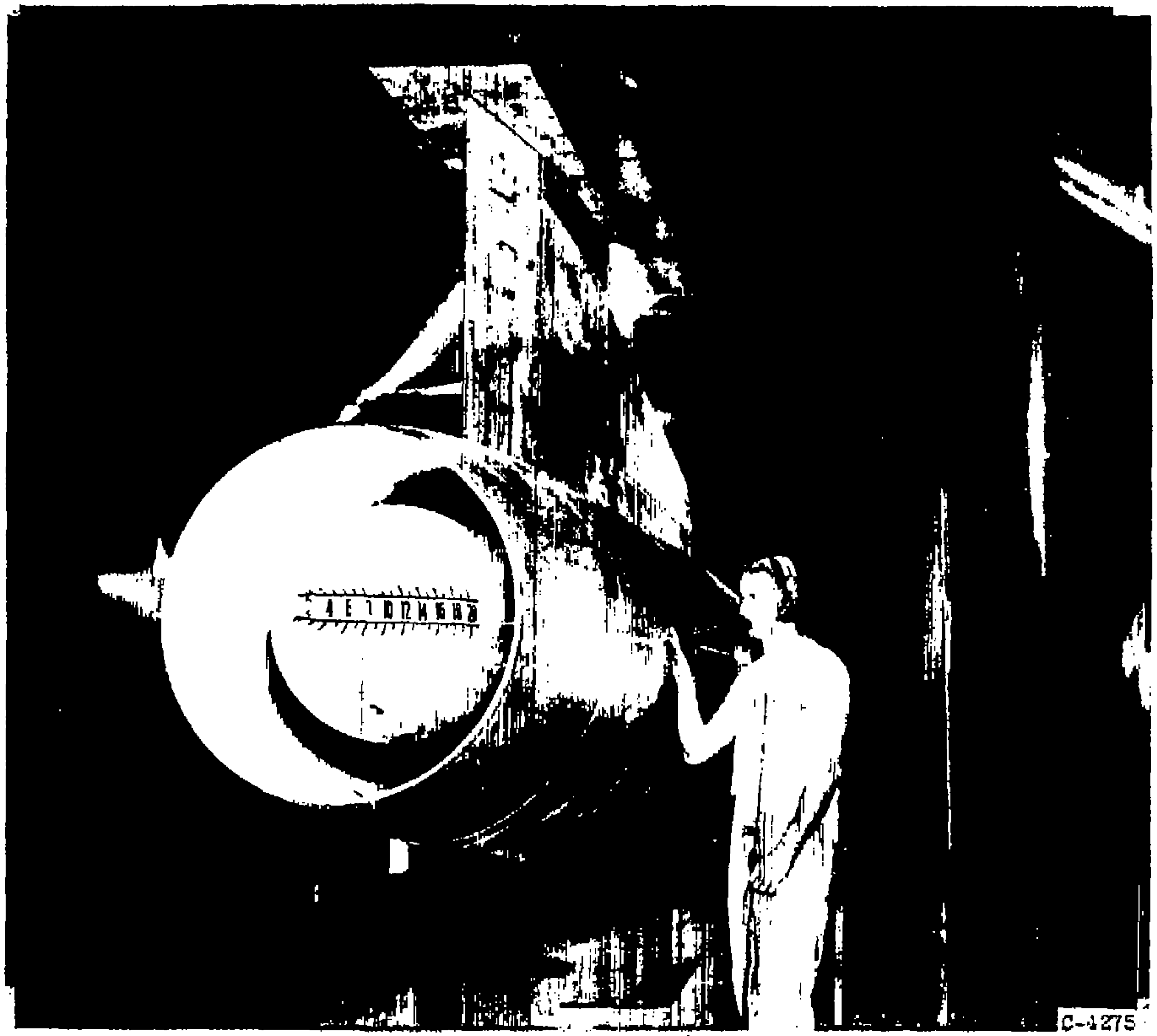
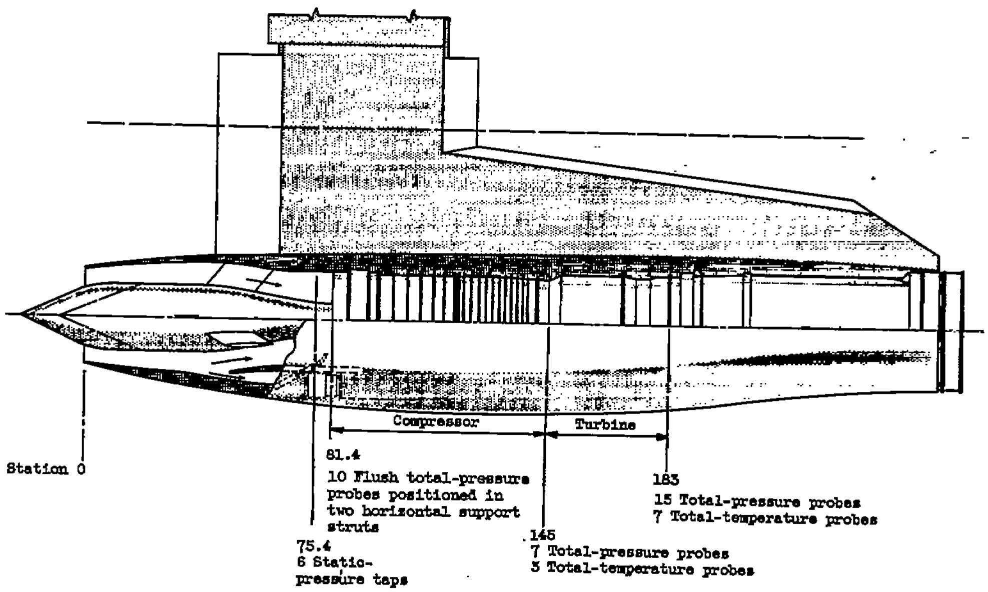
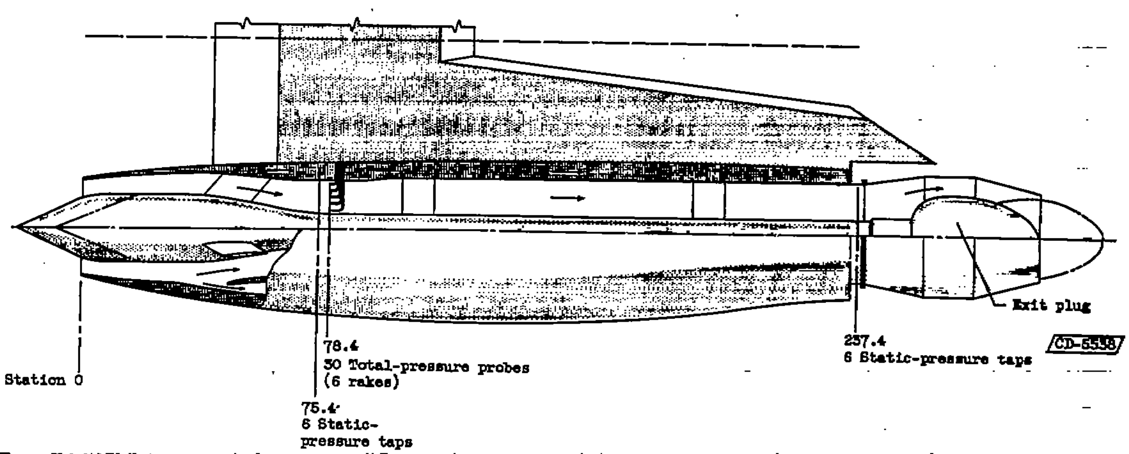


Figure 2. - Nacelle in tunnel.

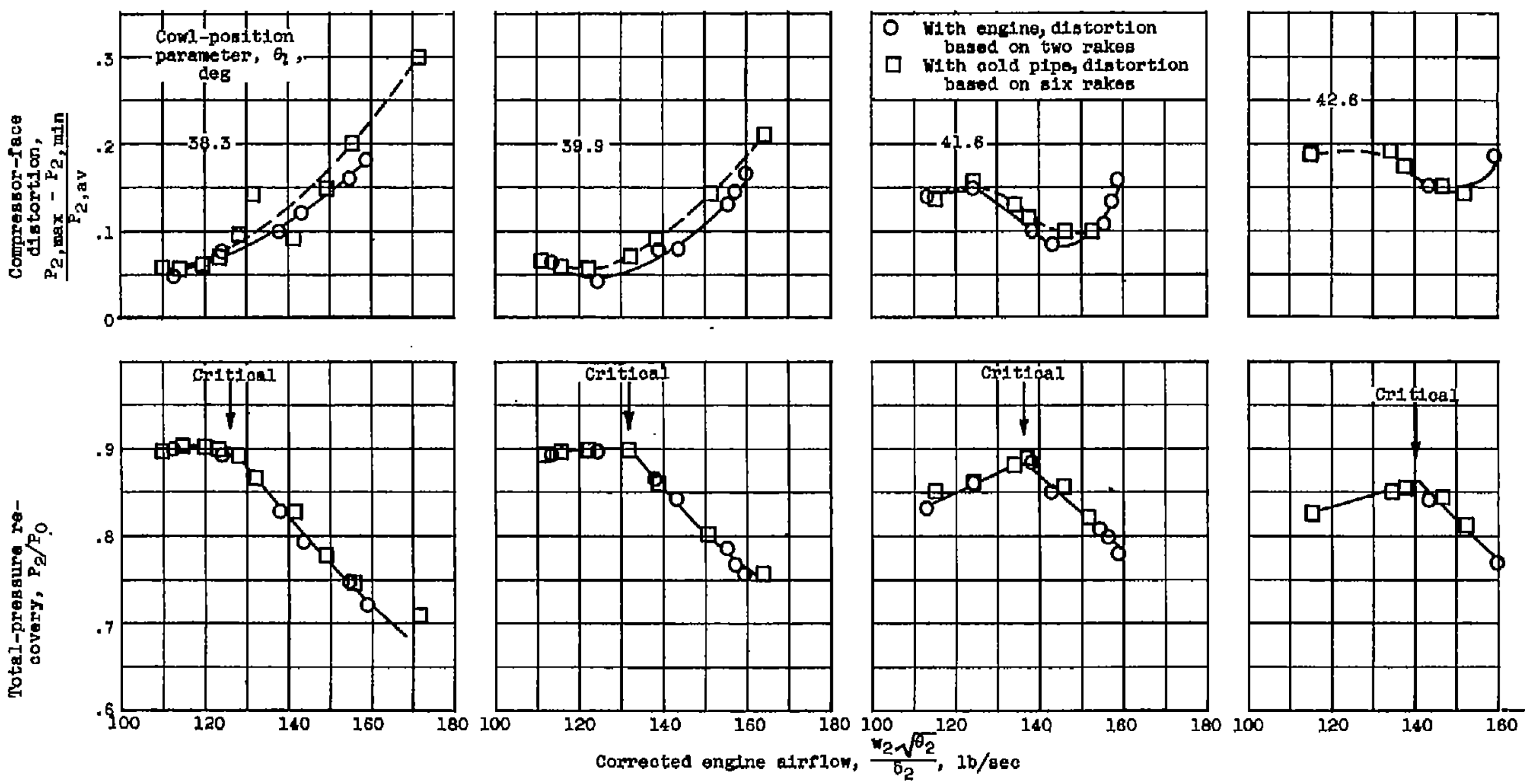


(a) With engine installed.



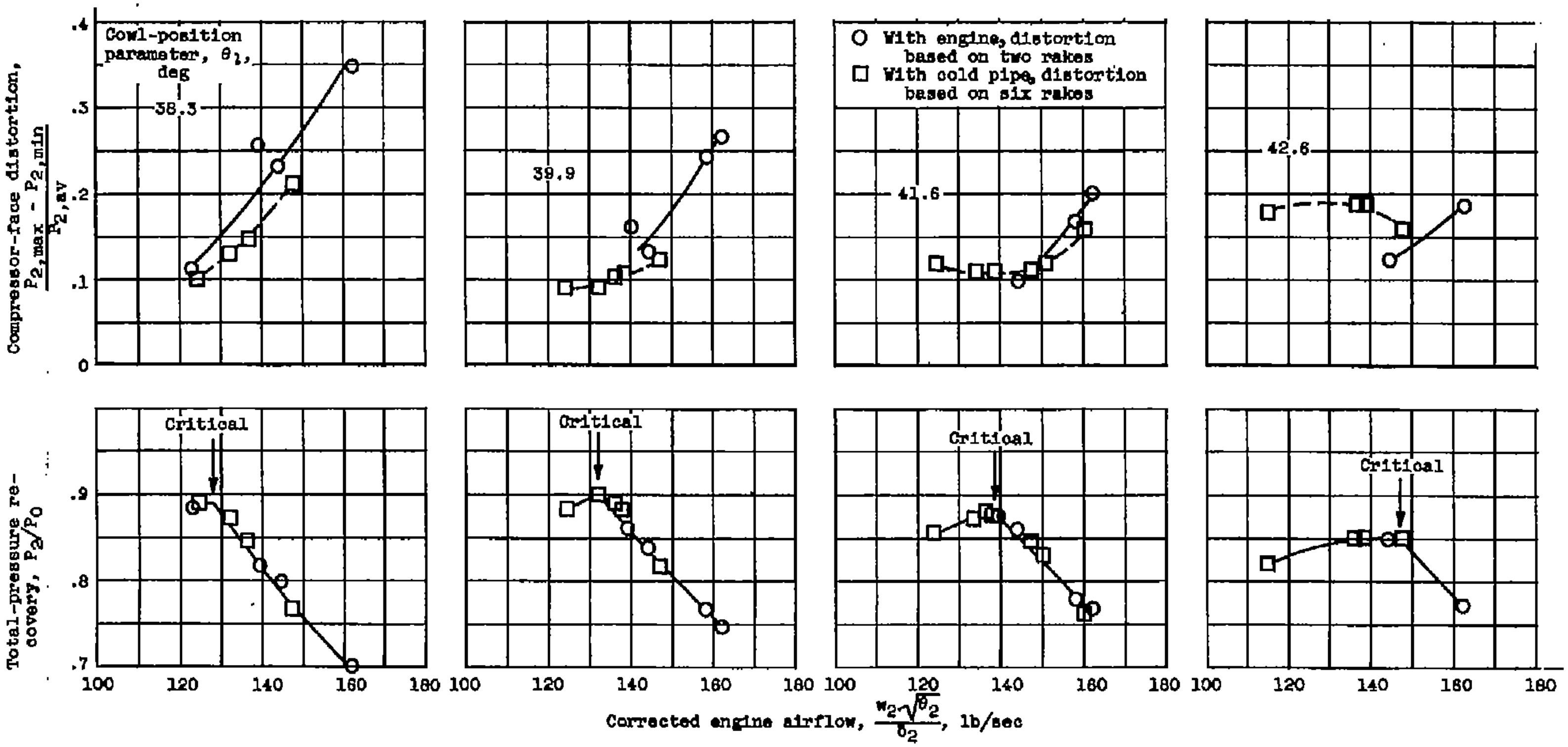
(b) With cold pipe installed.

Figure 3. - Nacelle and instrumentation for engine and cold-pipe installations.



(a) Angle of attack, 0°.

Figure 4. - Inlet performance.



(b) Angle of attack, 3°.

Figure 4. - Continued. Inlet performance.

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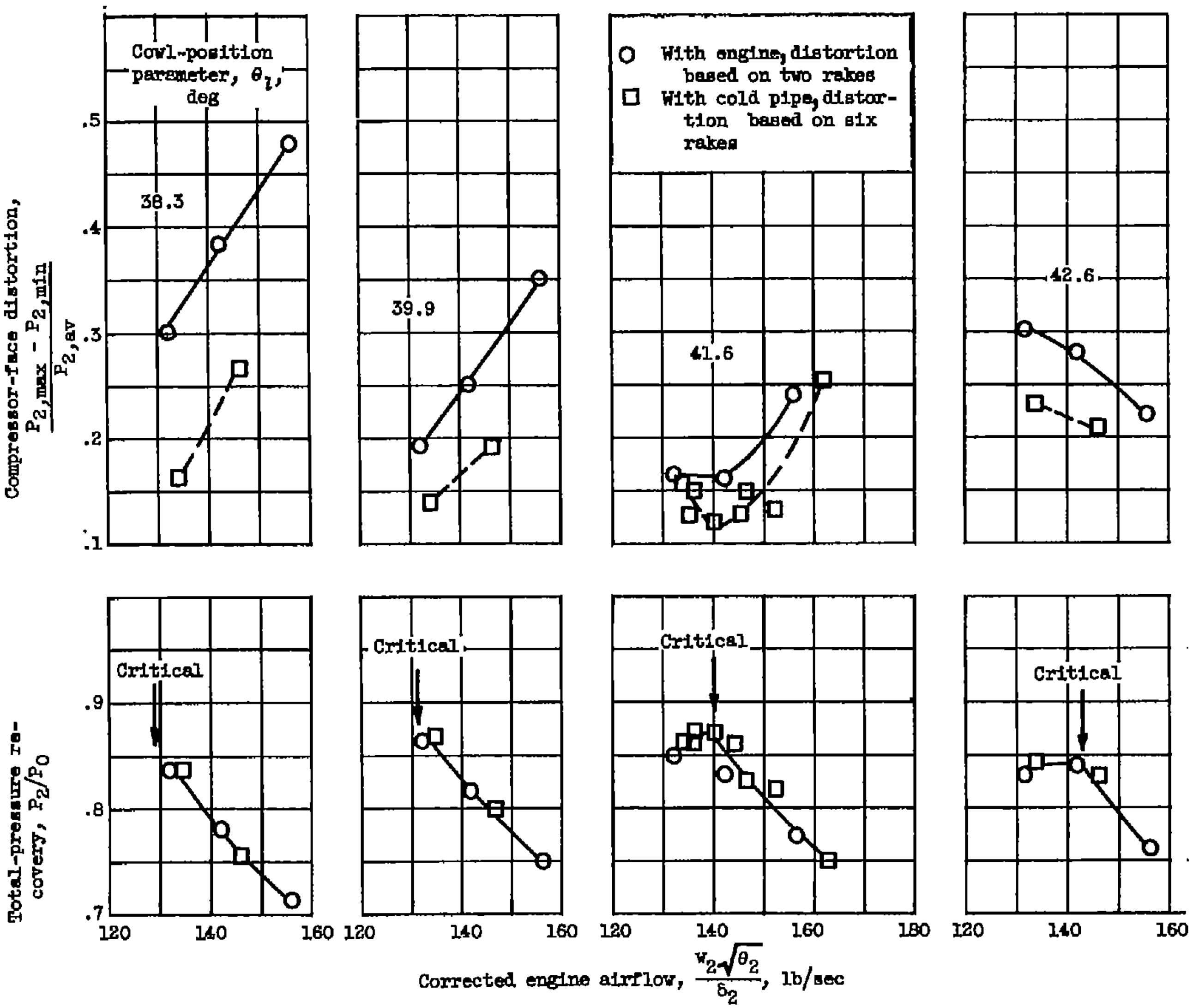

(c) Angle of attack, 6°.

Figure 4. - Concluded. Inlet performance.

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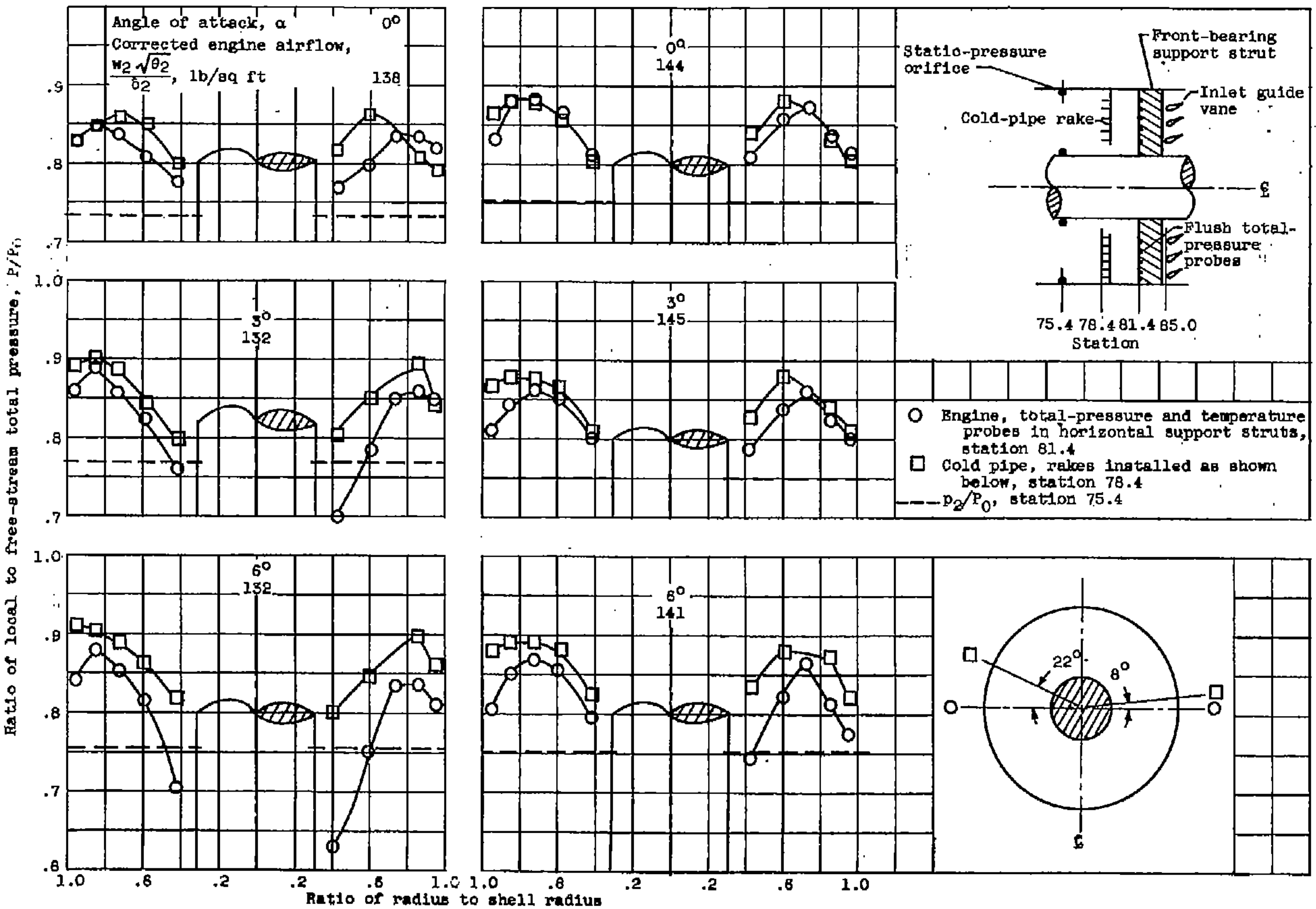

(a) Cowl position parameter, 38.3°.

(b) Cowl position parameter, 41.6°.

Figure 5. - Effect of engine installation on horizontal total-pressure profile. Slightly supercritical operation.

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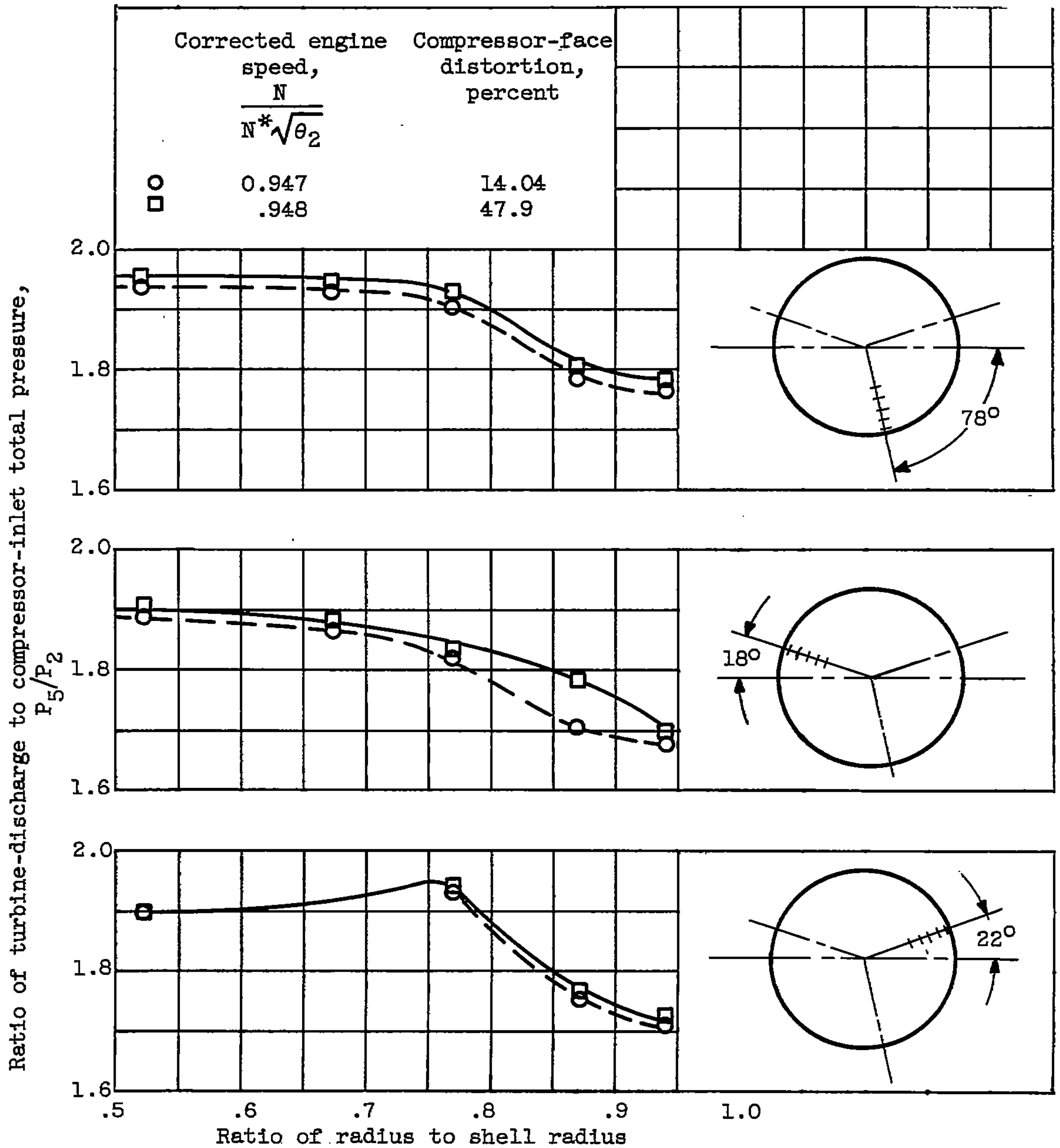


Figure 6. - Total-pressure profiles at turbine discharge.

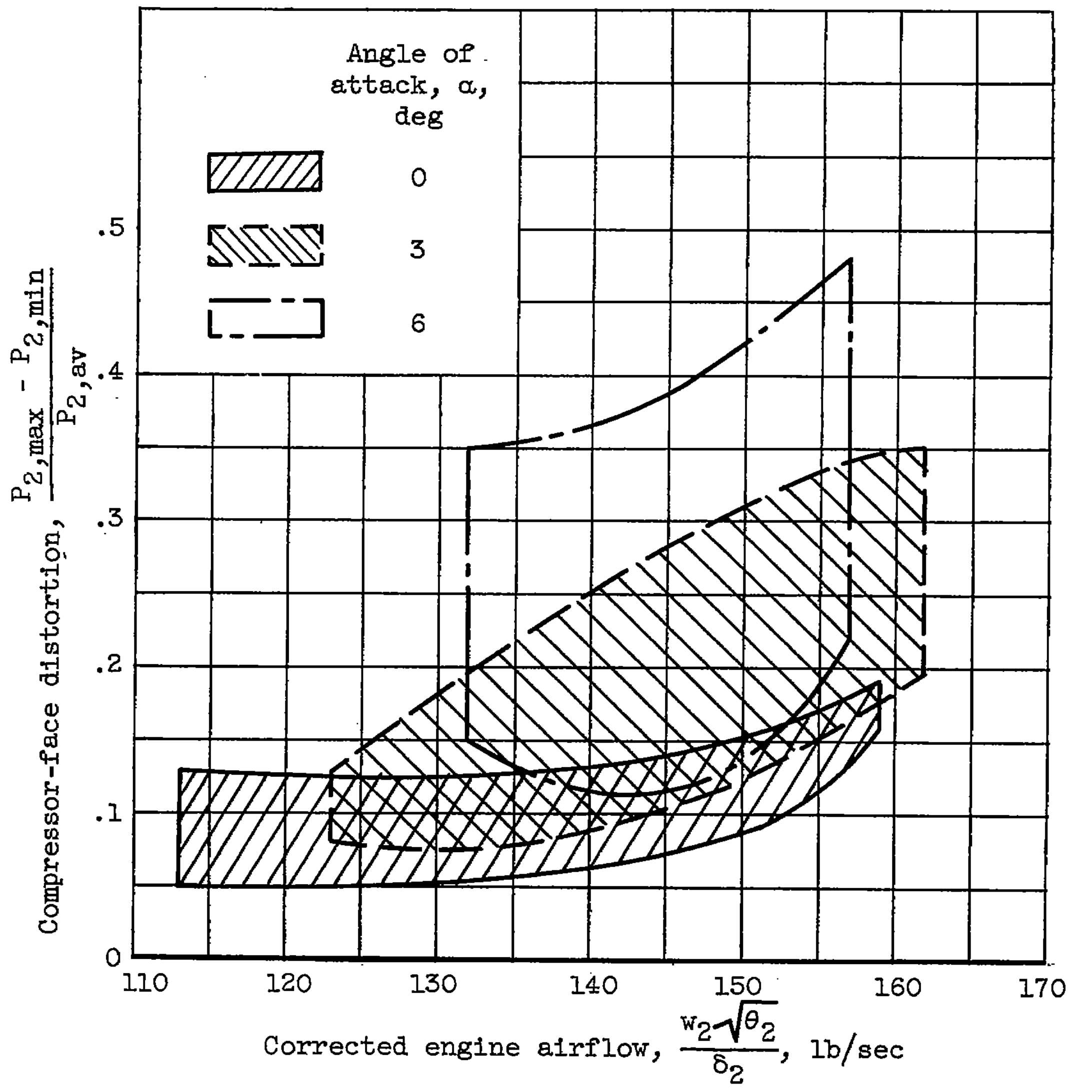
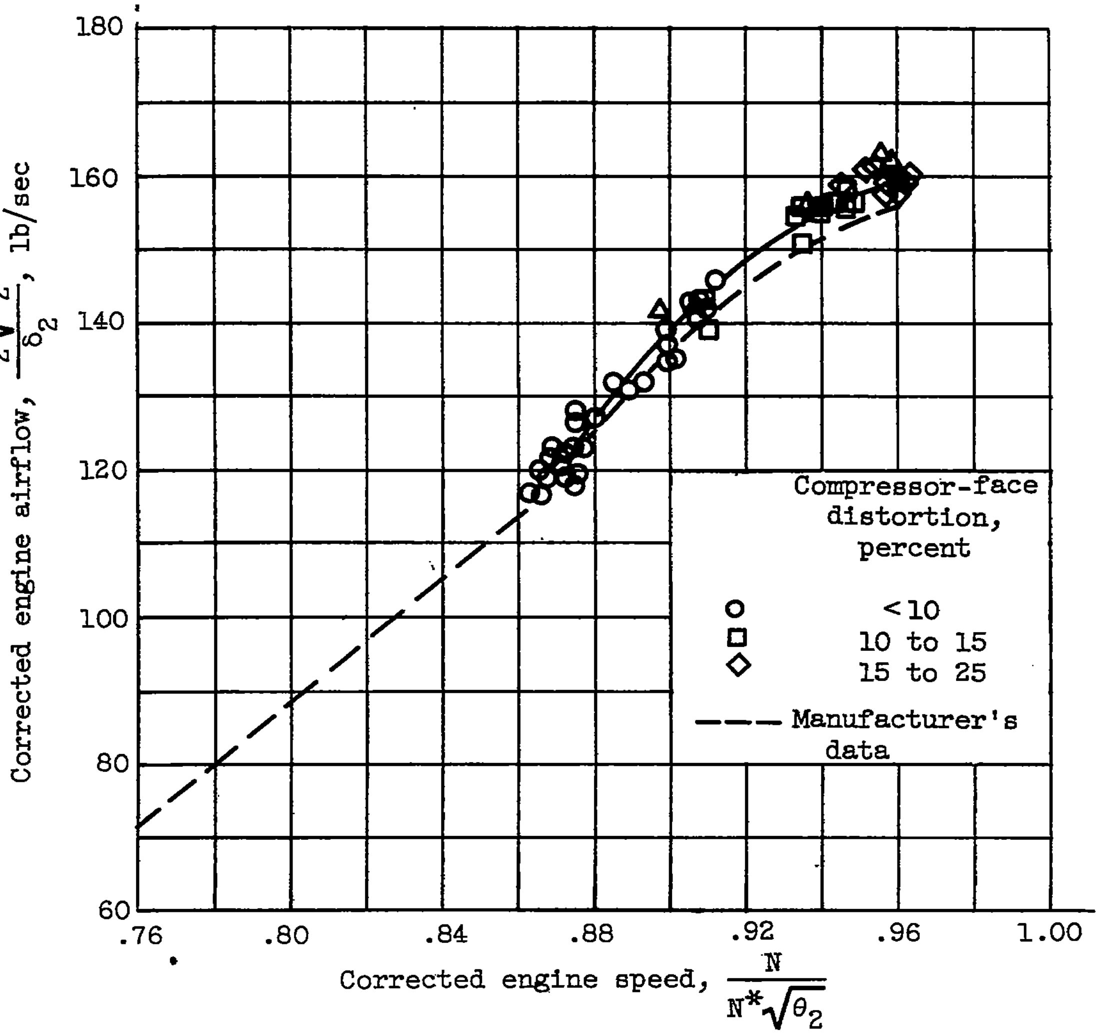
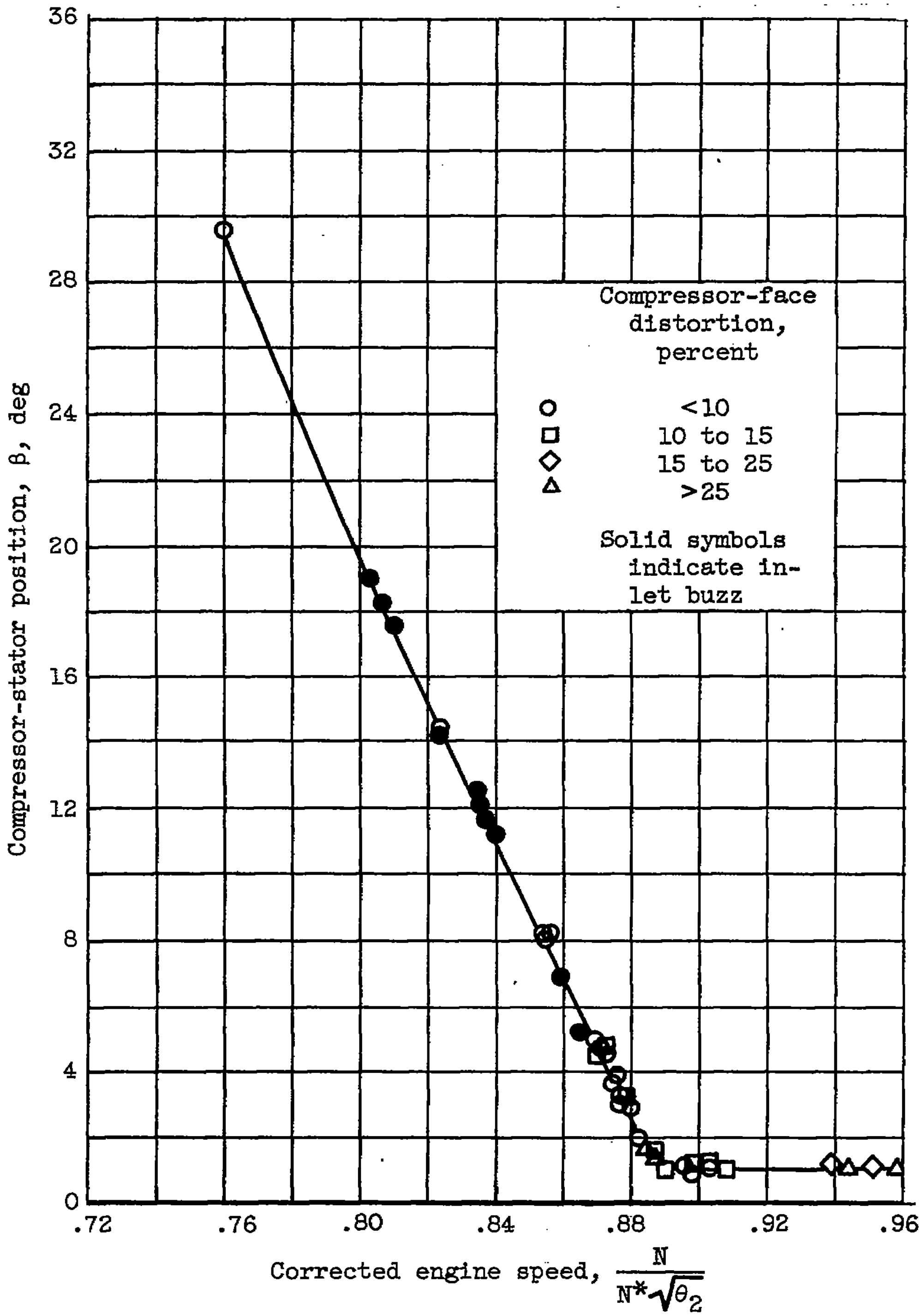


Figure 7. - Range of engine operating conditions.



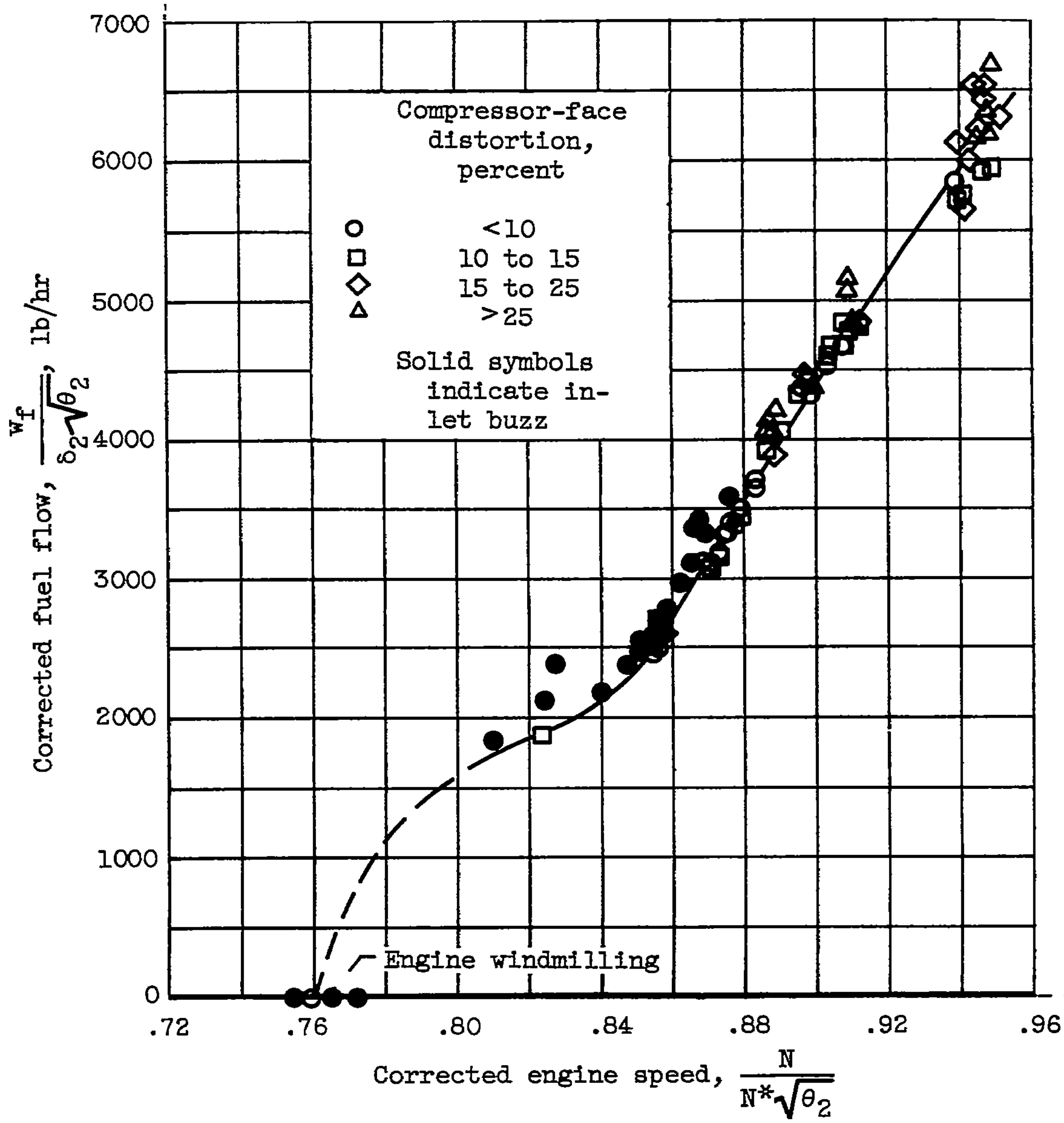
(a) Airflow.

Figure 8. - Engine performance.



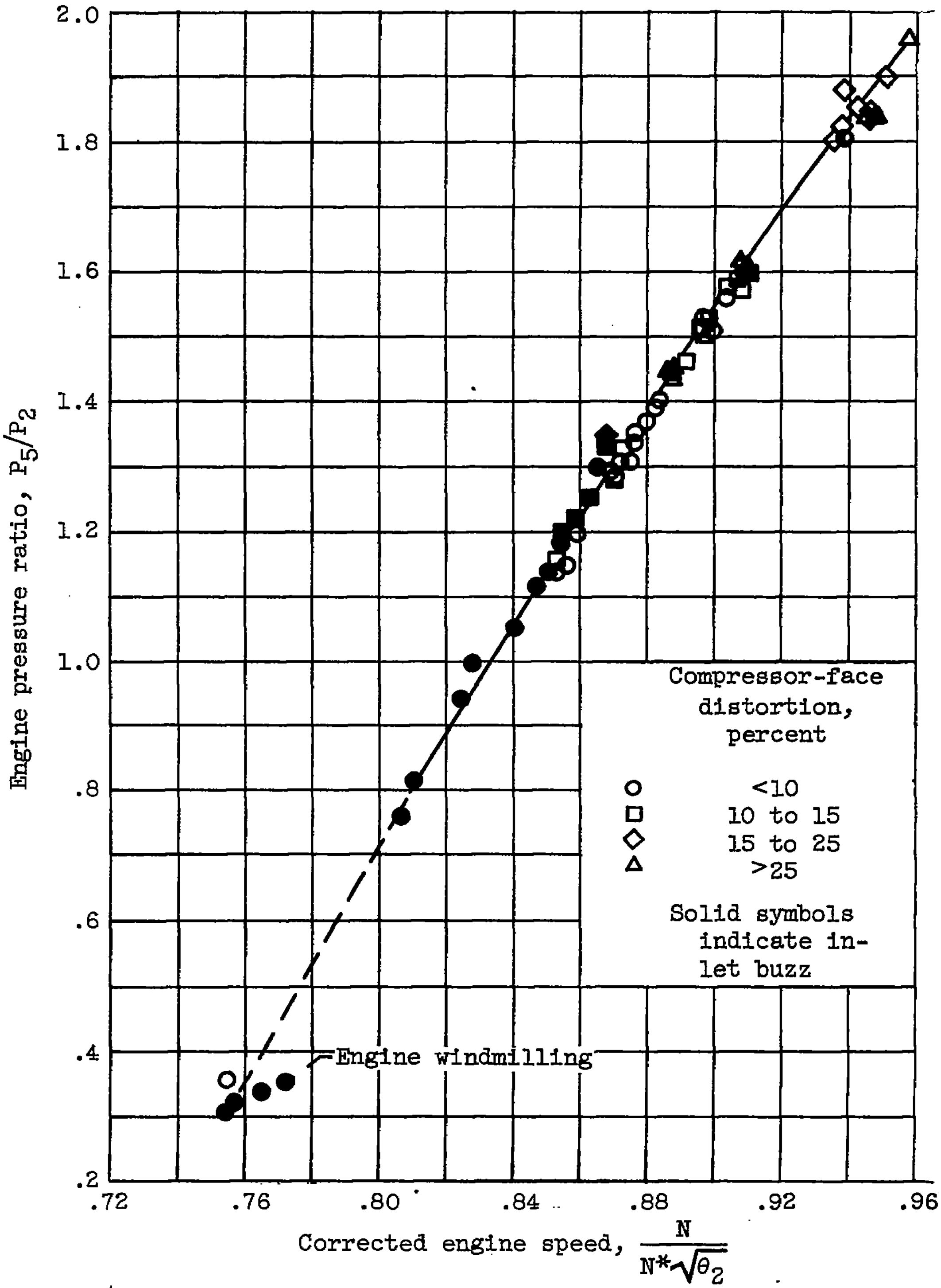
(b) Variation of compressor stators. Compressor-face temperature, 540° R.

Figure 8. - Continued. Engine performance.



(c) Fuel flow.

Figure 8. - Continued. Engine performance.



(d) Pressure ratio.

Figure 8. - Continued. Engine performance.

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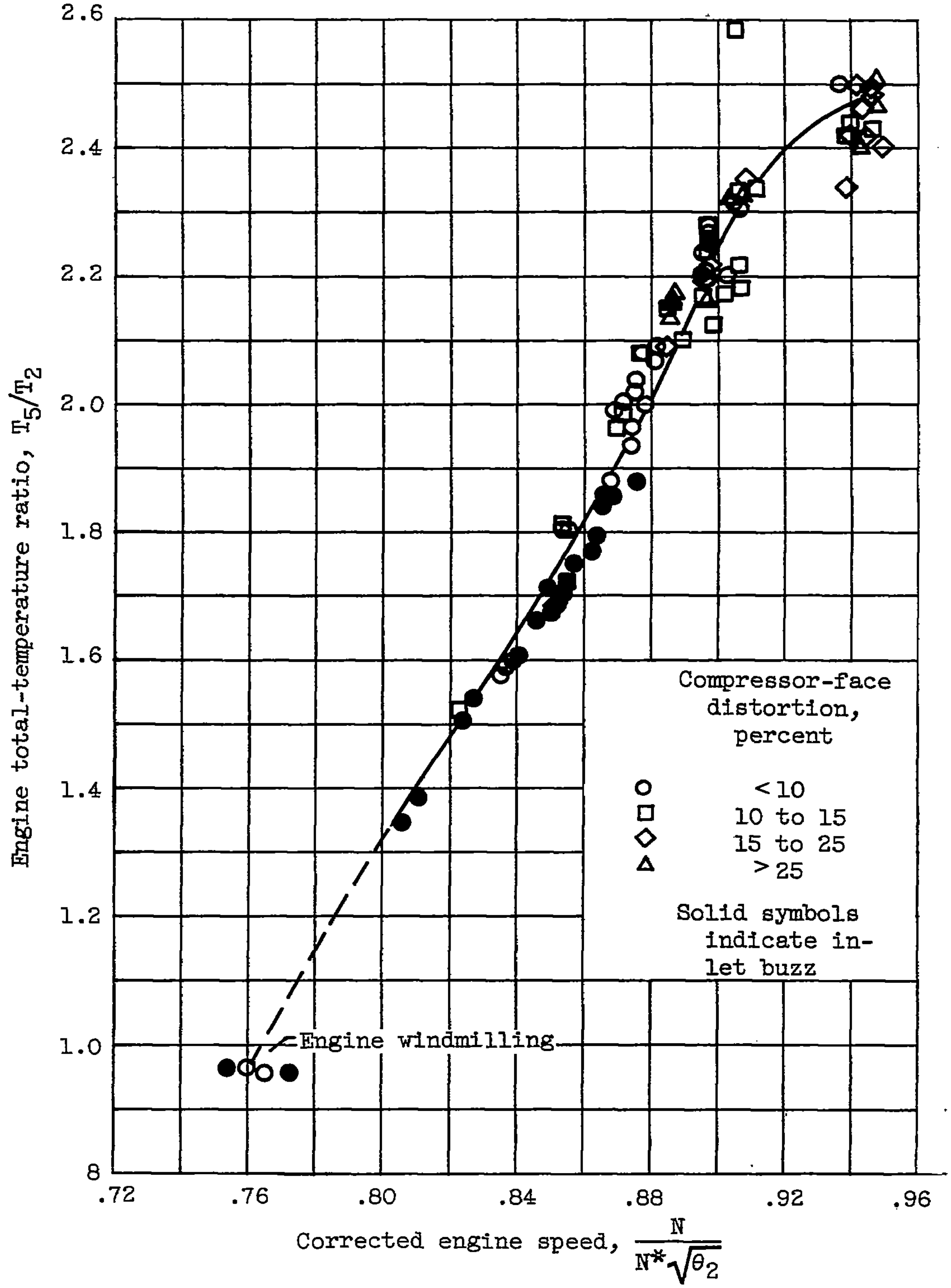
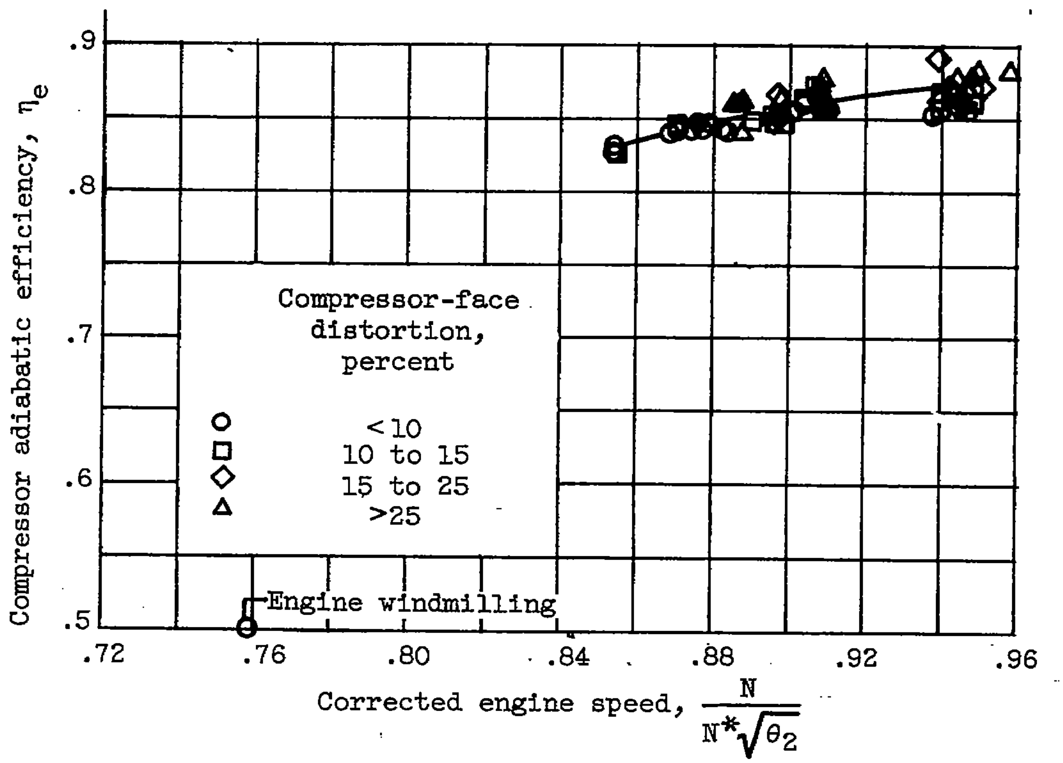


(e) Temperature ratio.

Figure 8. - Continued. Engine performance.



(f) Compressor adiabatic efficiency.

Figure 8. - Concluded. Engine performance.

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Figure 9. - Crack in front-bearing support strut.

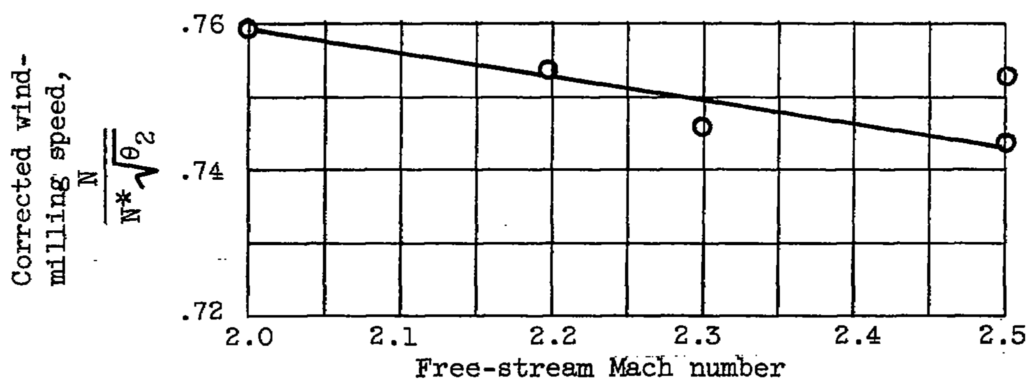

Figure 10. - Engine windmilling speed characteristics. Compressor-face temperature, 538° to 542° R.

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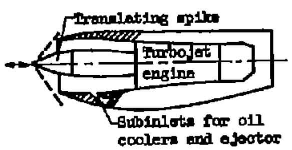
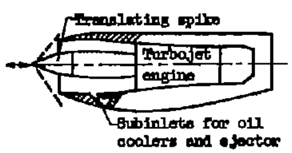
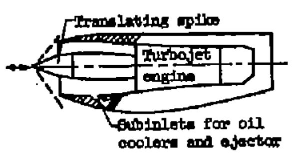
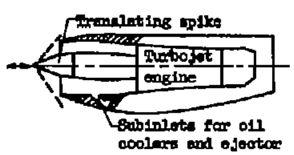
NOTES: (1) Reynolds number is based on the diameter of a circle with the same area as that of the capture area of the inlet.

(2) The symbol * denotes the occurrence of buzz.

Report and facility	Description			Test parameters				Test data				Performance		Remarks
	Configuration	Number of oblique shocks	Type of boundary-layer control	Free-stream Mach number	Reynolds number × 10^{-6}	Angle of attack, deg	Angle of yaw, deg	Drag	Inlet-flow profile	Discharge-flow profile	Flow picture	Maximum total-pressure recovery	Mass-flow ratio	
CONFID. RM E57D18 Lewis 10- by 10-Foot Unitary Wind Tunnel		One	None	2.0	6.8	$0^\circ, 3^\circ, 6^\circ$	0			√		0.90	0.5-0.9*	A present day turbojet engine being used currently for supersonic flight was studied in a production nacelle. The inlet had a translating spike.
CONFID. RM E57D18 Lewis 10- by 10-Foot Unitary Wind Tunnel		One	None	2.0	6.8	$0^\circ, 3^\circ, 6^\circ$	0			√		0.90	0.5-0.9*	A present day turbojet engine being used currently for supersonic flight was studied in a production nacelle. The inlet had a translating spike.
CONFID: RM E57D18 Lewis 10- by 10-Foot Unitary Wind Tunnel		One	None	2.0	6.8	$0^\circ, 3^\circ, 6^\circ$	0			√		0.90	0.5-0.9*	A present day turbojet engine being used currently for supersonic flight was studied in a production nacelle. The inlet had a translating spike.
CONFID. RM E57D18 Lewis 10- by 10-Foot Unitary Wind Tunnel		One	None	2.0	6.8	$0^\circ, 3^\circ, 6^\circ$	0			√		0.90	0.5-0.9*	A present day turbojet engine being used currently for supersonic flight was studied in a production nacelle. The inlet had a translating spike.

Bibliography

These strips are provided for the convenience of the reader and can be removed from this report to compile a bibliography of NACA inlet reports. This page is being added only to inlet reports and is on a trial basis.