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# RESEARCH MEMORANDUM

TEMPERATURE AND PRESSURE DISTRIBUTIONS IN DUAL PARALLEL

JETS IMPINGING ON THE GROUND FROM A TURBOJET ENGINE

By J. Elmo Farmer, Francis S. Stepka
and Floyd B. Garrett

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# NATIONAL ADVISORY COMMITTEE
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### TEMPERATURE AND PRESSURE DISTRIBUTIONS IN DUAL PARALLEL

### JETS IMPINGING ON THE GROUND FROM A TURBOJET ENGINE

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## SUMMARY

An investigation was conducted to determine the temperature
and pressure distributions in the jets issuing from two parallel
nozzles of a turbojet engine located close together and impinging
on the ground at an angle of 20°. The investigation was limited
to the following conditions: convergent nozzles; nozzle diameter,
13 inches; nozzle spacing, 1.42 nozzle diameters; jet total temper-
ature, 1550° to 1750° R; and nozzle-pressure ratio, 1.44 to 1.52.

Temperature and pressure profiles obtained indicated a pro-
nounced mutual interference between the jets beyond 1 diameter
downstream of the nozzle exists. The jet boundary was found to
be farther above the ground between the two jets than it was
directly behind either of them. In the portions of the jets
unaffected by the interference, expansion of the gases was
mostly horizontal; very little vertical rise was observed.

## INTRODUCTION

The need for greater power in high-speed jet aircraft has
led to consideration of designs incorporating two jet engines
installed side by side in the fuselage with the exit nozzles
located considerably forward of the tail surfaces. The tail sur-
faces can be so placed as to be well above the wakes of the jets
during flight. The take-off angle is such, however, that air-
planes with short landing gears may operate with the jets imping-
ing upon the runway. During such operation, the jets may be
deflected into the tail-surface region and cause excessive
heating and failure. The possibility of using afterburning as
a means of thrust augmentation during take-off makes this problem
even more serious, as the temperature of the exhaust gases would
be much higher.

A full-scale engine investigation to determine the temperature and pressure distributions in the wake of two adjacent parallel jets impinging on the ground at an angle of 20° simulating a nose-high take-off condition was conducted at the NACA Lewis laboratory. The measurements are presented in nondimensional terms to make them applicable to other jet diameters and gas temperatures.

### APPARATUS AND PROCEDURE

The engine used for this investigation has a dual-entry centrifugal compressor, 14 combustion chambers, and a single-stage turbine. The sea-level static thrust rating is about 4000 pounds.

The exhaust system of the engine was altered by attaching a Y-section of tail pipe to the exhaust cone. Straight parallel lengths of tail pipe with a convergent nozzle 13 inches in diameter were attached to the two branches of the Y-section. The distance between the nozzle center lines was 1.42 nozzle diameters. The inclined engine was so mounted on a rigid sea-level test stand that the tail pipe was at an angle of approximately 20° with respect to the ground; the nozzles were approximately 1/2 inch above the ground at the exit. In order to assure a reasonably smooth ground surface that would not be eroded by the high-temperature, high-velocity gases, two 1/4-inch steel plates, spaced 1/2 inch apart and cooled by circulating water between them, were used. The rake for making the temperature and pressure survey of the jet was so mounted on this plate as to minimize interference with the jets.

A rear view of the test stand (fig. 1) shows the engine, the tail pipe, the thermocouple rake, and arrangement of the nozzles. The thermocouple rake consisted of 27 bare chromel-alumel thermocouples spaced 2 inches apart; the bottom thermocouple was 1/4 inch above the plate.

Gas temperature at each jet nozzle was measured by four unshielded chromel-alumel thermocouples spaced equally about the circumference and extending radially $3\frac{1}{4}$ inches into the nozzles. All the thermocouples were connected through selector switches to a self-balancing potentiometer.

The construction of the rake used for the pressure survey was similar to that shown in figure 1, except that the thermocouples were replaced with total-pressure tubes spaced 1 inch apart. The rakes were shifted into desired positions by moving the deflection plate.

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The experiments were conducted with a constant mass flow of 70 pounds of air per second, corresponding to 90 percent of full-throttle air flow. The mass flow was correlated to standard conditions for each run. No correction was applied to any of the temperatures obtained from the thermocouples. A survey of 10 positions was made across the two jets at 1 to 6 jet-nozzle diameters downstream of the nozzle exits. The results of this investigation are presented in dimensionless form so that they may be readily extrapolated to other temperatures. Temperature parameter is the dimensionless ratio (reference 1)

$$\frac{T_x - T_0}{T_j - T_0}$$

where

$T_x$   measured temperature at any position  x

$T_0$   ambient temperature

$T_j$   jet total temperature

In all the calculations for the temperature parameter behind jet 1, the total temperature of jet 1 was used. The total temperature of jet 2 was used for all calculations for the temperature parameter behind jet 2 in the same manner. At the center line between the two jets, the average of the two jet temperatures was used.

In order to determine the boundary of the jet by the pressure survey, the height of the highest pressure tube that showed a positive pressure was taken as the boundary location for each rake position.

Water was injected into the tail pipe at the Y-section and high-speed moving pictures were made of the steam discharging from the nozzles to provide a visual indication of the flow pattern of the jets.

RESULTS AND DISCUSSION

During the investigation, jet-nozzle pressure ratio varied from 1.44 to 1.52 and gas temperature at the nozzles varied from about 1550° to 1750° R. The gas temperature of jet 2 was consistently about 30° F higher than that of jet 1, probably because

of unequal distribution of fuel to the burners. A three-
dimensional plot showing the contour of a constant-temperature
surface for a value of $T_x$-$T_0$/$T_j$-$T_0$ equal to 0.1 is presented
in figure 2. This figure also locates the sections for which
temperature and pressure contours are shown in subsequent figures.

The solid lines in figure 3 represent contours of constant-
temperature parameter in vertical planes perpendicular to a
vertical plane through the engine axis. Each figure presents the
contours for a given distance downstream of the jet nozzle. These
figures were obtained by cross-plotting from faired curves in
which values of the temperature parameter were plotted as a
function of height above the ground for each rake position. The
dashed line in each figure indicates the boundary of the jet as
determined by the pressure survey.

At a distance of 1 jet diameter downstream, the jet boundary
as determined by the pressure survey is very nearly symmetrical
(fig. 3(a)). The temperature survey in this plane indicates a
vertical expansion of the gases between the nozzles and on the
side of nozzle 1. Motion pictures of the steam issuing from the
nozzles, however, showed low-velocity eddies to be swirling up-
ward at this location between the jet nozzles. The eddies raised
the temperature in this region, as shown in the temperature
survey, but they were in a low-velocity area outside the boundary
of the main jets.

At 2 jet diameters downstream (fig. 3(b)), the temperature
distribution is similar to that at 1 diameter except that the
gradients are not so high and the contours are in general higher
above the ground. The jet boundary as determined by the pressure
survey is also considerably higher above the ground. The effect
of eddies in raising the temperature outside the jet boundary
is still apparent.

As the distance downstream is increased (figs. 3(c) to (f)),
the temperature contours remain approximately the same shape,
but are farther apart. The upward expansion of the gases between
the two jets, caused by mutual interference to free horizontal
expansion, becomes more pronounced. The boundary of the jets, as
determined by the pressure survey, expands outward until at a
distance of 6 jet diameters downstream it is practically coincident
with the temperature contour for $T_x$-$T_0$/$T_j$-$T_0$ = 0.1. The portions
of the jets not subject to interference expand, for the most part,
horizontally. At 6 jet diameters downstream, the lateral extremities
of the jet boundary are still less than 1 jet diameter above the
ground.

Figure 4 presents the temperature contours and the jet boundaries in planes parallel to a vertical plane through the engine axis. These curves were also obtained by cross-plotting from the faired curves used to obtain figure 3. Figures 4(c) to (g) show clearly that the gases expand upward between the two jets; figures 4(a), (b), and (h) show that the gases expand horizontally and remain close to the ground near the outer edge.

The investigation described was limited in scope; any attempt at generalization of the results should be made with care. Small changes in jet-nozzle spacing, angle of impingement, or height of nozzles above the ground would probably not alter the general characteristics of the jets, but the extent of the upward expansion between the two jets would undoubtedly be considerably influenced. Although obtained without afterburners, these data should be applicable to engine installations with afterburners unless part of the combustion takes place outside the tail pipes.

## SUMMARY OF RESULTS

The data for this investigation are limited to the following conditions: convergent nozzles; nozzle spacing, 1.42 nozzle diameters between center lines; angle of impingement, 20°; jet total temperature, 1550° to 1750° R; and nozzle pressure ratio, 1.44 to 1.52. The general results may be summarized as follows:

1. Temperature-distribution measurements indicate that two parallel jets located close together cause mutual interference, which results in an upward expansion of the gases between the jets beyond 1 diameter downstream of the nozzle exits. The jet boundary was farther above the ground between the two jets than it was directly behind either of the jet nozzles.

2. In the portions of the jets unaffected by the mutual interference, expansion of the hot gases was mostly horizontal with very little vertical rise.

3. Near the nozzles, the pressure survey showed the jet boundary to be much nearer the ground than indicated by the temperature survey. Eddies swirling upward carried high-temperature gases above the boundary indicated by the pressure survey.

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4. Beyond 4 nozzle diameters downstream of the nozzles, the pressure survey indicated that the jet boundary was approximately coincident with the constant-temperature contour in which the ratio of temperature rise above ambient to the temperature difference between jet and ambient was equal to 0.1.

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    National Advisory Committee for Aeronautics,
        Cleveland, Ohio,

### REFERENCE

1. Fleming, William A.:  Characteristics of a Hot Jet Discharged from a Jet-Propulsion Engine.  NACA RM E6L27a, 1946.
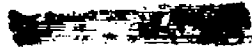
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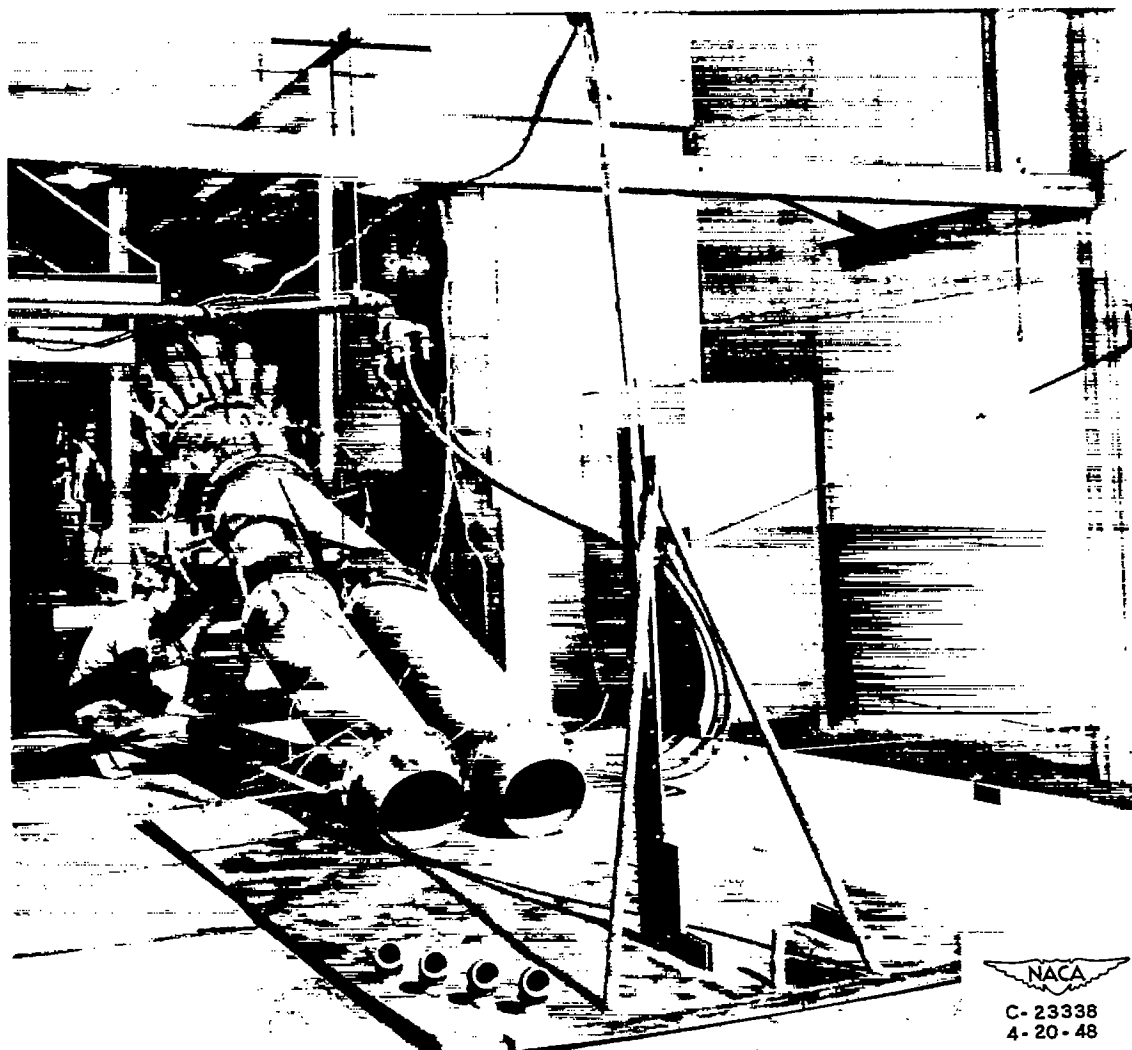
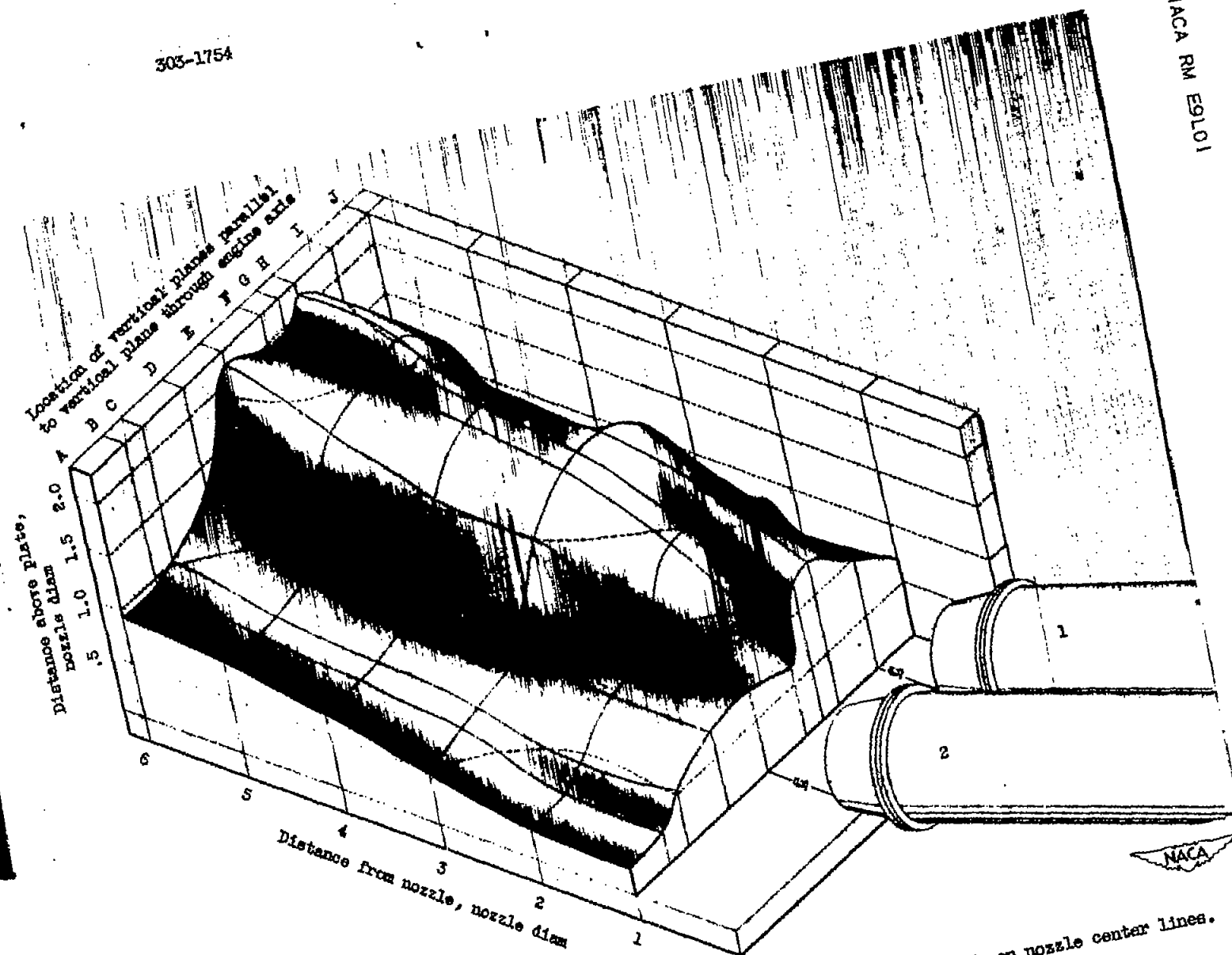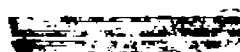Figure 1. - General view of test apparatus showing inclined jet nozzles and temperature-survey rake.
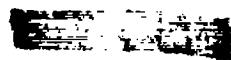
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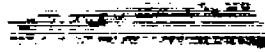


Figure 2. — Surface of constant temperature ratio $\frac{T_x - T_0}{T_j - T_0} = 0.1$. Planes E and I on nozzle center lines.

Distance above plate, nozzle diam

Distance from nozzle, nozzle diam

Location of vertical planes parallel to vertical plane through engine axis

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Location of vertical planes parallel to vertical plane through engine axis
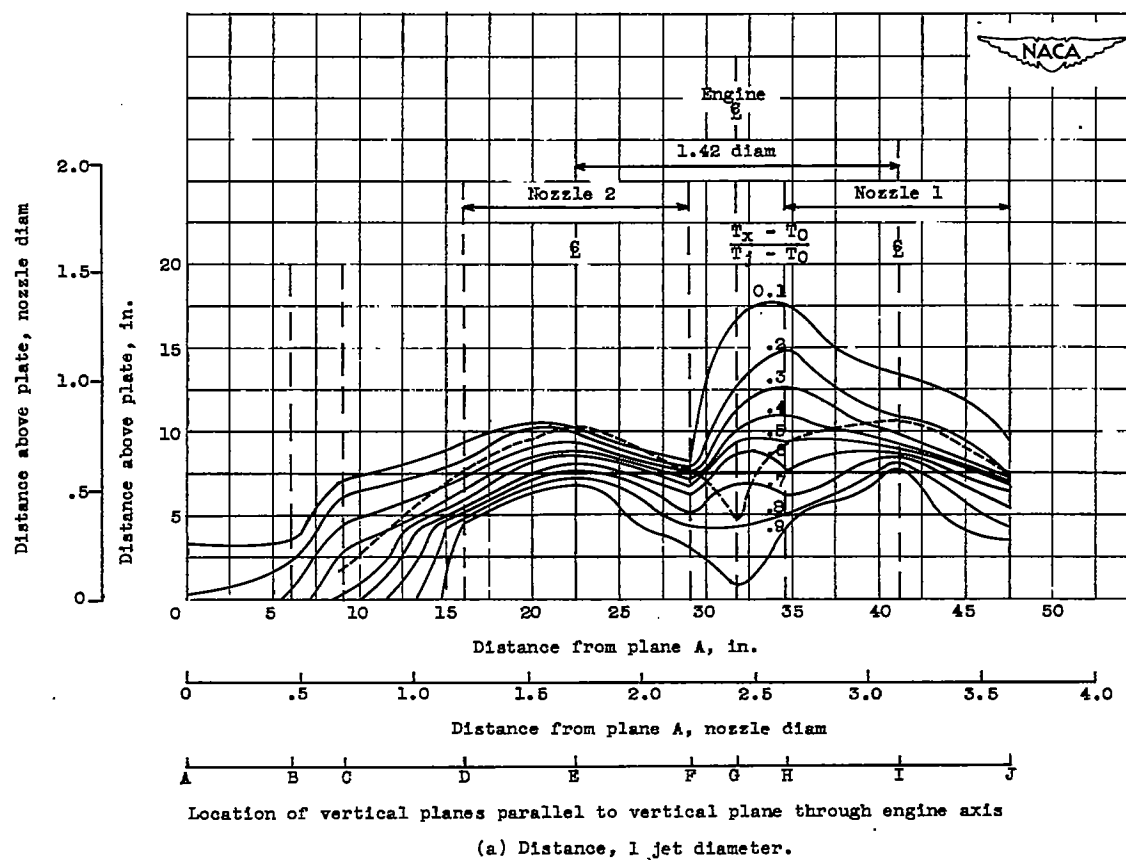
(a) Distance, 1 jet diameter.
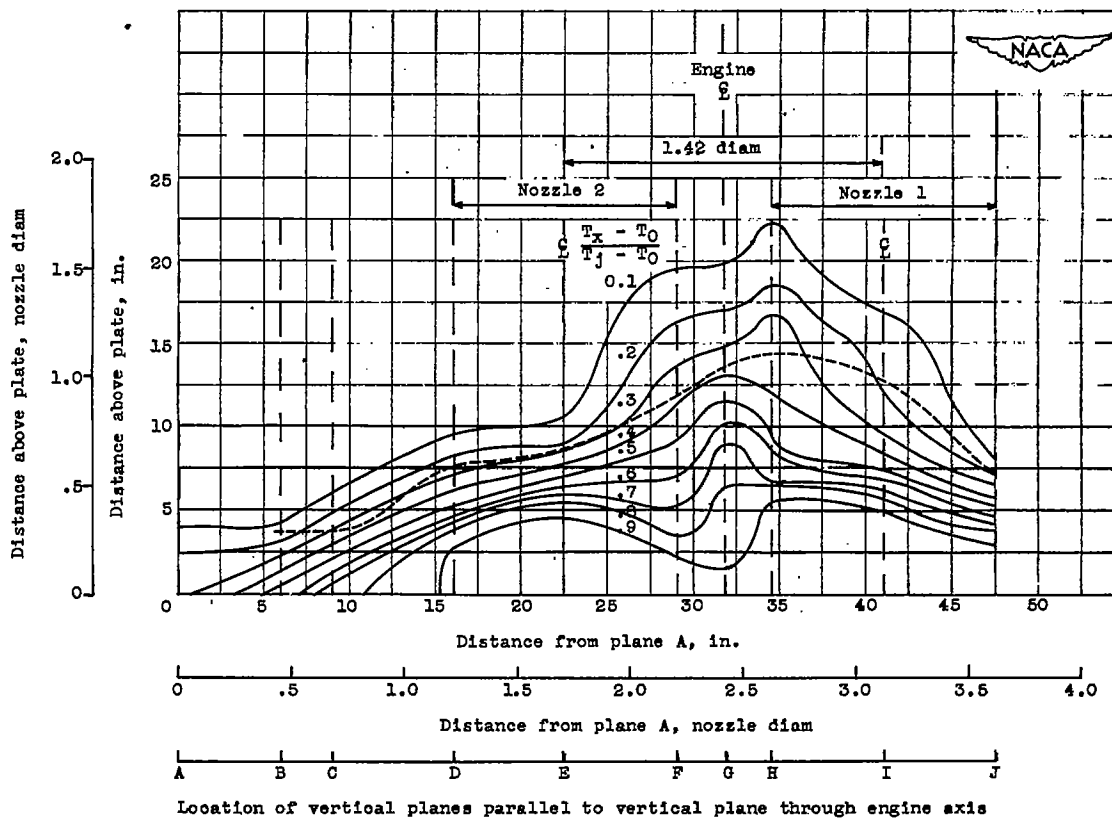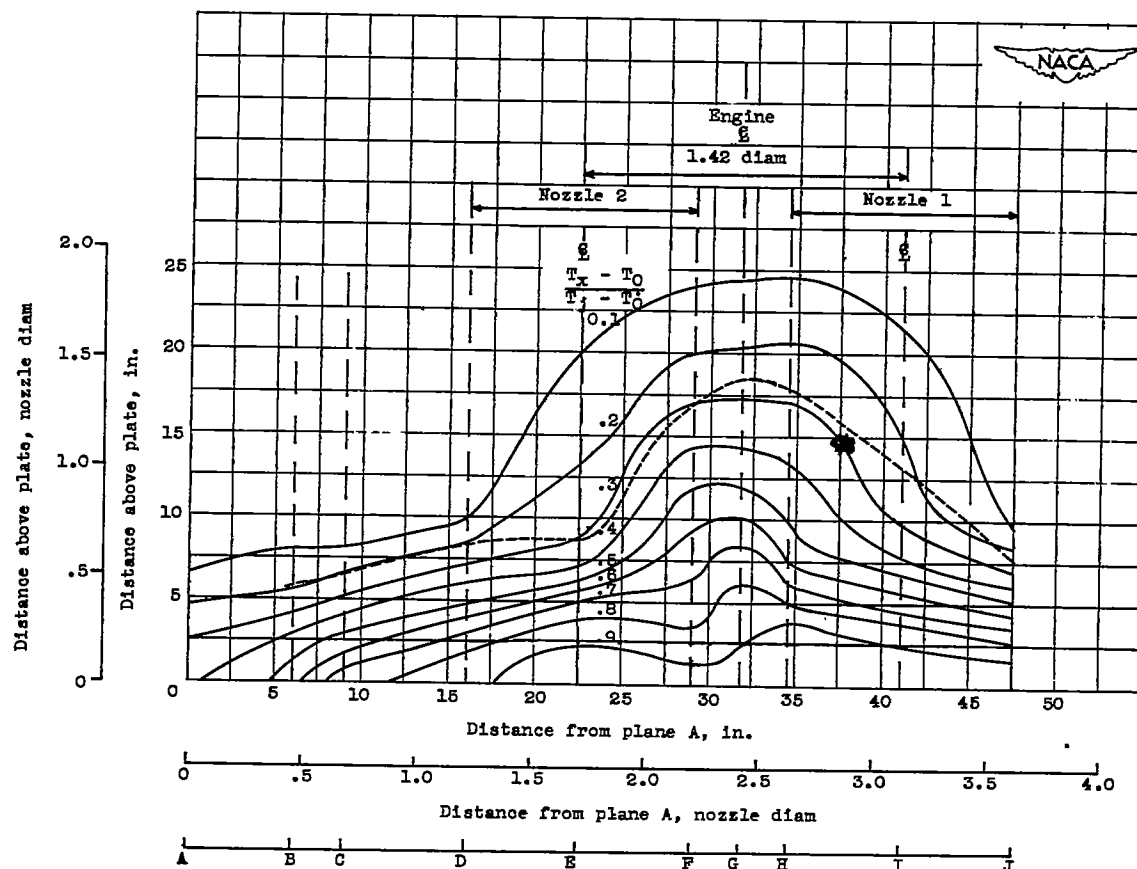
Figure 3. - Temperature distribution downstream of nozzle exits.  Dashed contour represents boundary of jets as determined by pressure survey.

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Distance above plate, nozzle diam

Distance above plate, in.

Engine
$\mathcal{C}$

1.42 diam

Nozzle 2

Nozzle 1

$\dfrac{T_x - T_0}{T_j - T_0}$

0.1

.2

.3

.4

.5

.6

.7

.8

.9

Distance from plane A, in.

Distance from plane A, nozzle diam

A    B    C    D    E    F    G    H    I    J

Location of vertical planes parallel to vertical plane through engine axis

(b) Distance, 2 jet diameters.

Figure 3. - Continued. Temperature distribution downstream of nozzle exits. Dashed
contour represents boundary of jets as determined by pressure survey.

(c) Distance, 3 jet diameters.
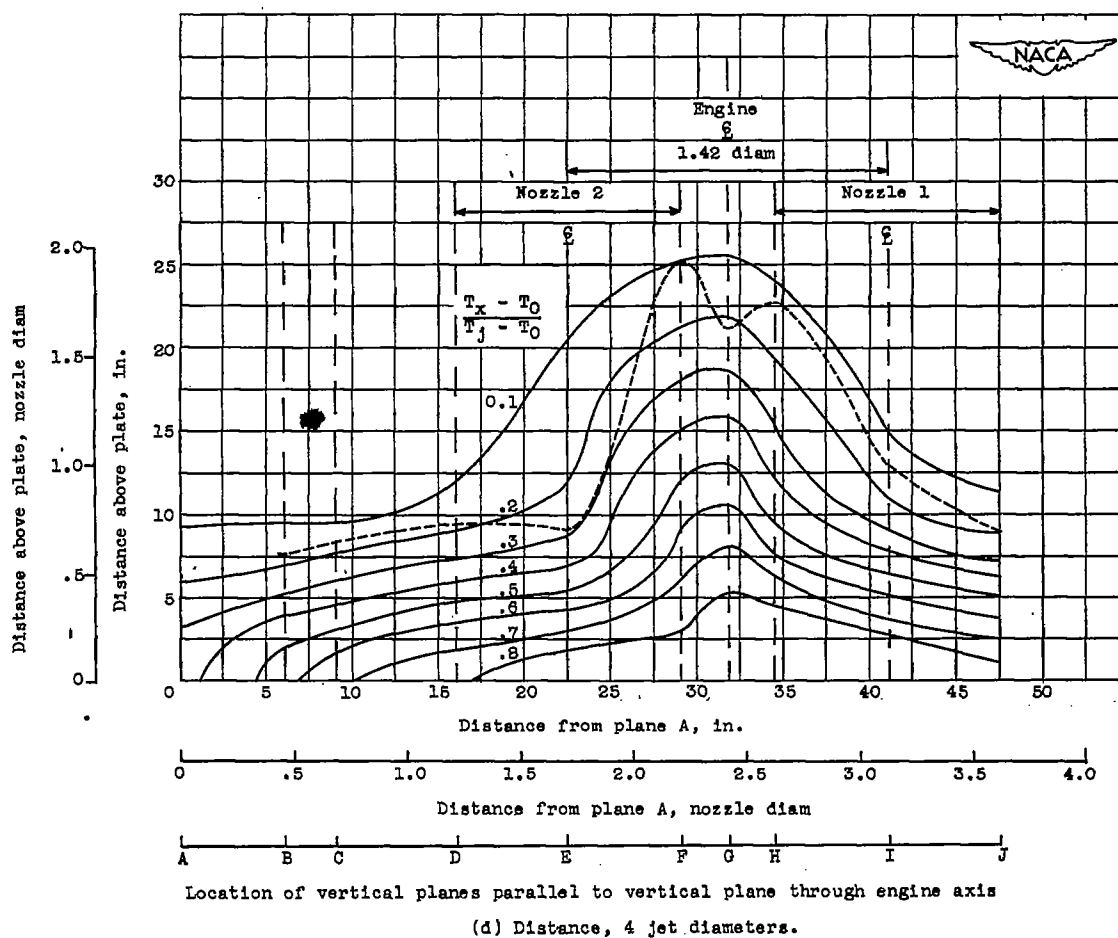
Figure 3. - Continued.  Temperature distribution downstream of nozzle exits.  Dashed
contour represents boundary of jets as determined by pressure survey.

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Location of vertical planes parallel to vertical plane through engine axis
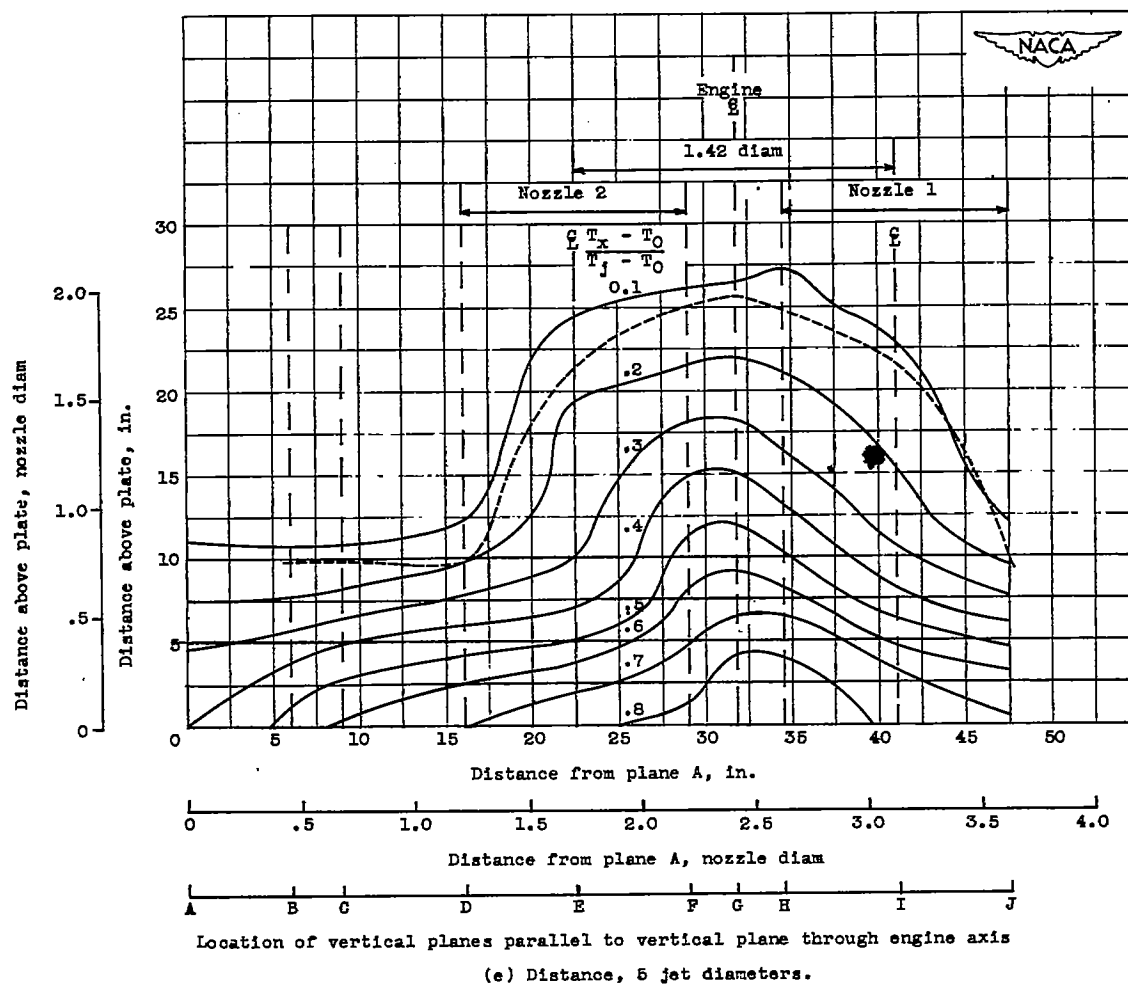
(d) Distance, 4 jet diameters.

Figure 3. - Continued. Temperature distribution downstream of nozzle exits. Dashed contour represents boundary of jets as determined by pressure survey.

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Location of vertical planes parallel to vertical plane through engine axis

(e) Distance, 5 jet diameters.

Figure 3. - Continued.  Temperature distribution downstream of nozzle exits.  Dashed
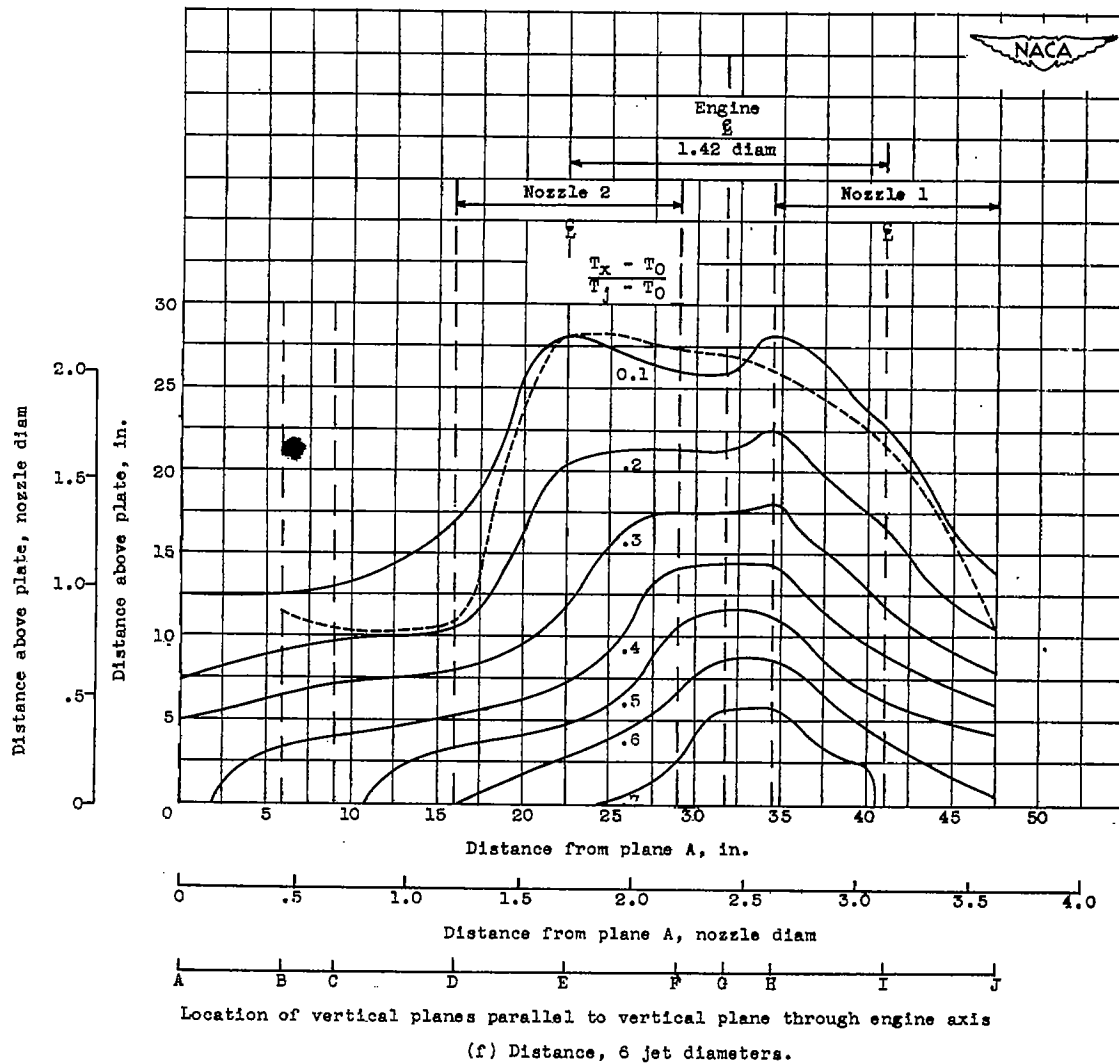contour represents boundary of jets as determined by pressure survey.

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Location of vertical planes parallel to vertical plane through engine axis

(f) Distance, 6 jet diameters.

Figure 3. - Concluded. Temperature distribution downstream of nozzle exits. Dashed contour represents boundary of jets as determined by pressure survey.
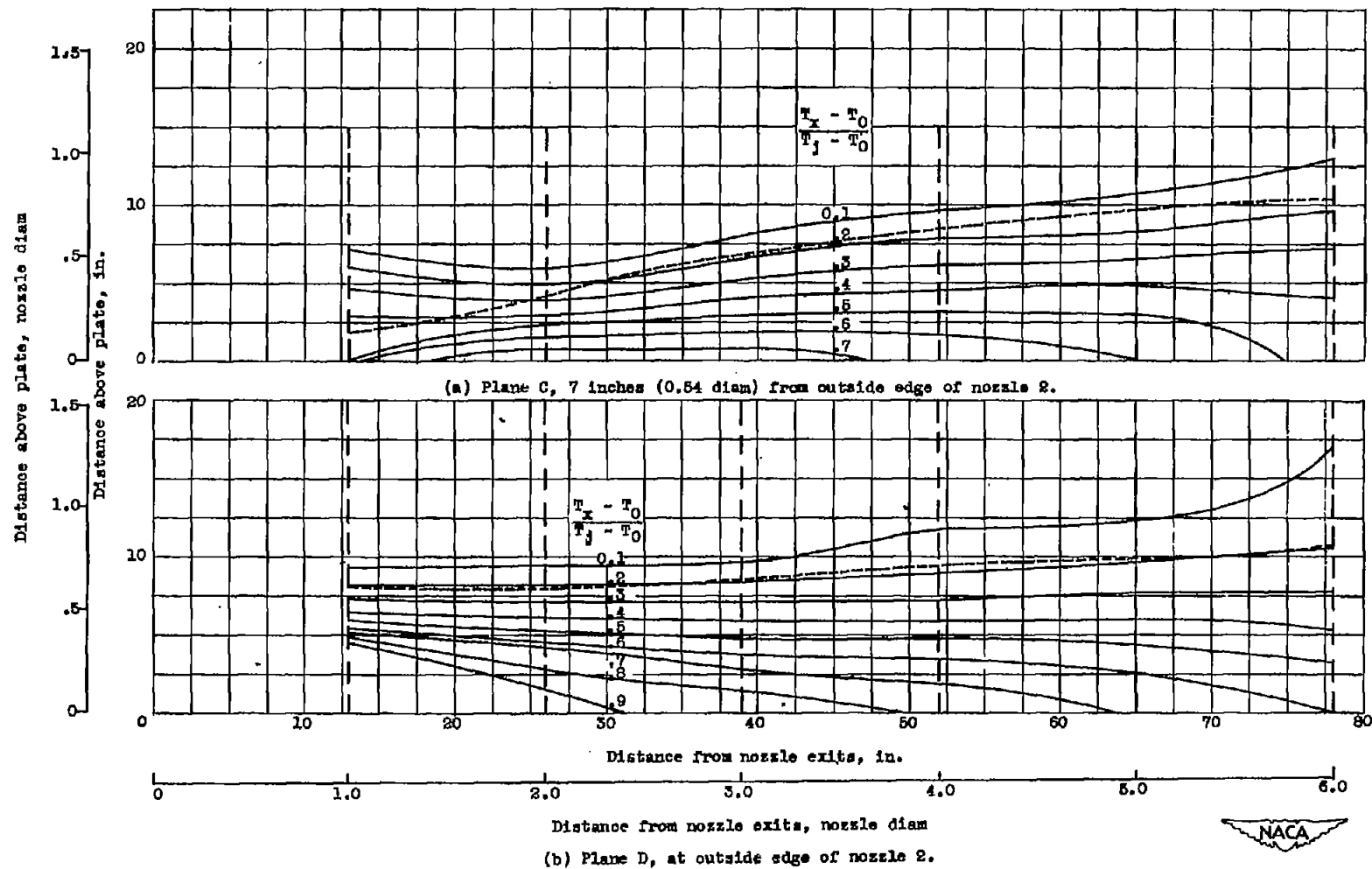
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(a) Plane C, 7 inches (0.54 diam) from outside edge of nozzle 2.

(b) Plane D, at outside edge of nozzle 2.

Figure 4. - Temperature distribution in vertical planes. Dashed curve represents boundary of jets as determined by pressure survey.
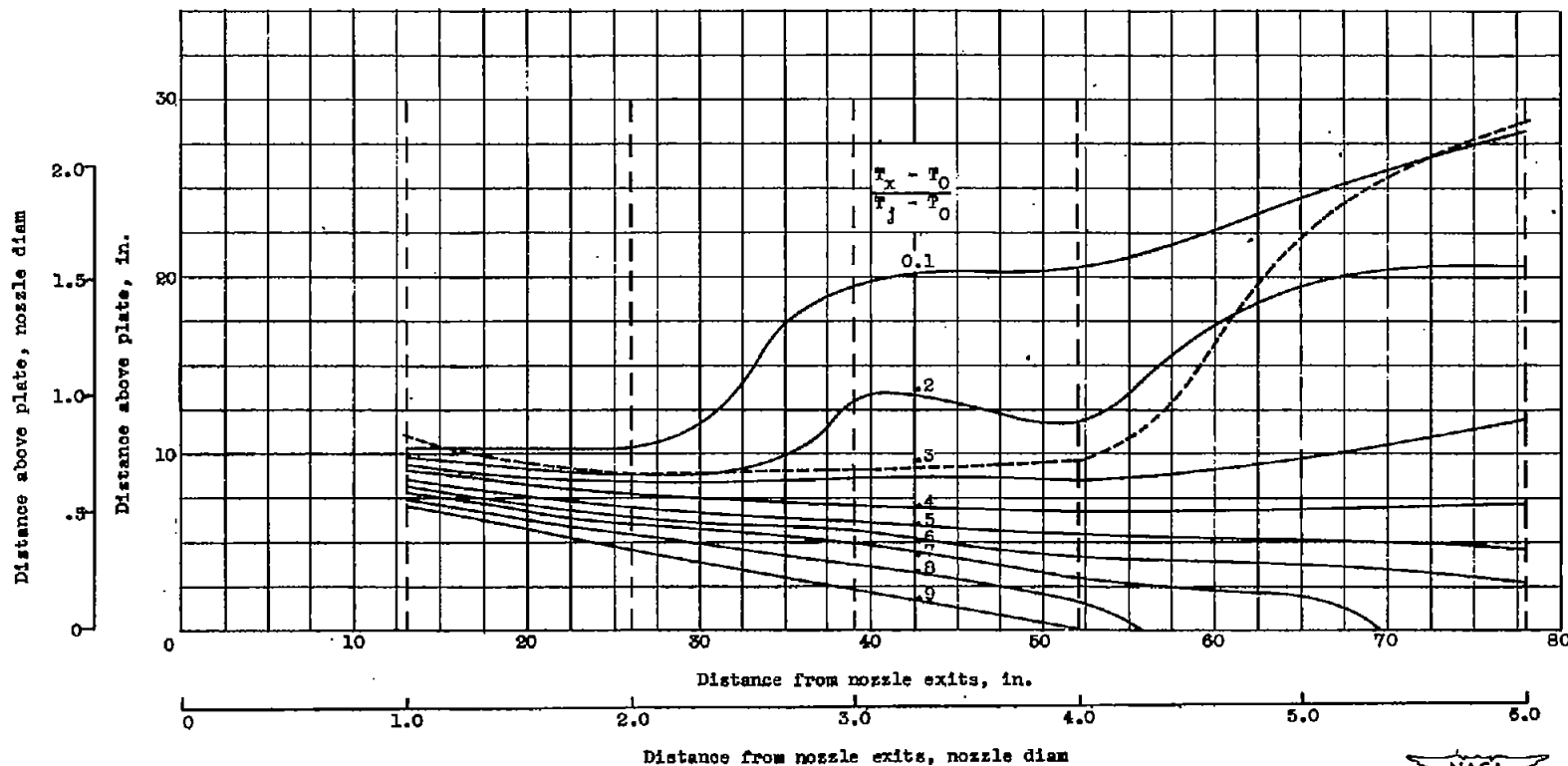
(c) Plane E, at center of nozzle 2.

Figure 4. - Continued.  Temperature distribution in vertical planes.  Dashed curve represents boundary of jets as determined by pressure survey.
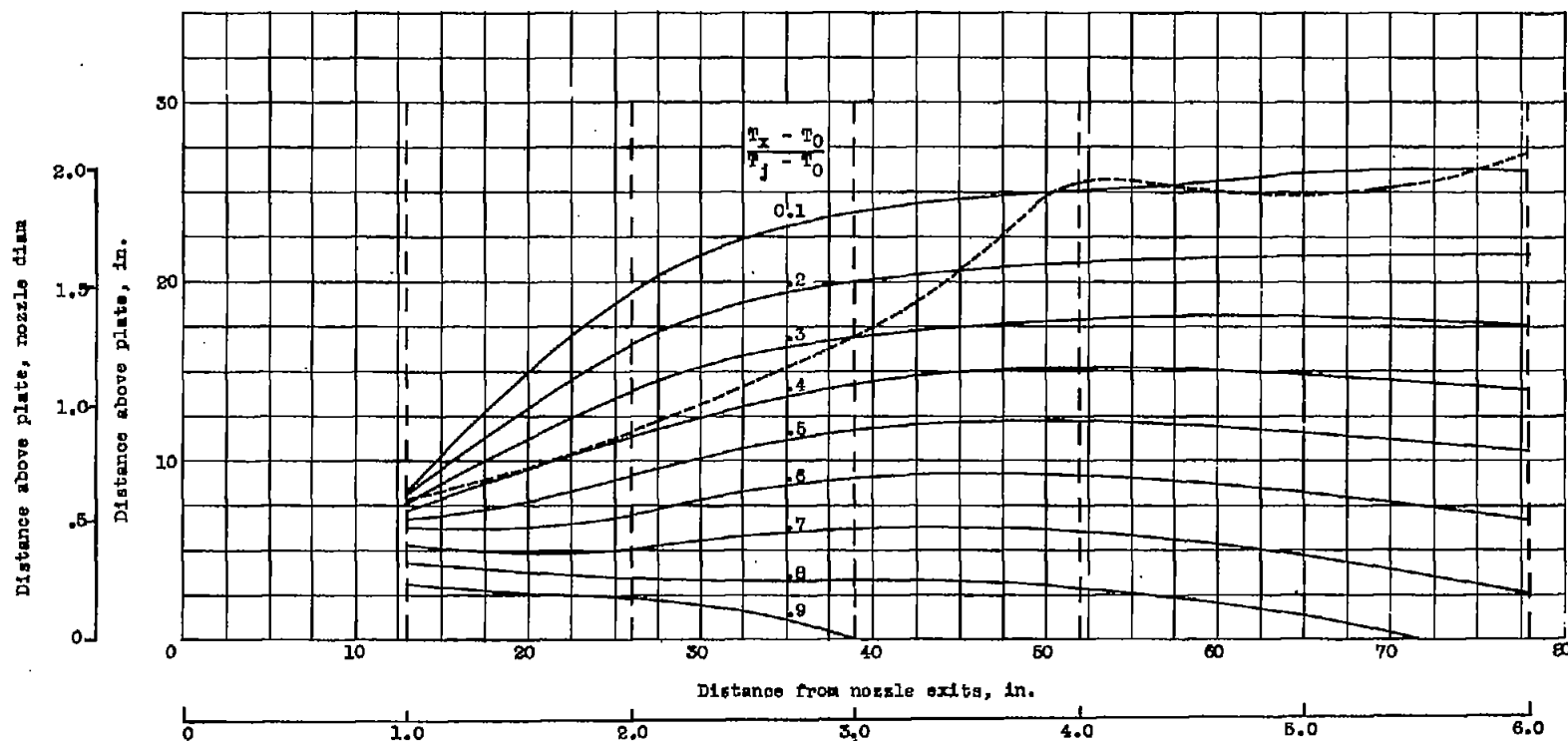
(d) Plane F, at inside edge of nozzle 2.

Figure 4. - Continued.  Temperature distribution in vertical planes.  Dashed curve represents boundary of jets as determined by pressure survey.
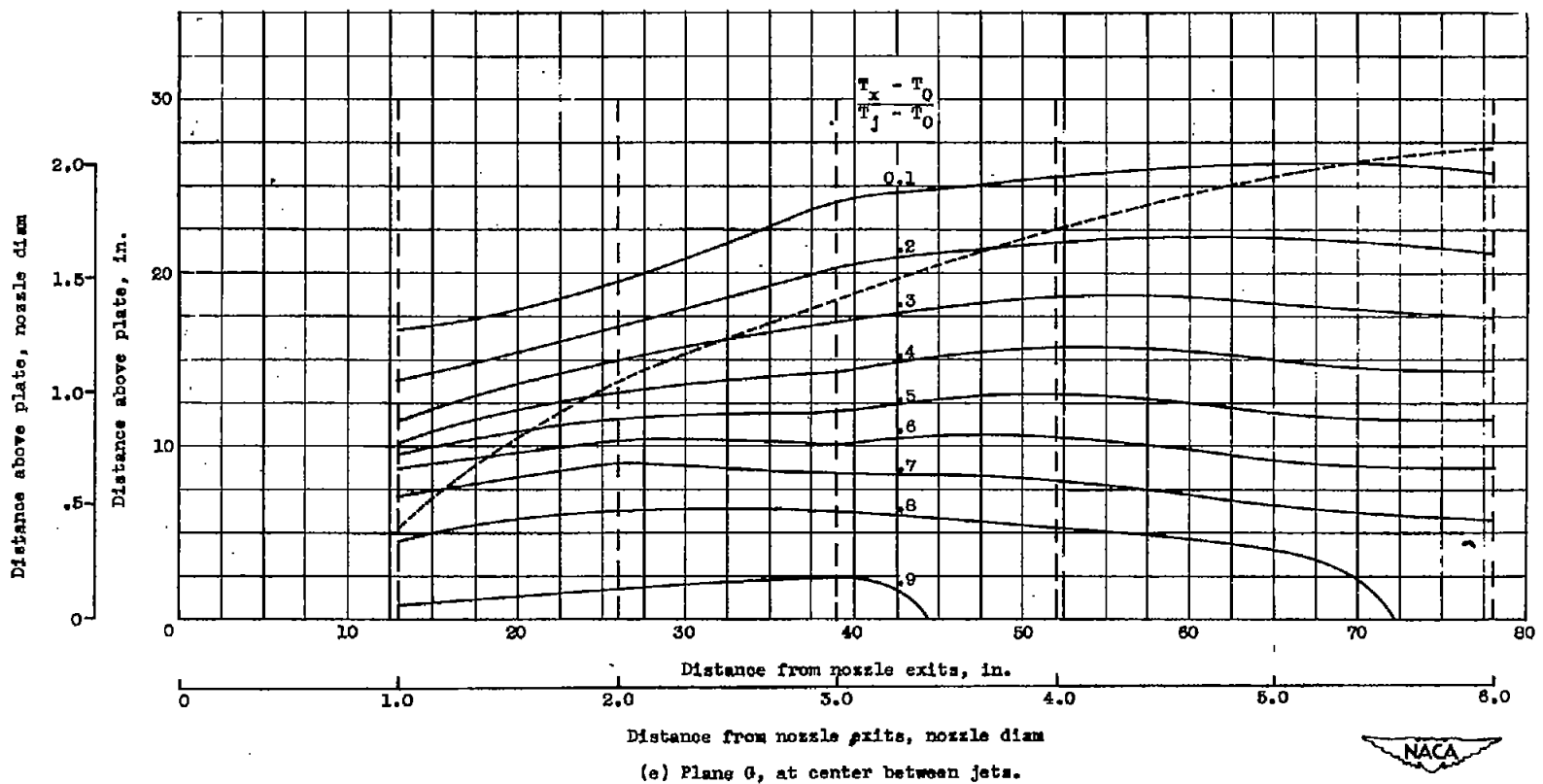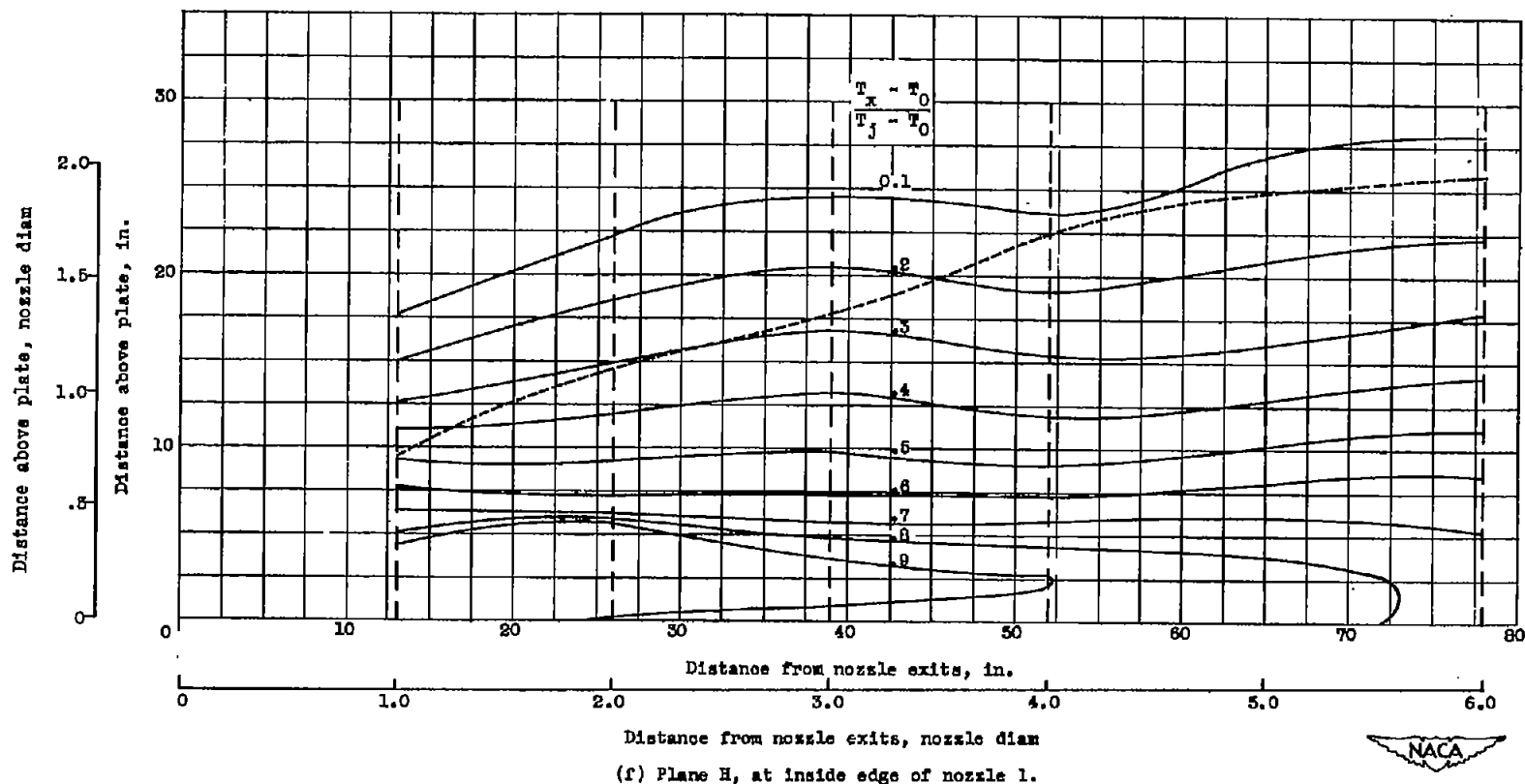
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(e) Plane G, at center between jets.

Figure 4. – Continued.  Temperature distribution in vertical planes.  Dashed curve represents boundary of jets as determined by pressure survey.

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$$\frac{T_x - T_0}{T_J - T_0}$$

(f) Plane H, at inside edge of nozzle 1.

Figure 4. - Continued.  Temperature distribution in vertical planes.  Dashed curve represents boundary of jets as determined by pressure survey.

(g) Plane I, at center of nozzle 1.
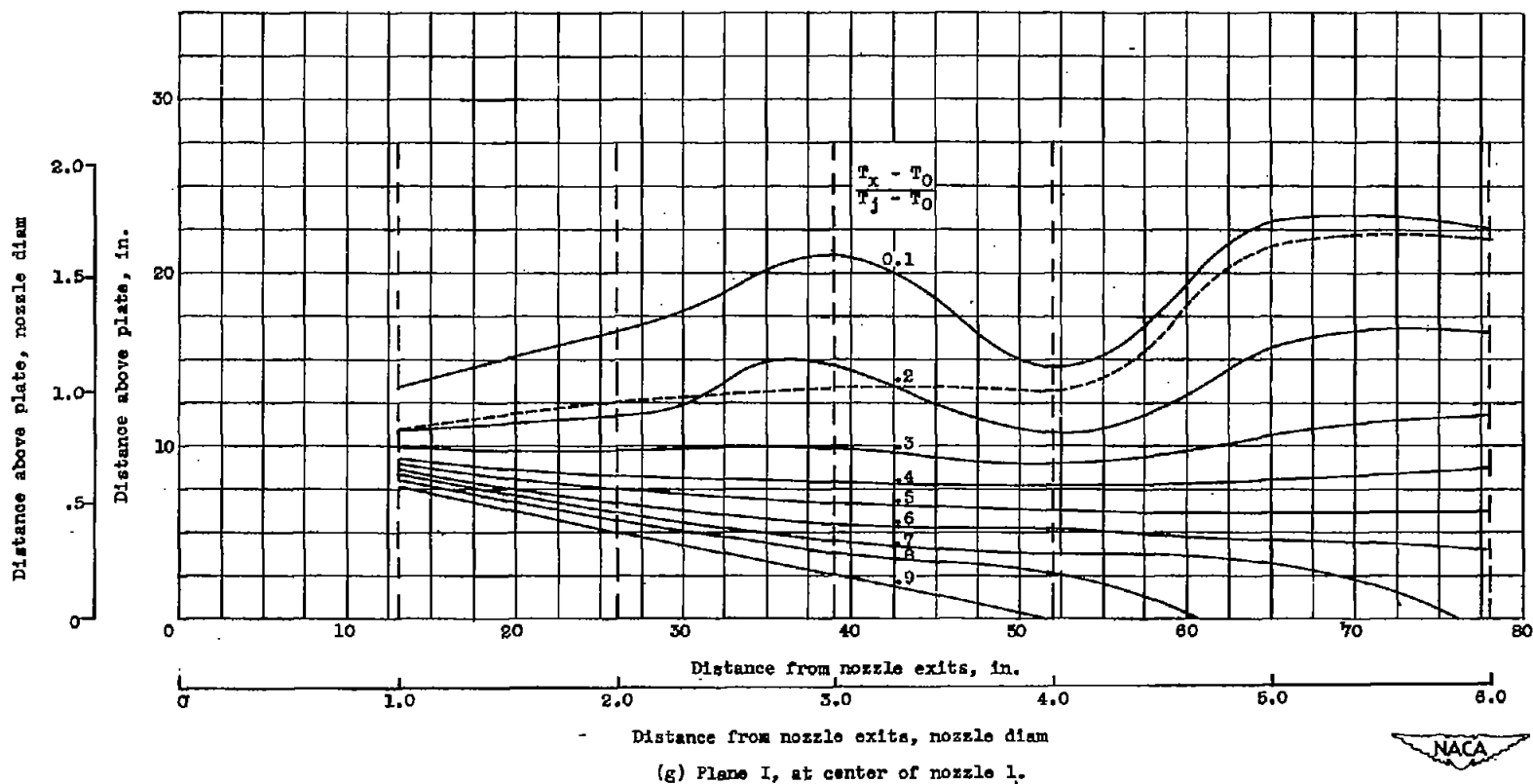
Figure 4. - Continued. Temperature distribution in vertical planes. Dashed curve represents boundary of jets as determined by pressure survey.

(h) Plane J, at outside edge of nozzle 1.

Figure 4. - Concluded.   Temperature distribution in vertical planes.   Dashed curve represents boundary of jets as determined by pressure survey.