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SUPERCHARGER OF A DOUBLE-ROW RADIAL AIRCRAFT ENGINE

I - EFFECT OF OPERATING VARIABLES

By Edmund J. Baas, William R. Monroe, and John M. Mesrobian

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NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

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SUMMARY

An investigation was conducted to determine the inherent flow
characteristics of the engine-stage supercharger or 18-cylinder
double-row radial aircraft engine. The supercharger inlet elbow
was flow-tested to determine the velocity profile of the air at
the impeller inlet for carburetor-throttle angles of 66°, 50°, and
40° from full closed. The 66° throttle angle is the maximum flow
setting for the carburetor used in the tests. The complete super-
charger assembly was set up and the flow distribution in the
18 outlets was determined. Tests were run at various speeds,
volume flows, outlet pressures, and carburetor-throttle angles to
investigate the effect of each on the flow distribution.

Considerable variation was found in the air flow in the
18 outlets of the supercharger. The distribution varied, for the
useful range of supercharger operation, from 40 percent above
average to 60 percent below average. The basic distribution
pattern was not appreciably altered by a change in the impeller
tip speed, the outlet reference pressure, the volume flow, or the
carburetor-throttle angle. The distribution spread tended to
decrease as the volume flow decreased but the basic pattern was
maintained. Because the discharge conditions of the test rig
differed from those in an engine installation, the nonuniform
distribution observed in the present tests will be very much less
in actual operation, but the trend will be similar.

INTRODUCTION

As part of an investigation requested by the Air Technical
Service Command, Army Air Forces, to improve the mixture distribu-
tion of a double-row radial engine, an extensive test program is
being conducted at the NACA Cleveland laboratory to determine the
air-flow characteristics of this engine.

The results of an investigation of the performance of an
18-cylinder double-row radial aircraft engine (reference 1) show a
large variation in cylinder-head temperatures. The hottest cylin-
der, which determines the cooling-air pressure drop and the degree
of fuel enrichment required for operation within specifications,
limits the engine performance and fuel economy. The variation in
cylinder-head temperatures may be attributed to an uneven distri-
bution of the fuel and the charge air to the individual cylinders
and to unequal cooling-air distribution.

The tests reported herein, conducted during the early part of
1945, were made to determine the inherent charge-air distribution
characteristics of the engine-stage supercharger of the double-row
radial engine. Preliminary to the present tests the supercharger
inlet-elbow and carburetor assembly was flow-tested to determine
the velocity distribution of the air at the outlet of the super-
charger inlet elbow for various carburetor-throttle angles. The
complete supercharger assembly was set up with 18 uniform outlet
pipes exhausting into a collector and the flow characteristics of
this assembly were determined. Tests were made to determine how
the distribution in the 18 outlets of the supercharger was affected
by the impeller tip speed, the volume flow, the outlet pressure, and
the distortion of the velocity profile at the impeller inlet. Com-
plete supercharger data were obtained for all tests in order to
locate the useful operating range of the supercharger.

APPARATUS AND TESTS

For the flow tests the supercharger inlet elbow with a conven-
tional injection-type hydrometering carburetor was set up in a
duct-component test rig which is shown schematically in figure 1.
Standard pitot-static tubes were used to make velocity surveys
across the elbow outlet (station 1) at traverses A, B, and C. The
tests were made for carburetor-throttle angles of 66°, 50°, and
40° from full closed. The 66° throttle-angle position is the maxi-
mum flow setting for this carburetor.

For the distribution studies the complete engine-stage supercharger and accessory drive units with the carburetor were set up for testing as shown in figure 2. The supercharger, driven by a liquid cooled aircraft engine, exhaust into a large symmetrical collector through 18 uniform outlet pipes. The supercharger rig was not lagged because the main objective of these tests was to obtain distribution data rather than supercharger efficiency. In order to eliminate any effect of the collector on the flow distribution in the 18 outlet pipes, a baffle was placed in the collector, dual collector outlets were used, and the collector was made as large as space limitations permitted. An inlet and an outlet throttle were used to control the air flow through the supercharger and to regulate the reference outlet pressure measured at the engine-manifold-pressure fitting on the rear supercharger-housing cover.

The instrumentation of the supercharger test rig conformed to the specifications of reference 2. The weight flow of air through the supercharger was determined by measuring the static-pressure drop across a thin-plate orifice with an NACA micromanometer. The inlet-air static pressure, total pressure, and temperature were measured upstream of the carburetor upper deck at a distance twice the narrow dimension of the inlet duct, which is a straight rectangular section 12 times the narrow dimension in length.

The inlet-air static pressure, the total pressure, and the temperature in each outlet pipe were measured at a station located 15 diameters downstream of the bend in the pipe and 6 diameters upstream of the collector. The point at which the total-pressure and the total-temperature measurements were taken was one-third the distance across the inside diameter of the pipe.

In order to determine if a possible nonuniformity of outlet pipes influenced the observed flow distribution, pipes 5 and 14, which exhibited the maximum and the minimum flows, respectively, were interchanged. The collector was then rotated 40° with respect to the supercharger outlet pipes to observe the influence of the collector outlets on the distribution pattern. A distortion plate was placed between the carburetor and the supercharger inlet-elbow mating flanges to study the effect on the flow distribution of a large distortion of the velocity profile at the impeller inlet. This plate blocked off half the inlet area at the inside of the bend. Tests were made to determine the effect of impeller tip speed, outlet pressure, volume flow, distortion at impeller inlet, outlet-pipe uniformity, and collector-outlet location on the air distribution in the 18 outlets of the supercharger. The variables for the tests are listed in the following table:

Engine speed (rpm)	Reference outlet pressure (in. Hg above atmospheric)	Carburetor-throttle angle (deg)	Test-rig variations (a)
1600-2800 (in increments of 200)	6	66	None
2200	6	66	A
2000	6	66	A,B
2400	6	66	A,B
2000	6	55	A,B
2000	6	50	A,B
2000	6	45	A,B
2000	6	40	A,B
2000	6	66	A,B,C
2400	6	55	A,B
2400	6	50	A,B
2400	6	45	A,B
2400	6	40	A,B
2400	6	66	A,B,C
2000	Wide-open outlet throttle	66	A,B
2000	3	66	A,B
2000	10	66	A,B
2400	Wide-open outlet throttle	66	A,B
2400	3	66	A,B
2400	10	66	A,B

[a]Test-rig variations are as follows:
    A Outlet pipes 5 and 14 interchanged.
    B Collector rotated 40°.
    C Distortion plate added.

    The test procedure recommended in reference 2 was followed except for obtaining the values of outlet pressure. Complete supercharger data were obtained for all tests in order to locate the useful operating range of the supercharger.

CALCULATIONS

    Inasmuch as low velocities existed in the outlet pipes, these velocities were computed from the dynamic pressure for incompressible flow. The mass-flow distribution in the 18 outlet pipes was

computed from the product of the velocity and the density in each
outlet pipe on the assumption that the velocity profiles in each
pipe were symmetrical and similar; the error introduced by this .
assumption is negligible because there were 15 diameters of straight
pipe before the measuring station and the flow was turbulent for
all tests.

The use of a constant value of load coefficient Q_1/n for com-
paring the results of these tests is unsatisfactory because a con-
stant value of Q/n at the inlet measuring station upstream of
the carburetor does not give a constant value of Q/n at the
impeller inlet. The design of the test rig prohibits the instal-
lation of instruments for determining the volume rate of flow at
the impeller inlet and a flow function determined by outlet condi-
tions must consequently be used to obtain comparable flow conditions
within the supercharger unit. The flow factors Q_{2_t}/n and $Q_{2_t}/\sqrt{T_{2_t}}$

where

Q   volume flow, cubic feet per second

n   impeller speed, revolutions per second

T   absolute temperature, °F

subscripts

2   outlet

t   total

are satisfactory as a basis for comparison; Q_2/n is a measure of
the geometry of flow and $Q_{2_t}/\sqrt{T_{2_t}}$ is a measure of the Mach number.
At constant impeller tip speeds the effect of both functions is the
same and either may be used. The derivation of $Q_{2_t}/\sqrt{T_{2_t}}$ is shown
in the appendix.

RESULTS AND DISCUSSION

The results of air-flow distribution for all tests are presented
as nondimensional plots of M/M_{av} against outlet-pipe number, where
M is the mass flow for any one pipe and M_{av} is the computed average
mass flow for one pipe. The outlet-pipe number corresponds to the
engine cylinder. Data are presented in only the useful operating
range of the supercharger.

Effect of impeller tip speed. - The effect of impeller tip
speed can be completely isolated only by holding constant either
the geometry of flow or the Mach number at every point in the system,
which may be done by using the flow function Q/n to study the
geometry of flow effect and the flow function $Q/\sqrt{T}$ to study the
Mach number effect. The geometry of flow or the Mach number can be
held constant at only one point in the system; at all other points
these factors will vary with changes in speed. Because the instru-
mentation of the test rig limits the stations at which the flow
functions can be determined, the outlet station was used. The flow
functions at this point reflect the geometry of flow and the Mach
number at the outlet pipes. In either case the resulting variation
from the basic pattern is not solely a speed effect but a summation
of speed effects and the effects represented by the flow function
that is varied.

Figure 3 is plotted for constant values of Q_{2_t}/n and figure 4
for constant values of $Q_{2_t}/\sqrt{T_{2_t}}$. A complete range of speeds is not
shown in all plots because of the impossibility of obtaining suffi-
ciently high flows at the low speeds. Poor air-flow distribution
existed at all speeds and flows; either outlet pipe 1 or 5 had the
highest mass flow and outlet pipe 14 the lowest mass flow. The maxi-
mum deviations from the computed average mass flow ranged from
40 percent above to 60 percent below average. For both flow parameters
the basic distribution pattern was maintained at all speeds and mass
flows. For the curves based on Q_{2_t}/n little scatter occurred at
any point other than outlet pipe 13 where the deviation from the com-
puted average increased with speed. Considerably more scatter
occurred in the plots using $Q_{2_t}/\sqrt{T_{2_t}}$ as a parameter than those
using Q_{2_t}/n. This difference in the amount of scatter indicates
that the geometry of flow had more influence on the air-flow distri-
bution than the Mach number. The impeller speed seemed to have no
decided effect on the basic distribution pattern.

Effect of outlet pressure. - The effect of outlet pressure on
the air-flow distribution in the supercharger outlets is presented
in figure 5 for wide-open outlet throttle and for reference outlet
pressures of 3, 6, and 10 inches of mercury above atmospheric. The
reference outlet pressure at wide-open outlet throttle ranged from
1.05 inches of mercury above to 0.28 inch of mercury below atmospheric
pressure. These runs were made at engine speeds of 2400 and 2000 rpm
with carburetor throttles at 66°. Comparison of the distribution
obtained at the different values of reference outlet pressure indi-
cates that the magnitude of the boost had no appreciable effect on
the air-flow distribution.

Effect of volume flow. - The effect of volume flow on the air-
flow distribution is shown in figure 6. The test data presented
were obtained from runs at 2000 and 2400 rpm, a carburetor-throttle
setting of 66°, and a reference outlet pressure of 6 inches of mer-
cury above atmospheric. The values of $Q_{2_t}/\sqrt{T_{2_t}}$ for the flows
used were approximately 2.7, 1.9, and 1.5 at 2400 rpm and 2.3, 1.8,
and 1.3 at 2000 rpm. Although the trend is not reflected at all
individual outlet pipes, a reduction in volume flow tends to mini-
mize the magnitude of the deviation from the average mass flow
without appreciably altering the basic distribution pattern. This
effect is to be expected because the conditions contributing to
distortion become more critical with the high velocities that accom-
pany increases in volume flow. At high volume flows beyond the
normal operating range of the supercharger, a tendency toward back-
flow was noted in outlet pipe 6.

Effect of distortion at impeller inlet. - The results of the
flow tests of the supercharger inlet elbow are presented in figure 7
as plots of V/V_{av} against l/L where V/V_{av} is the ratio of the
local velocity at a point to the computed average velocity and l/L
is the ratio of the distance of the particular point from the inside
wall of the bend to the total length of traverse of the survey.
There was a change in velocity profile with a change in carburetor-
throttle angle but the basic profile was not appreciably altered.

The effect of carburetor-throttle angle on the supercharger air-
flow distribution in the outlet pipes is shown in figure 8. Any
variation in carburetor-throttle angle and the subsequent distortion
of the velocity profile at the impeller inlet had no apparent effect
on the air-flow distribution pattern. The slight scatter in data at
low values of $Q_{2_t}/\sqrt{T_{2_t}}$ may be partly attributed to the difficulty
of obtaining precise measurements at low flows.

A comparison of similar tests, with and without the distortion
plate (fig. 9), shows that the velocity profile of the air at the
impeller inlet has a slight effect on the air-flow distribution of
the supercharger. The change in velocity profile with change in
throttle angle through the operating range, however, is not of suf-
ficient magnitude to appreciably affect the air-flow distribution.

Effect of outlet-pipe uniformity and collector-outlet location. -
The results of the tests to check the uniformity of the outlet pipes
by interchanging pipes 5 and 14 (fig. 10) show that any effect of
outlet-pipe nonuniformity on the air-flow distribution obtained is
negligible.

The investigation of the effect of collector-outlet location (fig. 11) shows that the distribution pattern was not appreciably altered by rotating the collector outlets and therefore the design of the collector did not influence the distribution pattern obtained.

Duplication of results. - Figure 12 is a comparison of the results for two approximately equal values of flow function to demonstrate the degree of accuracy with which data for the same test conditions could be reproduced. Although excellent agreement of data is shown for most of the outlet pipes, there was some variation in pipes 3, 11, and 13 as a result of a small fluctuation of the flow in these pipes. In no case was the variation in distribution sufficient to influence the results obtained.

Supercharger performance. - The adiabatic efficiency η_{ad} and the pressure coefficient q_{ad} were obtained for a carburetor-throttle setting of 66° and impeller tip speeds V_T corresponding to engine speeds of 1600, 1800, 2000, 2200, 2400, 2600, and 2800 rpm. These data are presented in figure 13 as plots against $q_{2t}/\sqrt{T_{2t}}$. The supercharger performance was taken from the inlet measuring station upstream of the carburetor to the measuring stations in the outlet pipes. Because the test rig was not lagged, the adiabatic efficiencies tend to be high. The inclusion of the carburetor pressure drop in the pressure ratio of the supercharger, however, would tend to counteract the increase in efficiency due to heat transfer and would, in all cases, reduce the pressure coefficients. Absolute values of the efficiency were not considered important inasmuch as the air-distribution data were the principal objective of these tests; the supercharger data are included only to show the range of operation for which the air-distribution data are presented.

GENERAL COMMENTS

The variation in mass flow in the outlets of the supercharger may be interpreted as an indication of the pressure distribution around the collector of the supercharger. Because the flow in each outlet pipe was intermittent during actual engine operation, the nonuniform distribution of charge air for an engine-supercharger combination will not be so great as these tests indicate. The air-flow distribution may be expected to follow the same trend with the highest flow in either outlet 1 or 5 and the lowest flow in outlet 14.

The asymmetry of the air-flow distribution at the outlets is the result of a summation of the asymmetry of flow paths throughout the supercharger system. The tests of the inlet elbow showed a low-velocity area behind the impeller-shaft bearing support that was not

appreciably altered by changes in carburetor-throttle angle. Inas-
much as poor flow conditions existed at the impeller inlet, it is
logical to assume that the flow at the impeller outlet would be
distorted. The diffuser had 13 vanes which caused an unsymmetrical
location of vanes with respect to the 18 outlets and an uneven
pressure distribution around the collector. This distortional
effect of the diffuser may even further amplify the uneven flow.
distribution present at the diffuser inlets.

Throughout this investigation variations in impeller speed,
volume flow, carburetor-throttle angle, and outlet pressure did not
appreciably alter the basic distribution pattern. The slight vari-
ations from the basic pattern, produced by the distortion plate,
indicated the significance of impeller-inlet conditions on air-flow
distribution in the outlets. The distribution pattern obtained was
not caused by inlet or diffuser conditions alone but by a summation
of both effects. The air-flow distribution could probably be
improved by a symmetrical arrangement of diffuser vanes and super-
charger outlets and by improving the velocity profile at the impeller
inlet by redesigning the inlet elbow.

SUMMARY OF RESULTS

From tests made to determine the flow distribution in the 18 out-
lets of the engine-stage supercharger of an 18-cylinder double-row
radial aircraft engine, the following results were obtained:

1. Poor air-flow distribution was observed in the outlets of
the engine-stage supercharger during all tests. Outlets 1 and 5
received the highest mass flow and outlet 14 the lowest. The maxi-
mum deviations from the computed average mass flow encountered for
the useful range of supercharger operation varied from 40 percent
above average to 60 percent below average. The nonuniform distri-
bution under conditions of actual engine operation, however, would
not be so great as these tests indicated.

2. A variation in impeller tip speed for the normal engine
operating range had a negligible effect on the basic air-flow dis-
tribution pattern.

3. A variation in outlet pressure from approximately 0 to
10 inches of mercury above atmospheric pressure had a negligible
effect on the basic air-flow distribution pattern.

4. A decrease in volume flow caused a decrease in the magnitude
of the deviation of the air-flow distribution from the average but
the basic distribution pattern was maintained.

5. Changes in carburetor-throttle angle for the normal oper-
ating range had a negligible effect on the basic air-flow distri-
bution pattern. A pronounced distortion of the velocity profile
at the impeller inlet, however, had a slight effect on the distri-
bution pattern.

Aircraft Engine Research Laboratory,
     National Advisory Committee for Aeronautics,
          Cleveland, Ohio, August 28, 1945.

APPENDIX - DERIVATION OF THE FLOW FUNCTION $Q_{2_t}/\sqrt{T_{2_t}}$

When the supercharger load coefficient Q_{1_s}/n and the speed ratios are given, the flow function $Q_{1_s}/\sqrt{T_{1_s}}$ may be determined by

$$\frac{Q_{1_s}}{\sqrt{T_{1_s}}} = \frac{Q_{1_s}}{n} \cdot \frac{S\sqrt{\gamma g R}}{\pi D}$$

where

S   speed ratio, ratio of impeller tip speed to sonic velocity at supercharger inlet

γ ratio of specific heats for normal air $(c_p/c_t = 1.3947)$

g   ratio of absolute to gravitational unit of mass, lb/slug (32.174)

R   gas constant for normal air, ft-lb/lb/$^\circ$F (53.50)

D   impeller diameter, ft

and the subscripts

s   static

1   inlet

If the performance of a supercharger is uniquely determined by the variables Q_{1_s}/n and S, it is therefore uniquely determined by the variables $Q_{1_s}/\sqrt{T_{1_s}}$ and S.

In order to avoid the effect of changes in flow area on the actual volume flow, it is convenient to use the total temperature T_{1_t} with the fictitious volume flow Q_{1_t}, which is the quotient of the mass flow and the total density. The factor $Q_{1_t}/\sqrt{T_{1_t}}$ is related to $Q_{1_s}/\sqrt{T_{1_s}}$ by

$$\frac{Q_{1_t}}{\sqrt{T_{1_t}}} = \frac{Q_{1_s}}{\sqrt{T_{1_s}}} \left[\frac{1}{1 + \frac{\gamma - 1}{2\gamma g A_1^2 R}\left(\frac{Q_{1_s}}{\sqrt{T_{1_s}}}\right)^2} \right]^{\frac{\gamma + 1}{2(\gamma - 1)}} \tag{1}$$

where A is area in square feet. The flow function at the outlet
of the supercharger $Q_{2_t}/\sqrt{T_{2_t}}$ may also be used with S for com-
parison of supercharger performance. This relation may be expressed

$$\frac{Q_{2_t}}{\sqrt{T_{2_t}}} = \frac{Q_{1_t}}{\sqrt{T_{1_t}}} \ \frac{P_{1_t}}{P_{2_t}} \ \frac{\sqrt{T_{2_t}}}{\sqrt{T_{1_t}}}$$

where P is the pressure in pounds per square foot.

Then

$$\frac{Q_{2_t}}{\sqrt{T_{2_t}}} = \frac{Q_{1_s}}{n} \ \frac{S\sqrt{\gamma g \bar{R}}}{\pi D} \left[\frac{1}{1 + \frac{\gamma-1}{2} \frac{S^2}{\pi^2 D^2 A_1^2} \left(\frac{Q_{1_s}}{n}\right)^2} \right]^{\frac{\gamma+1}{2(\gamma-1)}} \left(\frac{P_{1_t}}{P_{2_t}}\right) \left(\frac{T_{2_t}}{T_{1_t}}\right)^{1/2} \quad (2)$$

Inasmuch as P_{2_t}/P_{1_t} and T_{2_t}/T_{1_t} are functions of Q_{1_s}/n and S,
$Q_{2_t}/\sqrt{T_{2_t}}$ is also a function of Q_{1_s}/n and S. If the performance
of a given supercharger is a unique function of Q_{1_s}/n and S, it
is therefore also a unique function of $Q_{2_t}/\sqrt{T_{2_t}}$ and S.

Tho value of this flow function $Q_{2_t}/\sqrt{T_{2_t}}$ is determined from
the equation

$$\frac{Q_{2_t}}{\sqrt{T_{2_t}}} = \frac{WR\sqrt{T_{2t}}}{P_{2_t}} \quad (3)$$

where W is the weight flow in pounds per second.

REFERENCES

1. Supercharger and Airflow Research Division: Effect of the NACA
      Injection Impeller on the Mixture Distribution of the Wright
      R-3350 Engine. NACA MR No. E4L23a, Army Air Forces, 1944.
      (Available as NACA TN No. 1069, 1946.)

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

Inside of bend

Reference station

C   B   A

Section A-A

Air flow

Throttles

Carburetor

A

A

Dummy impeller shaft

Station I
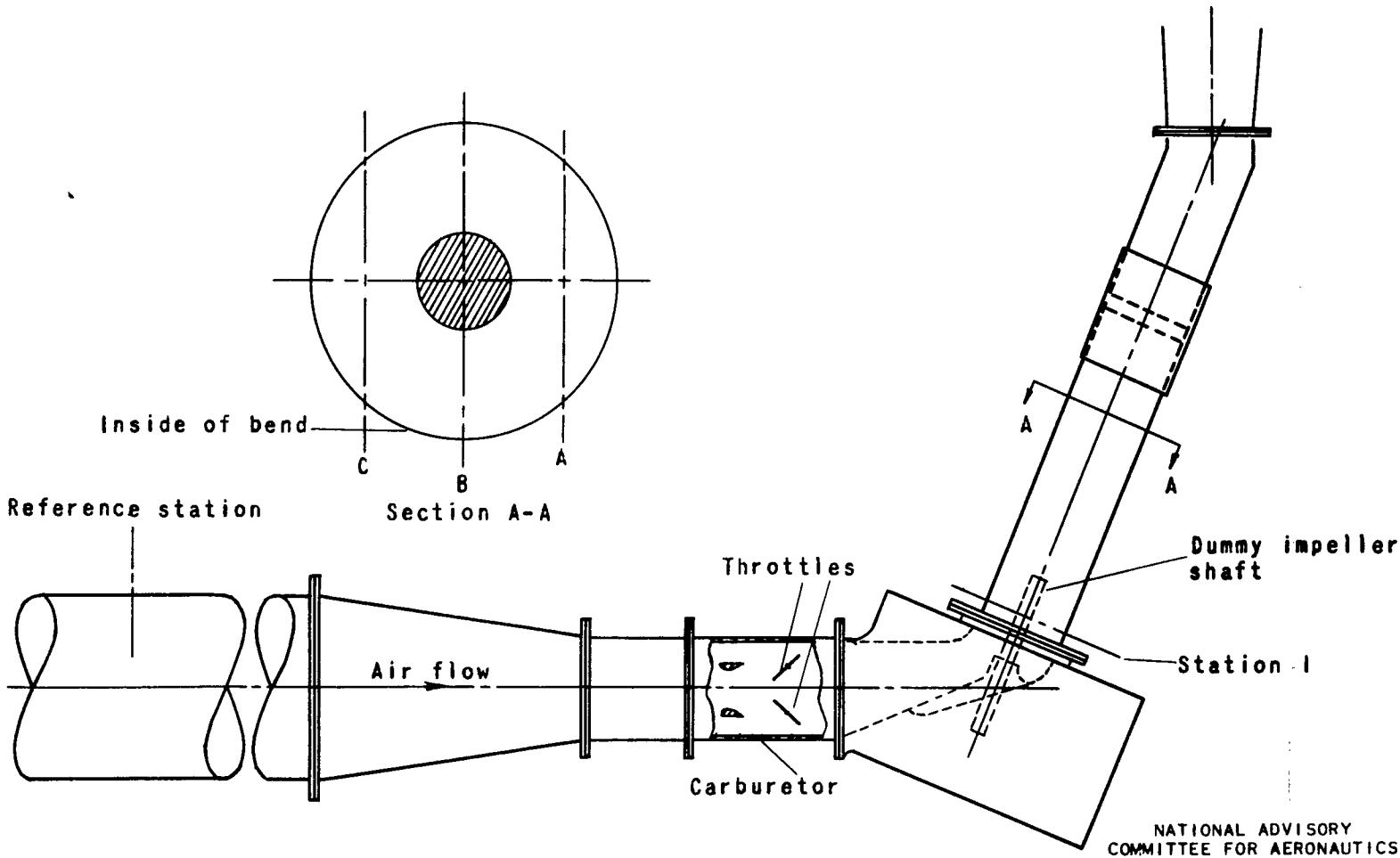
Figure I. — Schematic diagram of engine-stage supercharger inlet elbow of double-row radial engine.

A Inlet-air throttle
B Orifice tank
C Discharge throttle
D Inlet-air measuring station
E Collector baffle
F Drive unit
G   Carburetor
H   Supercharger assembly
I Collector
J Discharge-measuring station
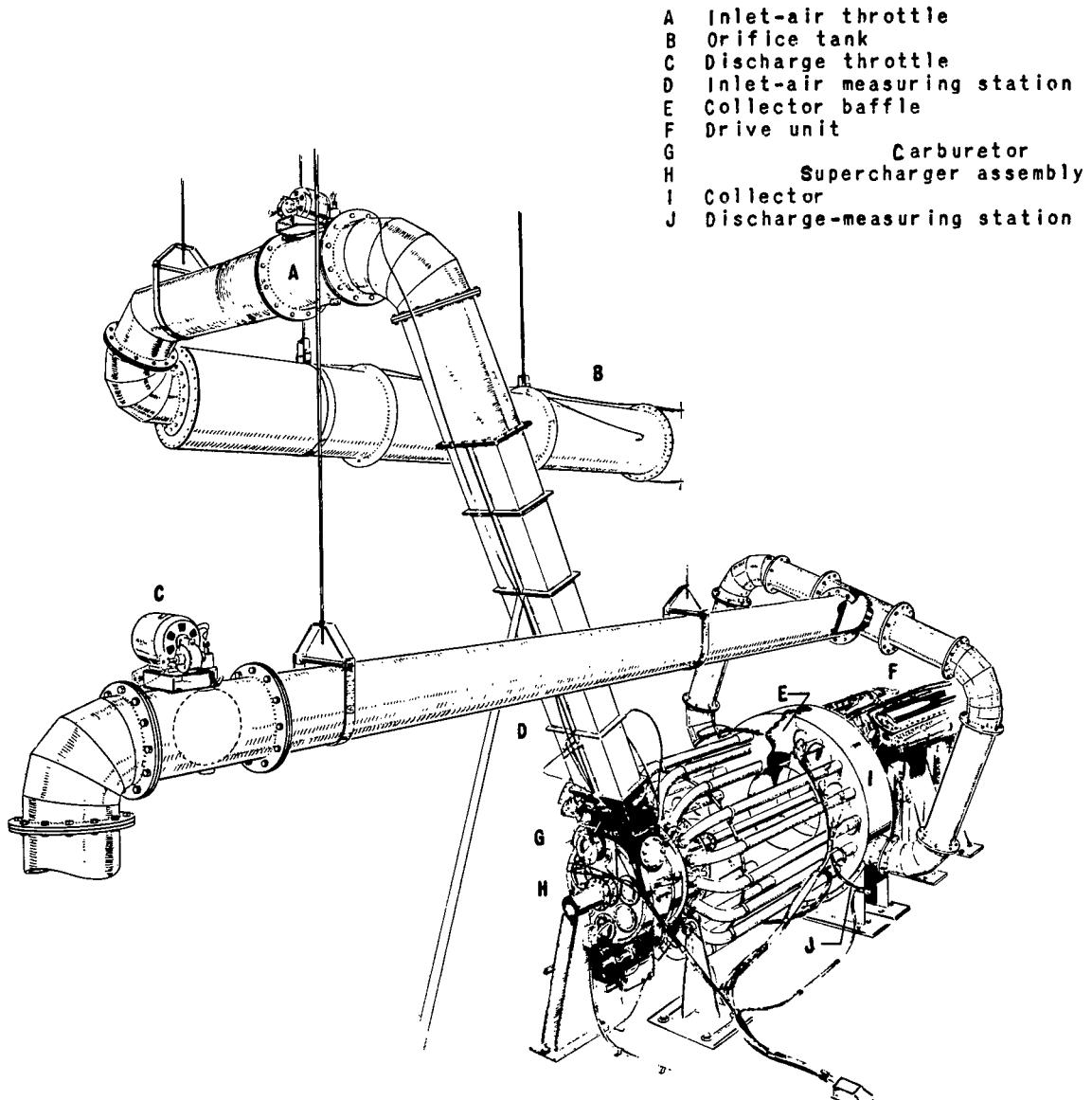
(a) Test rig.

Figure 2. — Double-row radial engine-stage supercharger test setup.
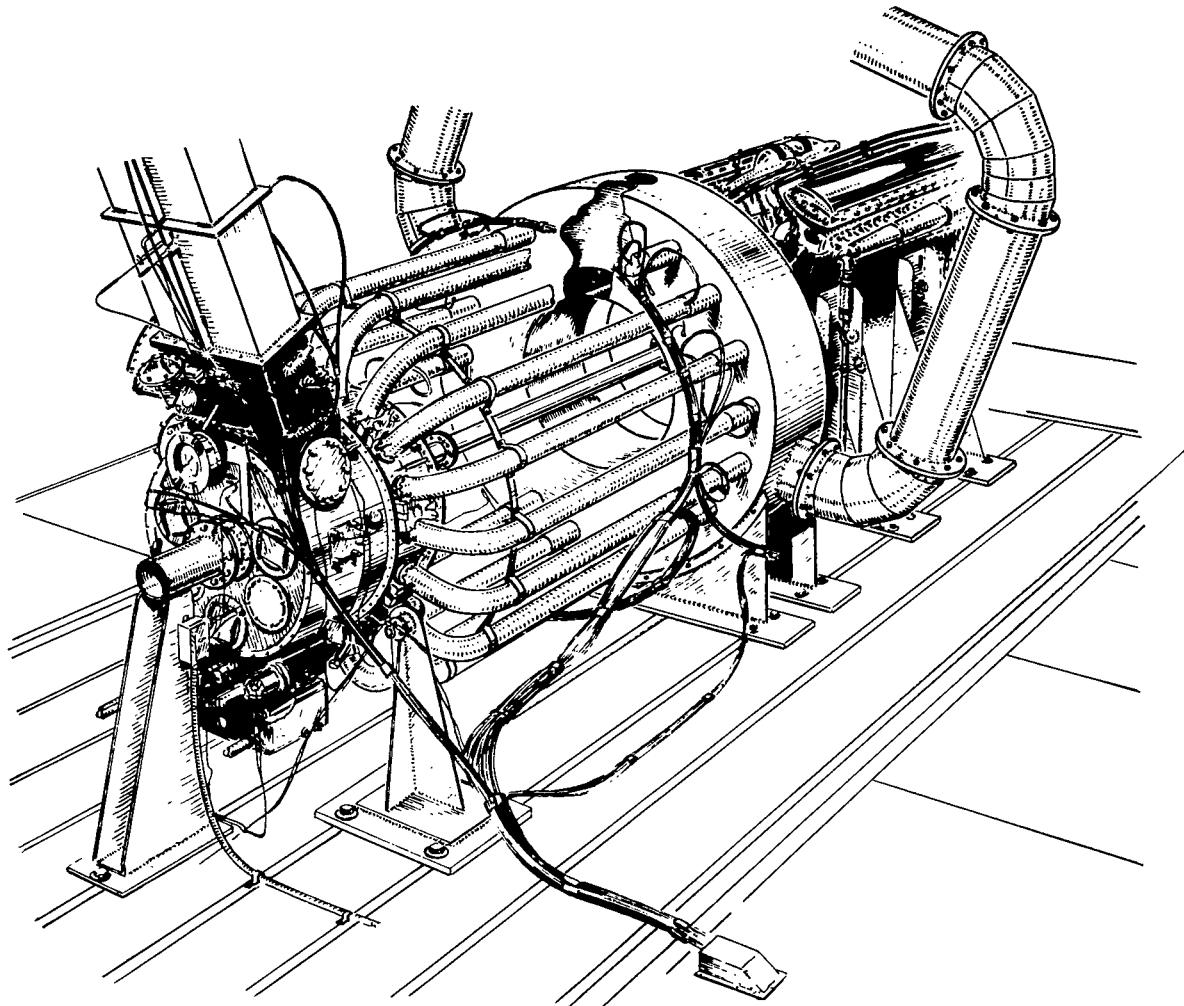
(b)   Close-up view of test unit.

Figure 2. - Concluded.

| Engine speed (rpm)	Q_{2_t}/n	$Q_{2_t}\sqrt{T_{2_t}}$
+ 1800	0.2648	1.980
× 2000	.2559	2.102
□ 2200	.2617	2.345
◇ 2400	.2587	2.499
△ 2600	.2522	2.600
▷ 2800	.2519	2.753

M/M_{av}

Outlet pipe
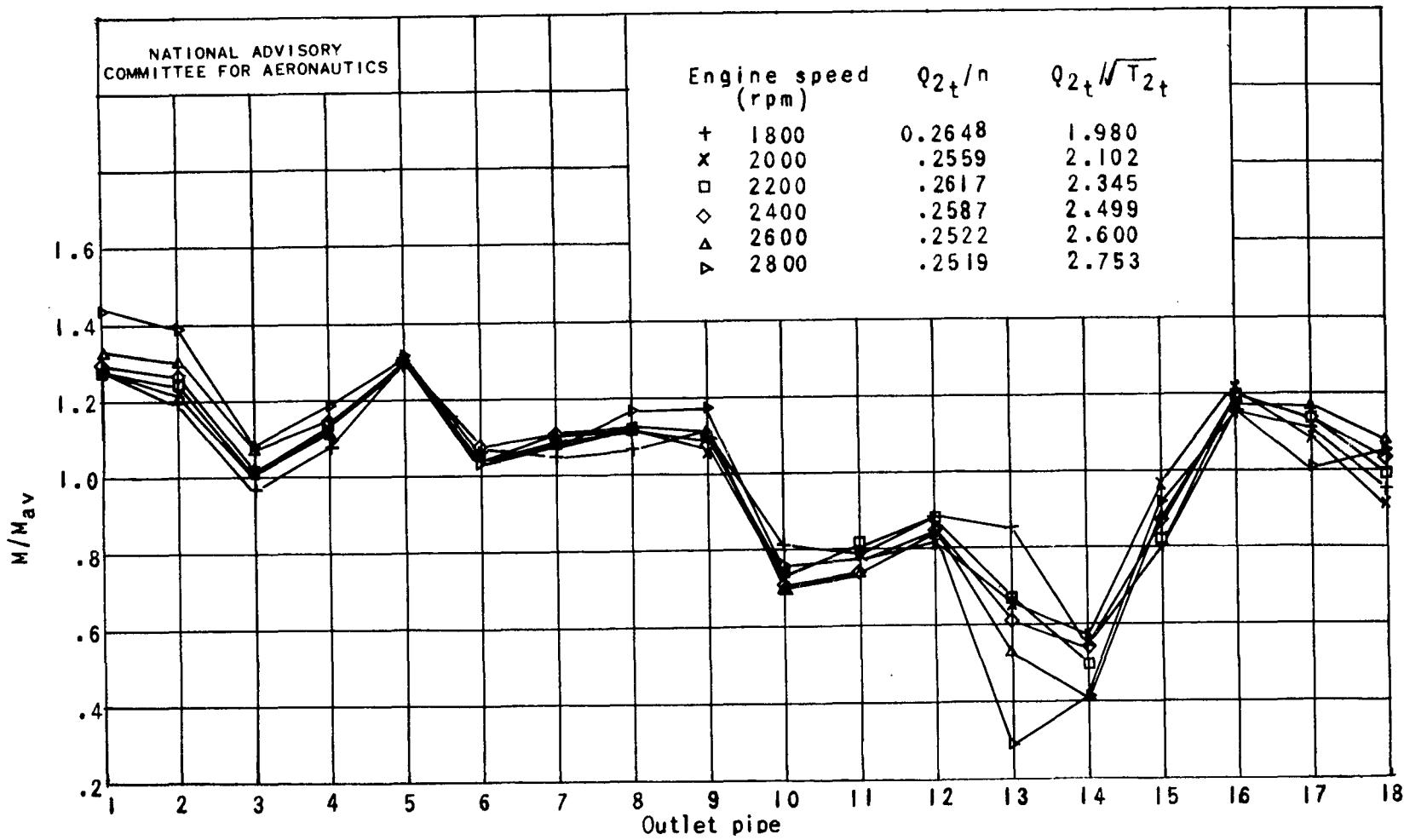
(a) Q_{2_t}/n, approximately 0.26.

Figure 3. – Effect of engine speed on air-flow distribution in outlets of engine-stage supercharger of double-row radial engine on the basis of approximately constant values of Q_{2_t}/n; reference outlet pressure, 6 inches of mercury above atmospheric; carburetor-throttle angle, 66°.
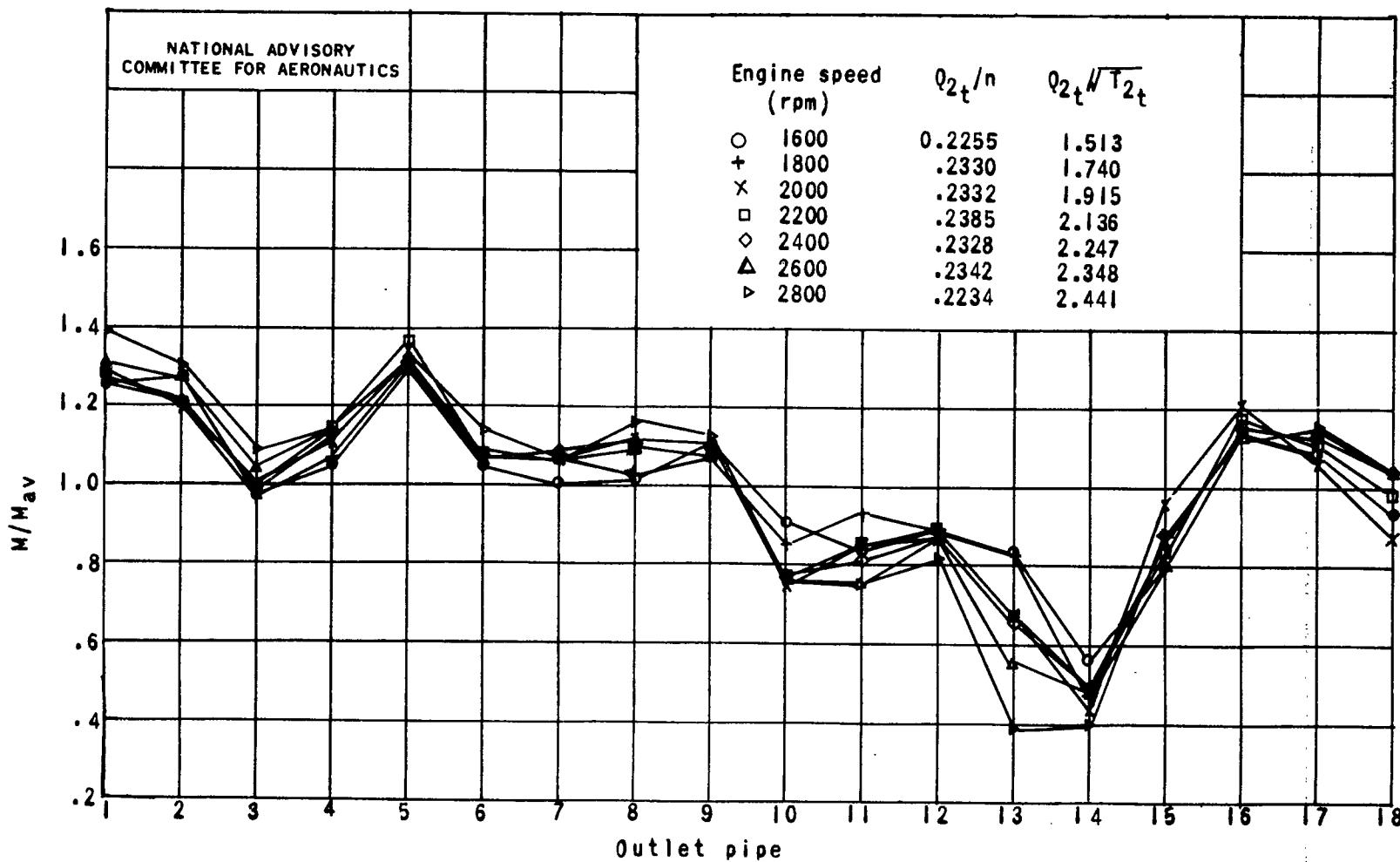
(b) Q_{2_t}/n, approximately 0.23.

Figure 3. - Continued.

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Engine speed (rpm)		Q_{2_t}/n	$Q_{2_t}/\sqrt{T_{2_t}}$
o	1600	0.2087	1.399
+	1800	.2101	1.569
x	2000	.2138	1.754
□	2200	.2069	1.853
◇	2400	.2048	1.975
△	2600	.2058	2.123
▷	2800	.1971	2.151
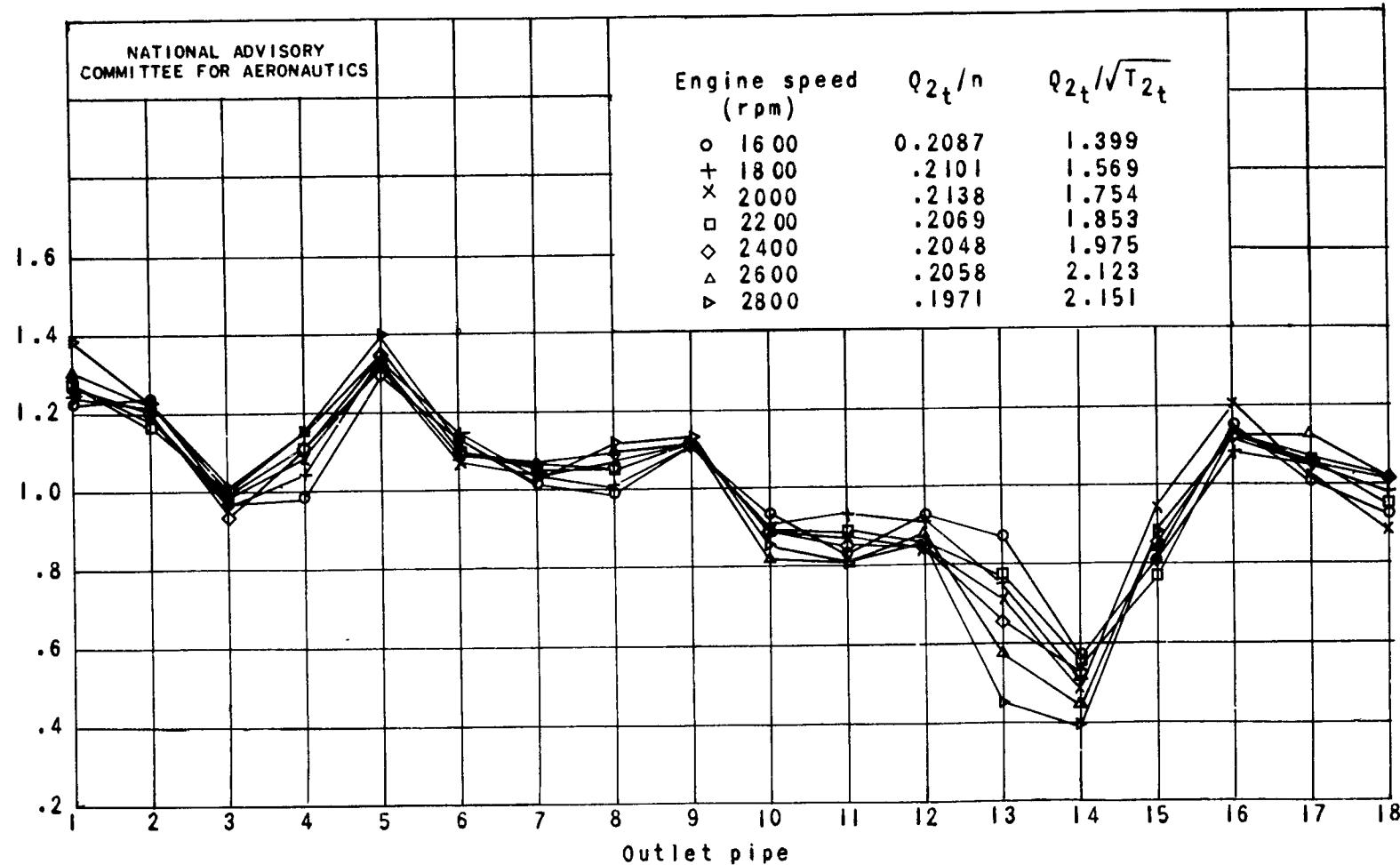
(c) Q_{2_t}/n, approximately 0.20.

Figure 3. - Concluded.

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Engine speed $Q_{2_t}/\sqrt{T_{2_t}}$		
	(rpm)	
+	1800	1.980
X	2000	1.915
□	2200	1.988
◇	2400	1.975
△	2600	1.956
▷	2800	1.971
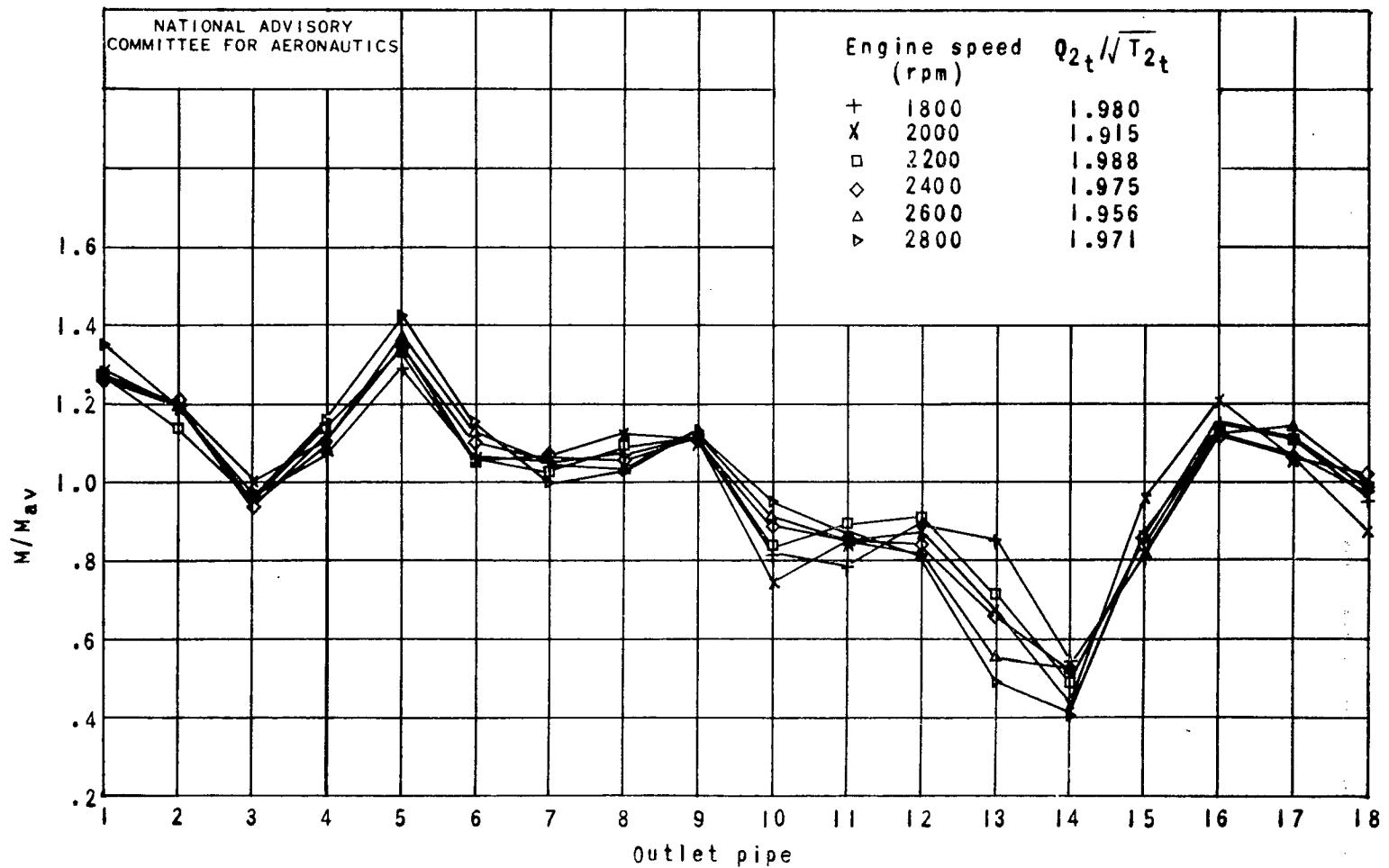
(a) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 2.0.

Figure 4. — Effect of engine speed on air-flow distribution in outlets of engine-stage supercharger of double-row radial engine on the basis of approximately constant values of $Q_{2_t}/\sqrt{T_{2_t}}$; reference outlet pressure, 6 inches of mercury above atmospheric; carburetor-throttle angle, 66°.
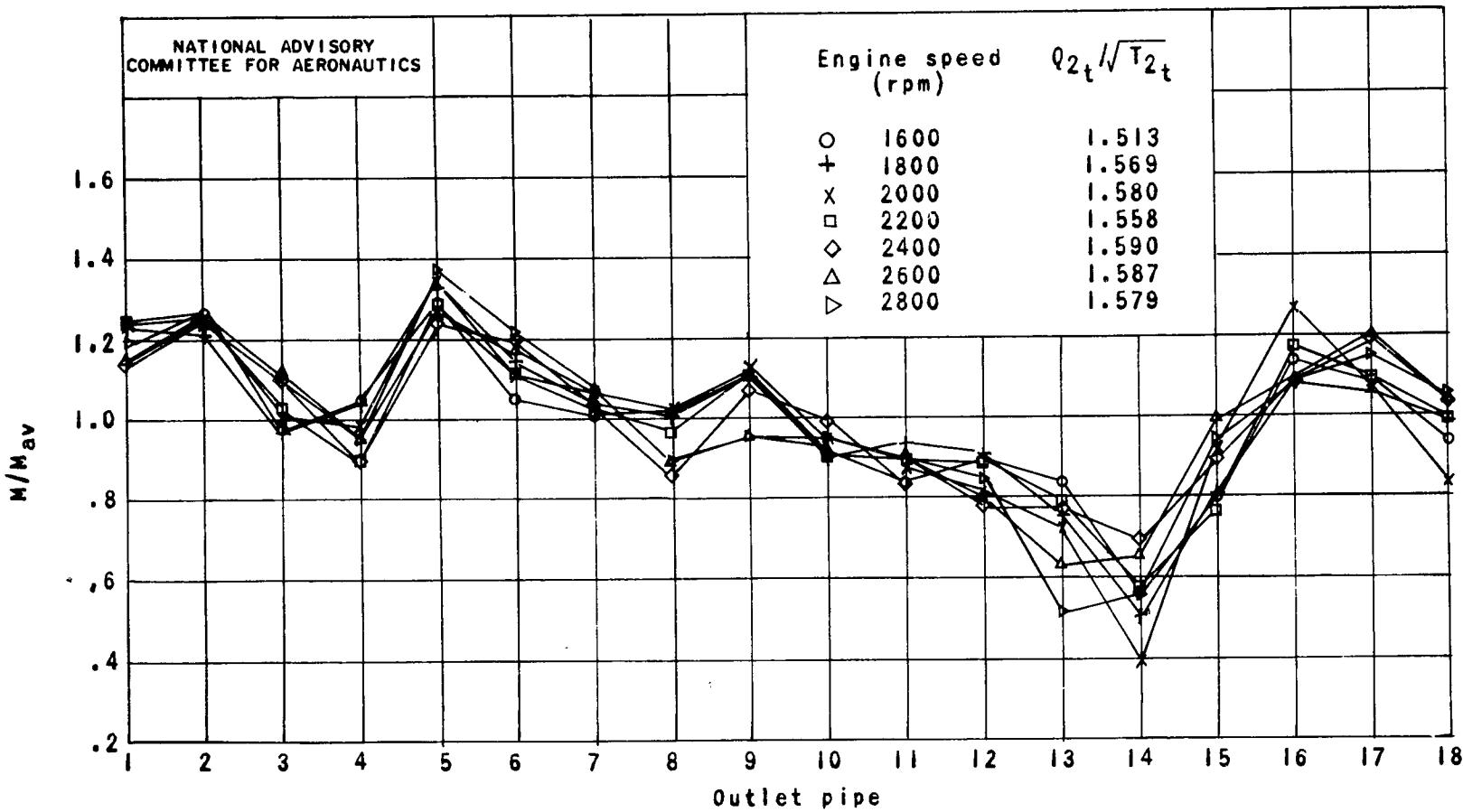
(b) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 1.6.

Figure 4. - Continued.
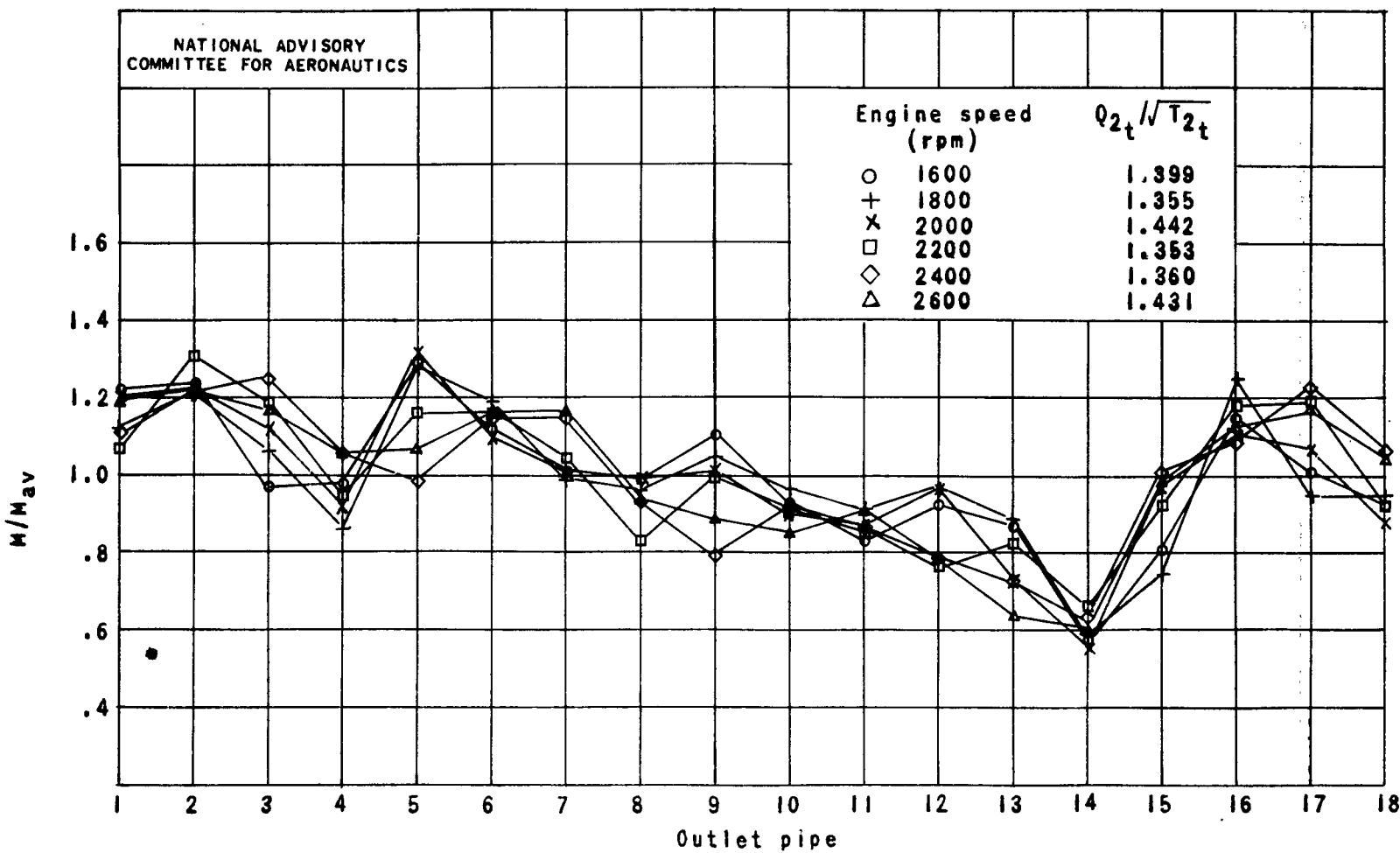
(c) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 1.4.

Figure 4. - Concluded.

	Reference outlet pressure (in. Hg above atmospheric)	$Q_{2_t}/\sqrt{T_{2_t}}$
o	Wide-open outlet	2.585
+	3	2.361
□	6	2.452
◇	10	2.441
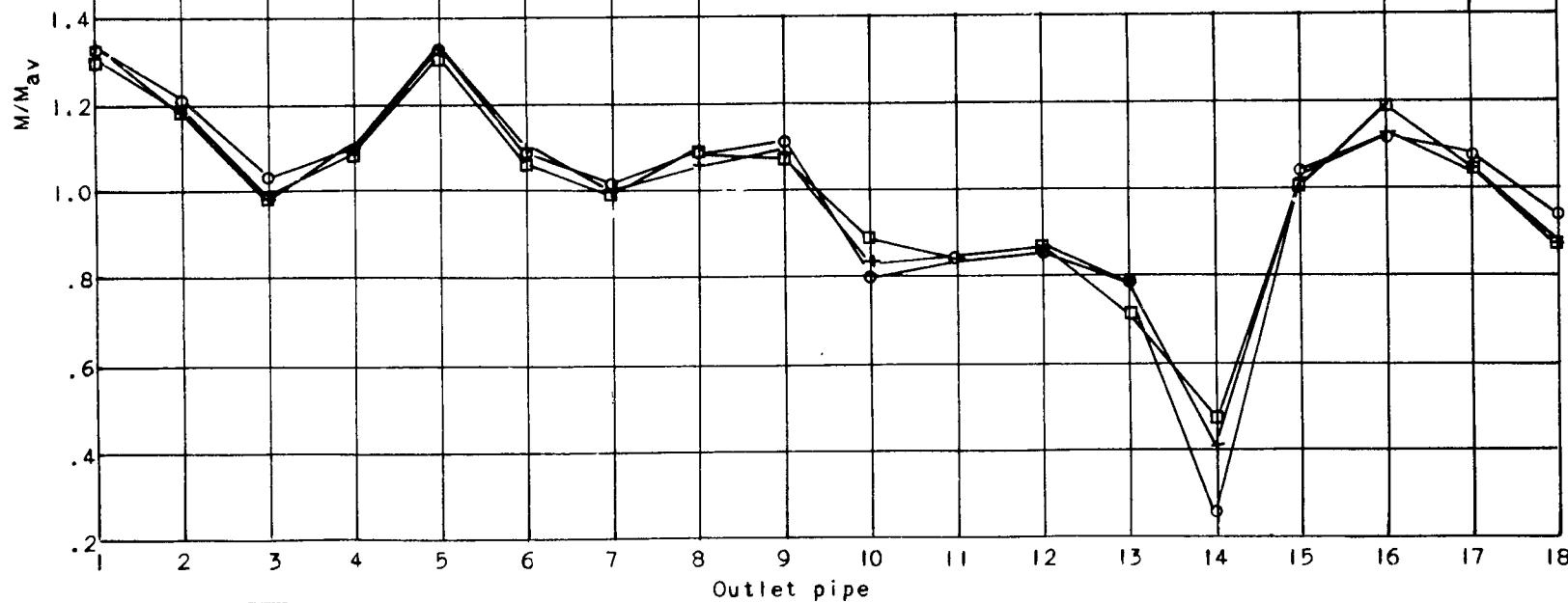
M/M_{av}

Outlet pipe

(a) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 2.4; engine speed, 2400 rpm.

Figure 5. — Effect of outlet pressure on air-flow distribution in outlets of engine-stage super-charger of double-row radial engine; carburetor-throttle angle, 66°.

(b) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 1.5; engine speed, 2400 rpm.

Figure 5. - Continued.

(c) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 1.9; engine speed, 2000 rpm.

Figure 5. — Continued.

(d) $Q_{2_t}\sqrt{T_{2_t}}$, approximately 1.5; engine speed, 2000 rpm.
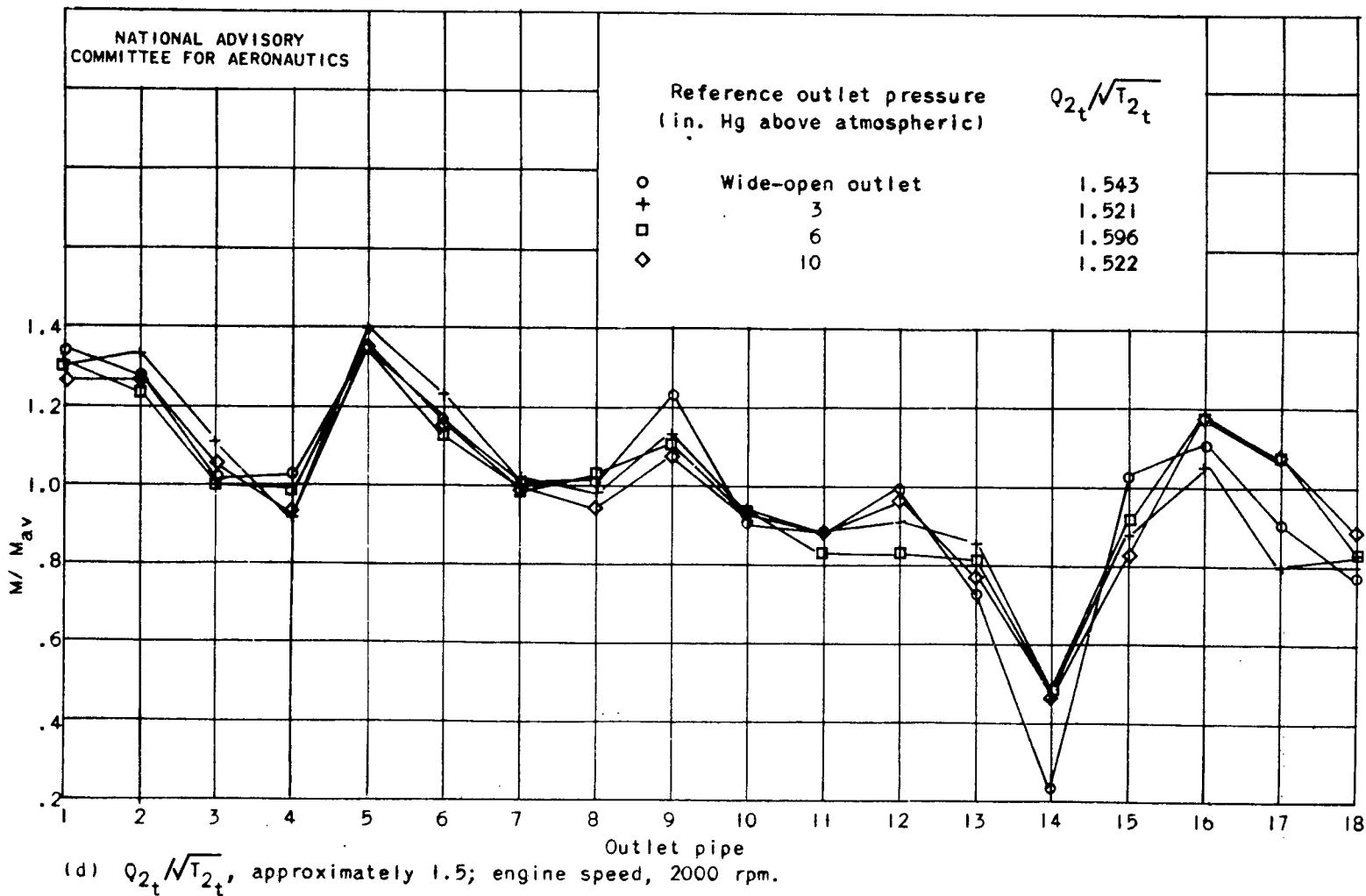
Figure 5. - Concluded.
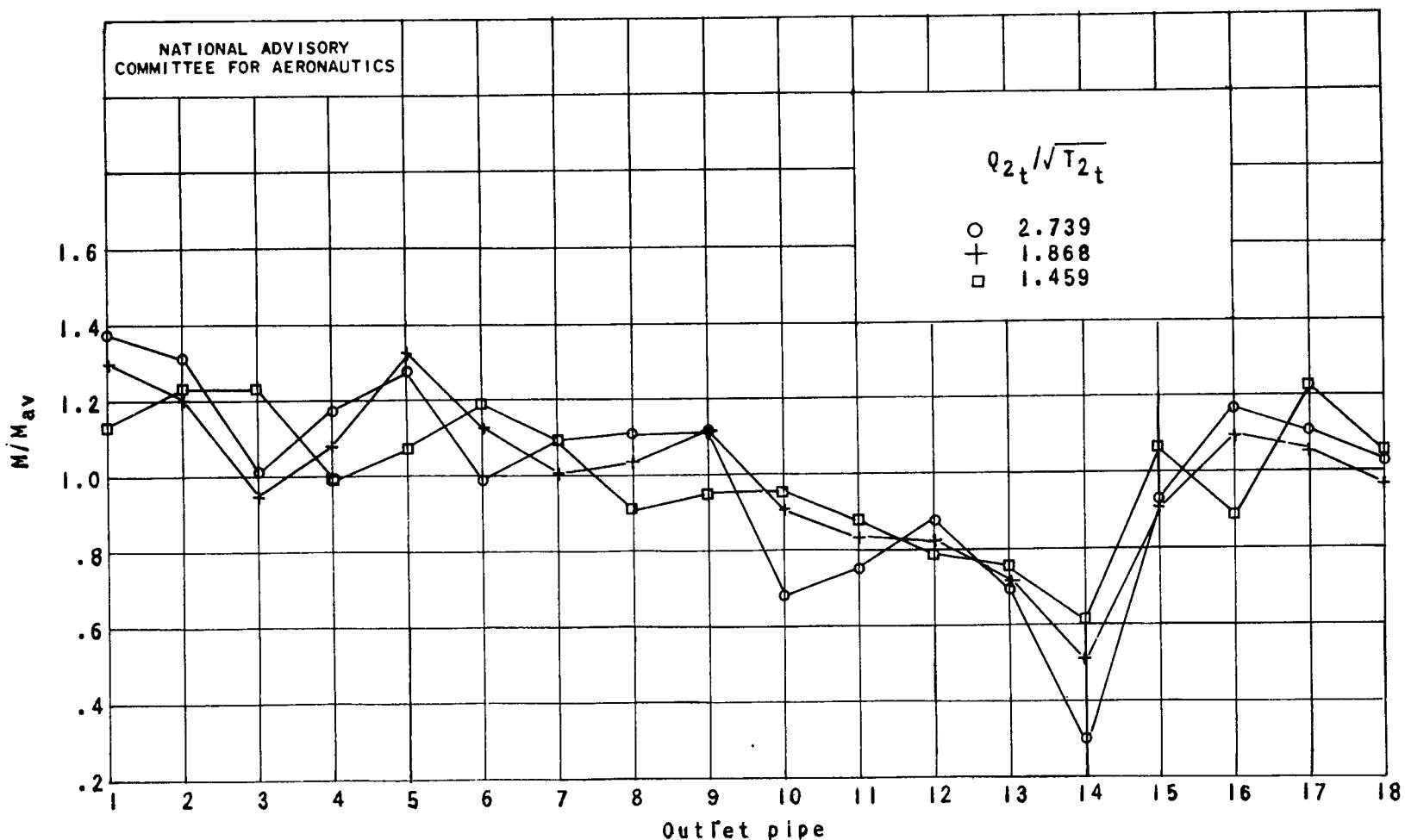
(a)   Engine speed, 2400 rpm.

Figure 6. — Effect of volume flow on air-flow distribution in outlets of eng. e-stage supercharger of double-row radial engine; reference outlet pressure, 6 inches of mercury above atmospheric; carburetor-throttle angle, 66°.
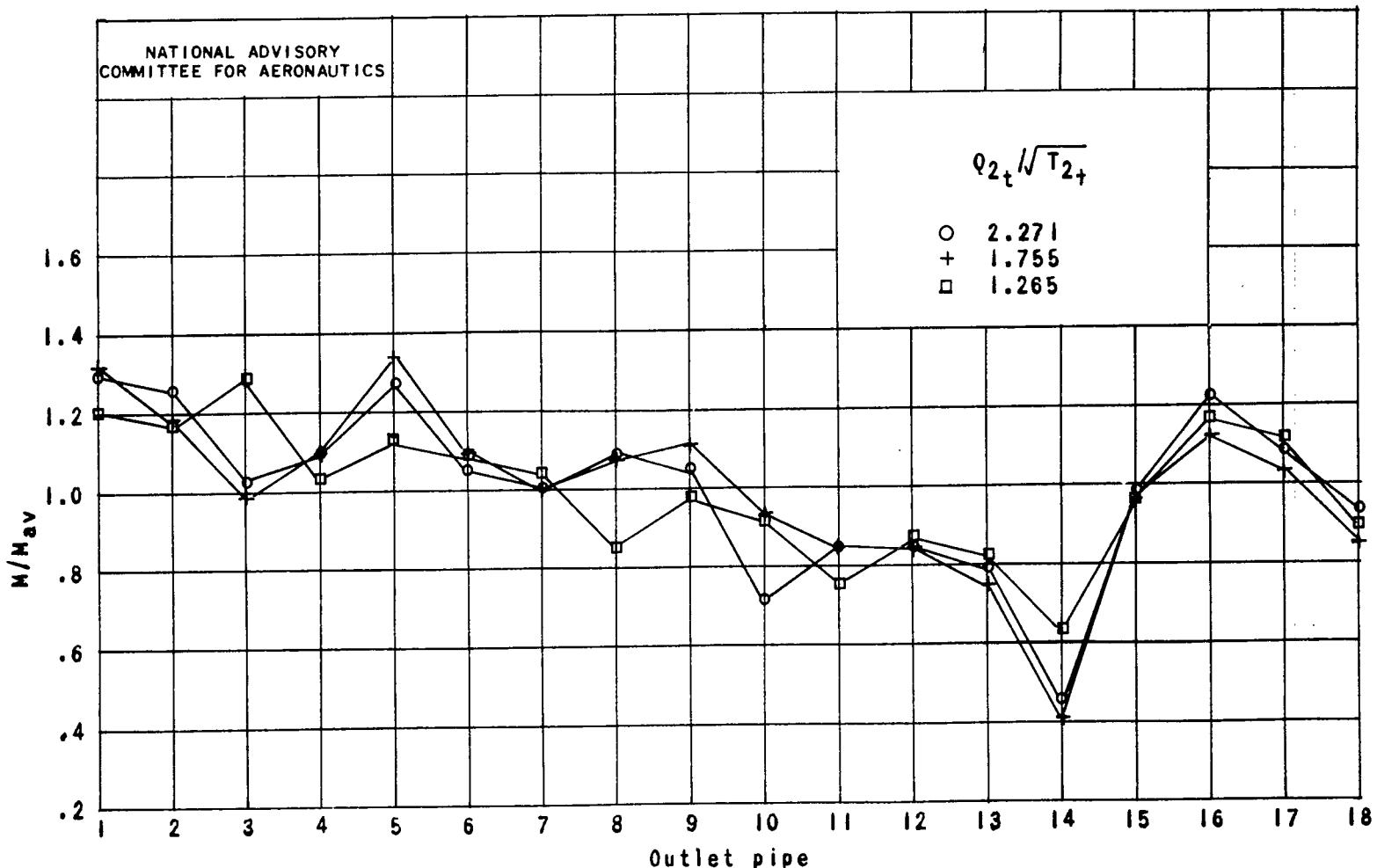
(b) Engine speed, 2000 rpm.

Figure 6. - Concluded.
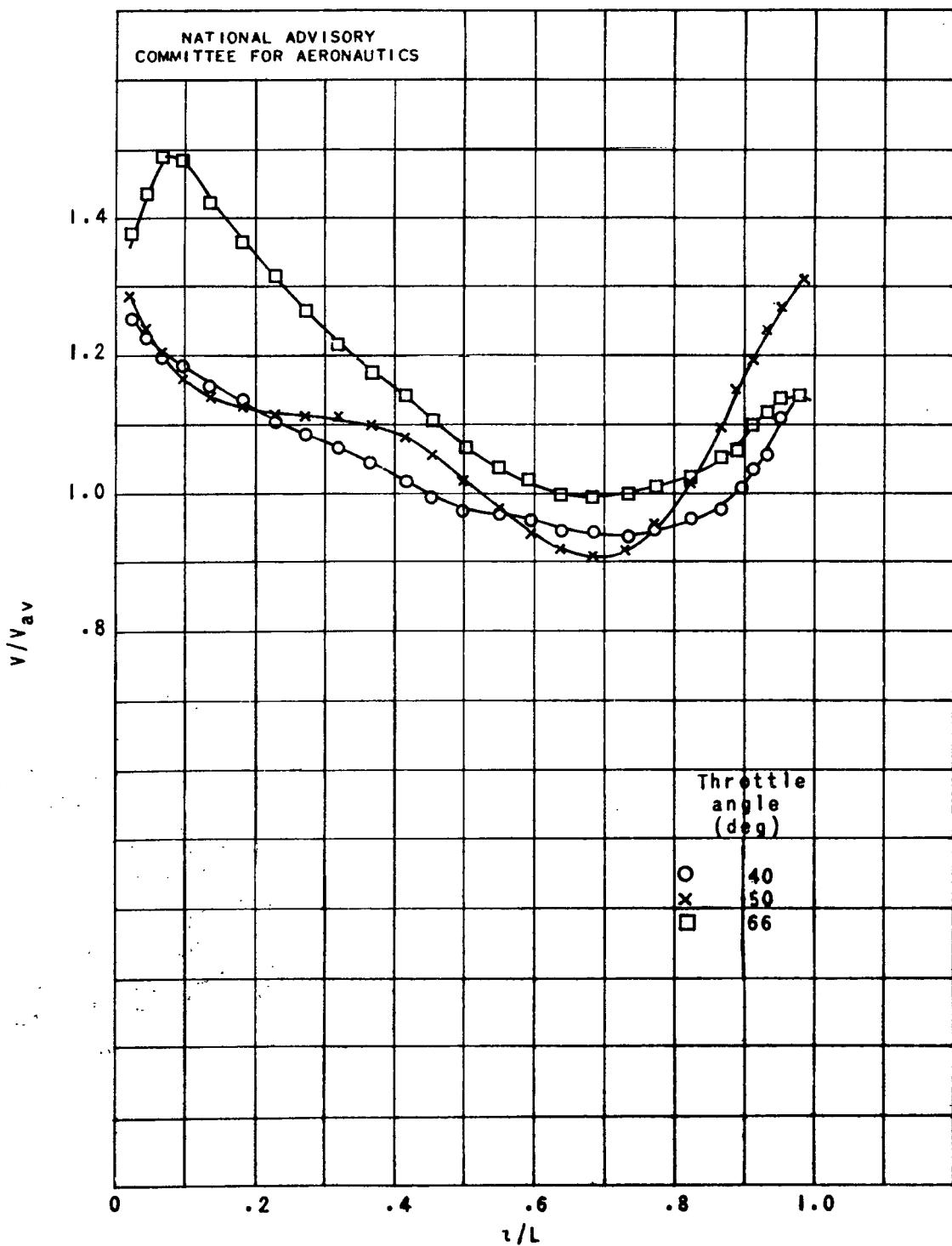
(a)   Survey A.

Figure 7. – Velocity profiles at station I for various carburetor-throttle angles.
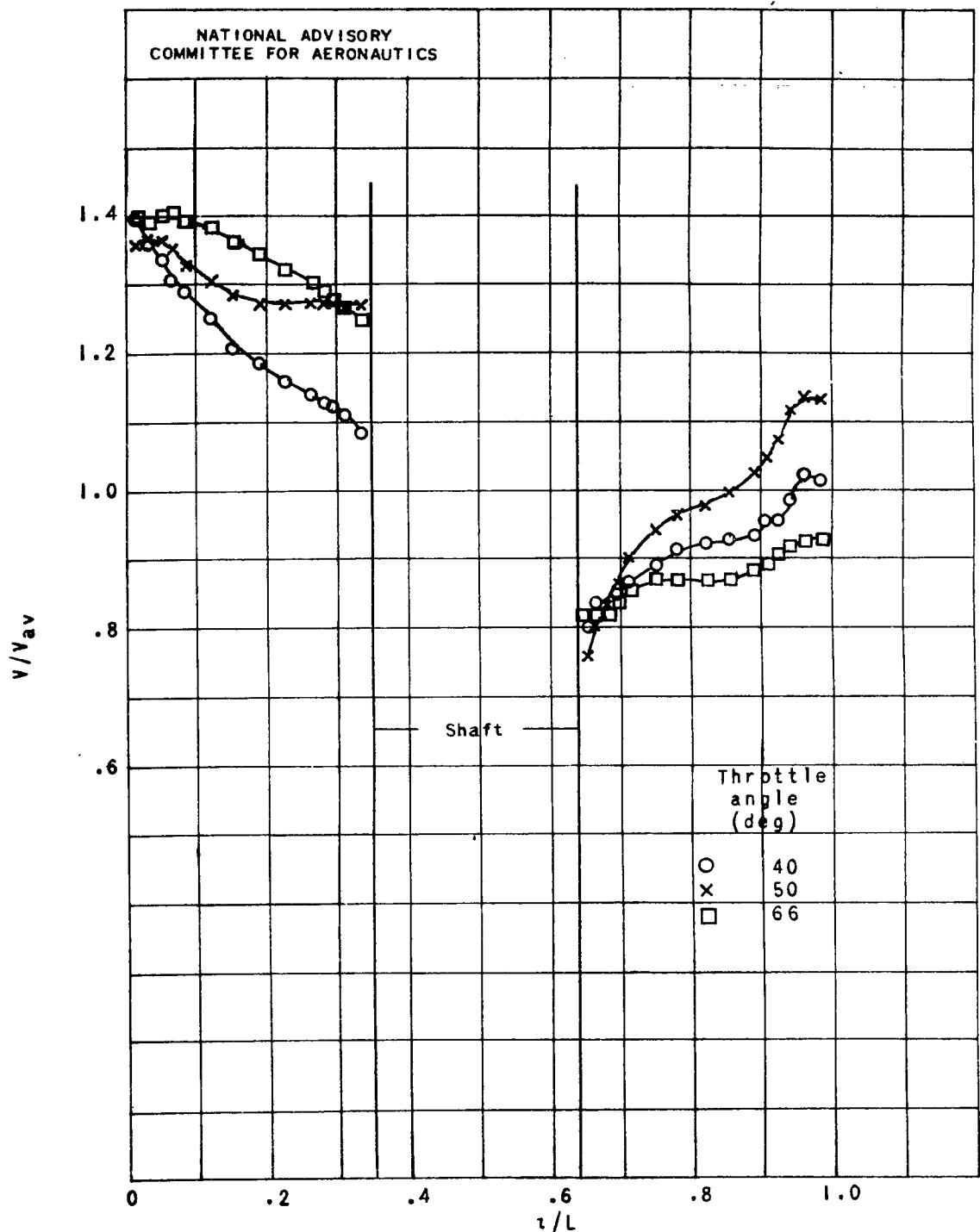
(b) Survey B.

Figure 7. — Continued.
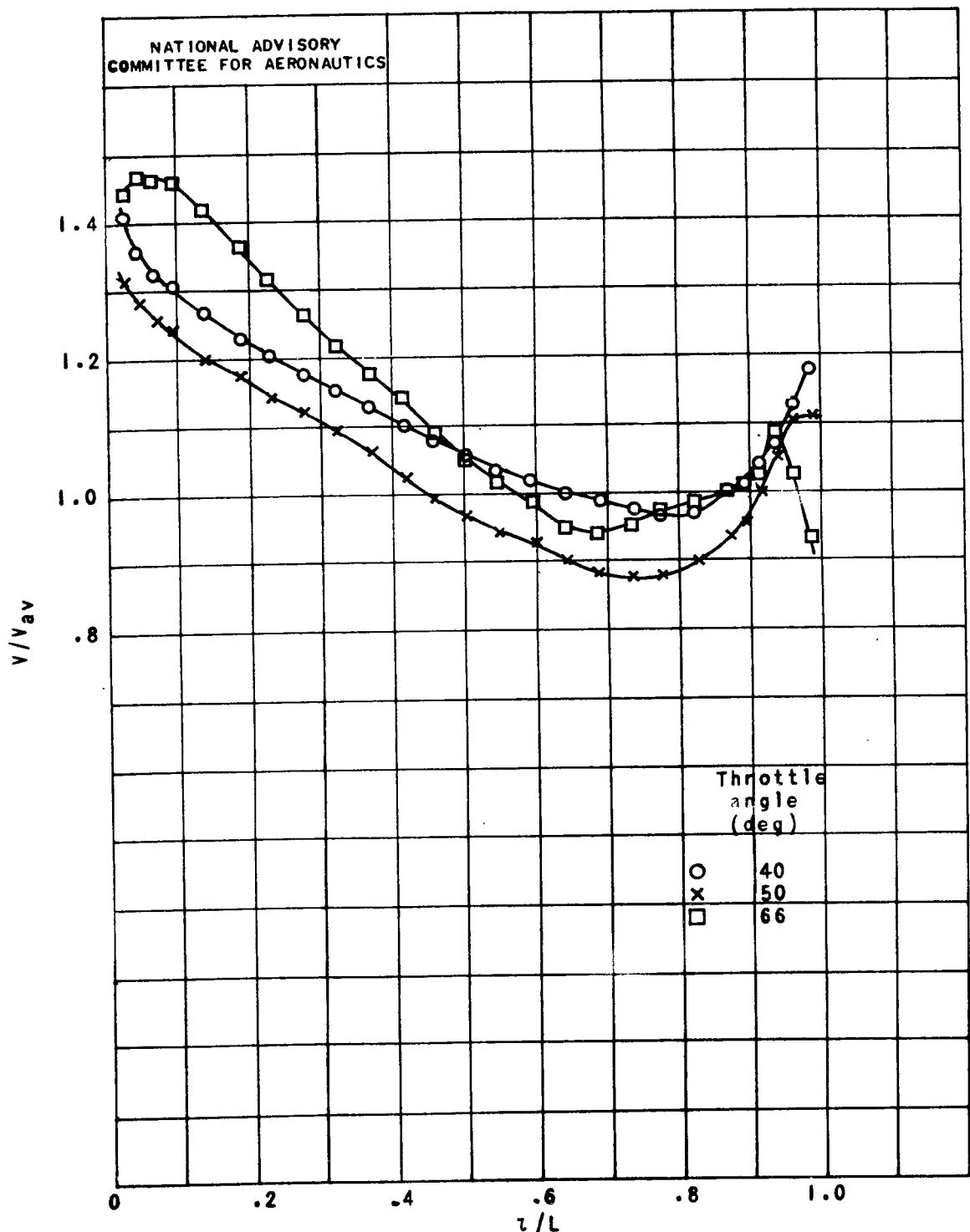
(c) Survey C.

Figure 7. – Concluded.
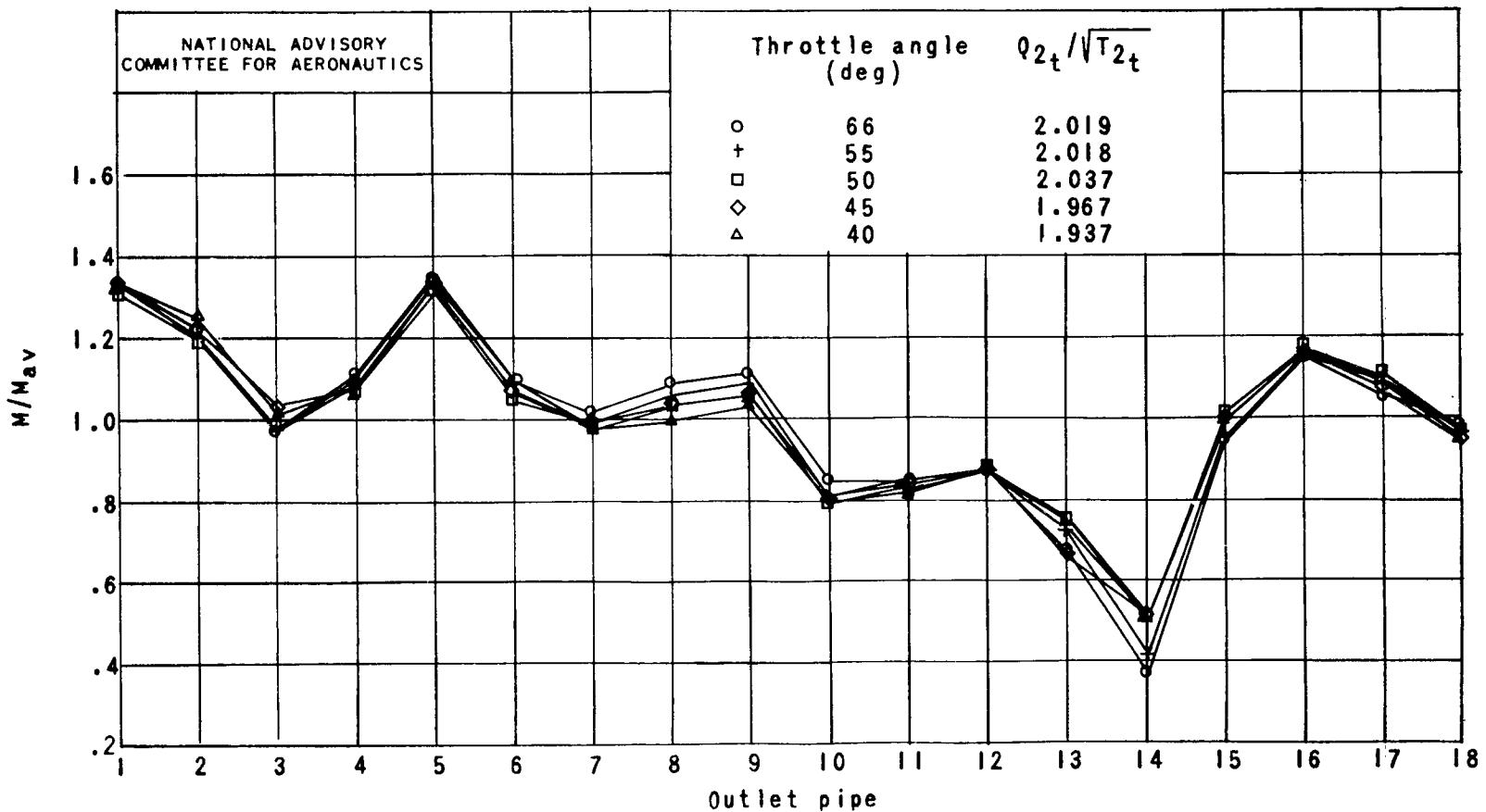
(a) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 2.0; engine speed, 2400 rpm.

Figure 8. – Effect of carburetor–throttle angle on air–flow distribution in outlets of engine–stage supercharger of double–row radial engine; reference outlet pressure, 6 inches of mercury above atmospheric.
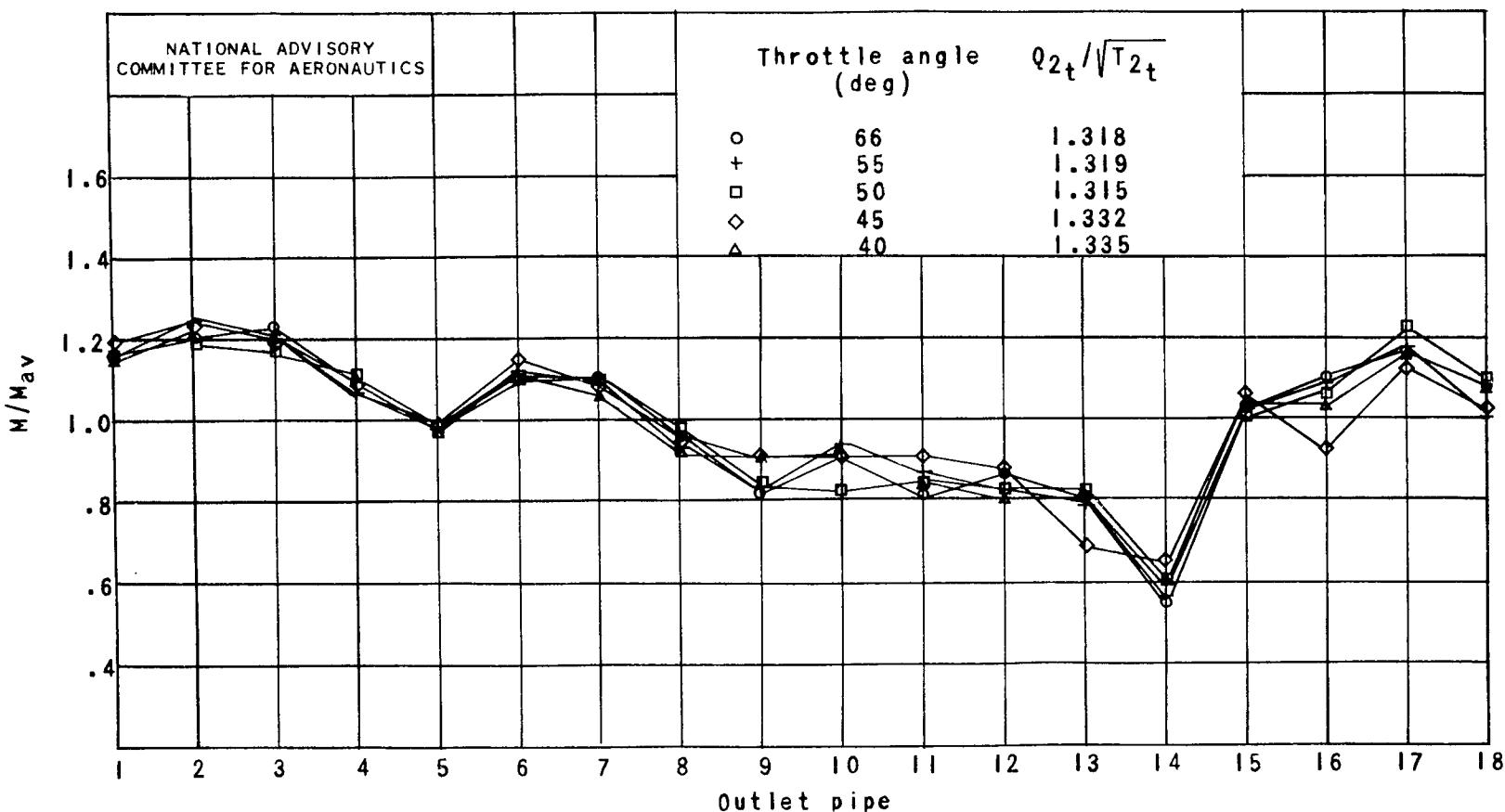
(b) $Q_{2t}/\sqrt{T_{2t}}$, approximately 1.3; engine speed, 2400 rpm.

Figure 8. – Continued.
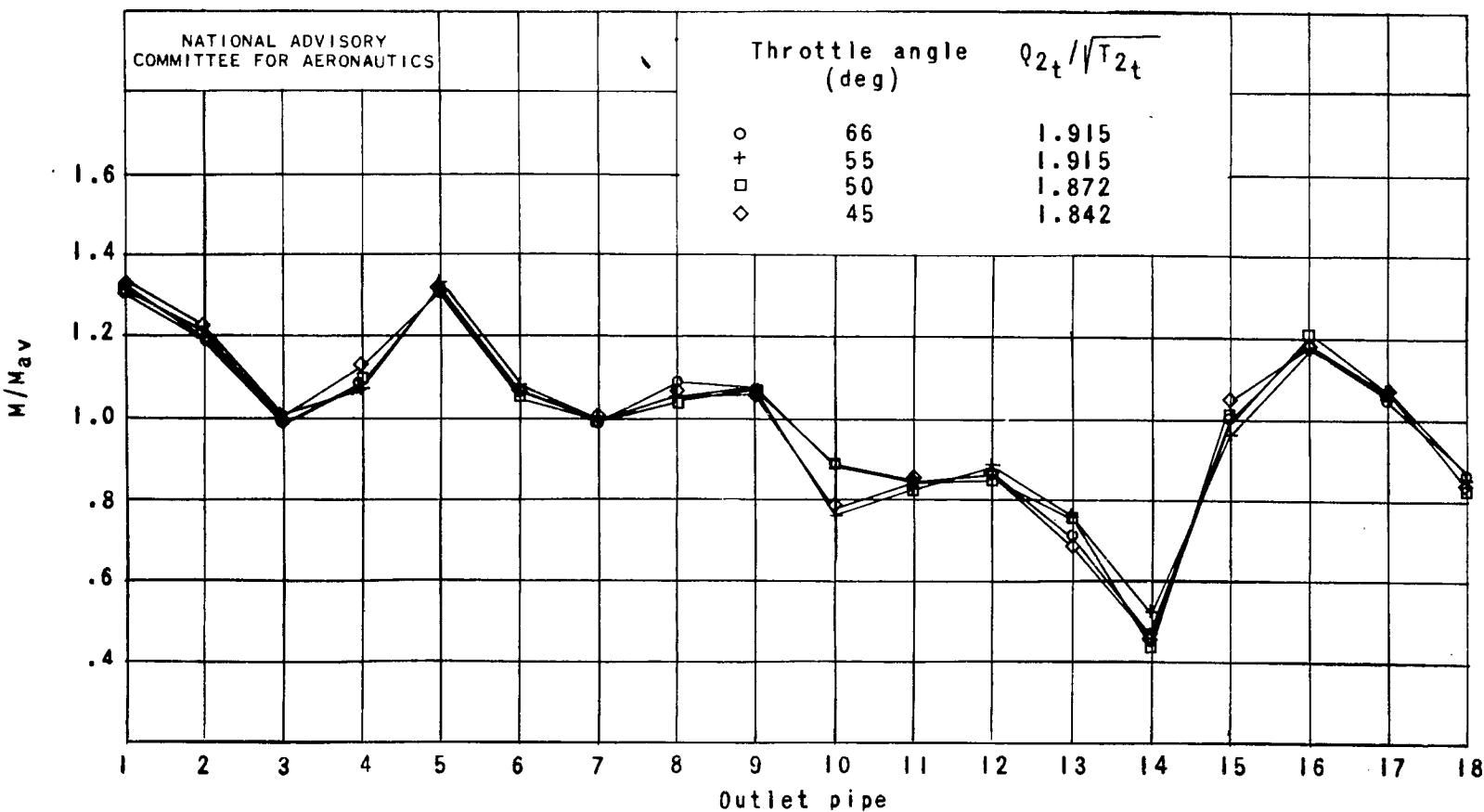
(c) $Q_{2_t} / \sqrt{T_{2_t}}$, approximately 1.9; engine speed, 2000 rpm.

Figure 8. - Continued.

	Throttle angle (deg)	$Q_{2_t}/\sqrt{T_{2_t}}$
○	66	1.455
+	55	1.425
□	50	1.493
◇	45	1.470
△	40	1.431
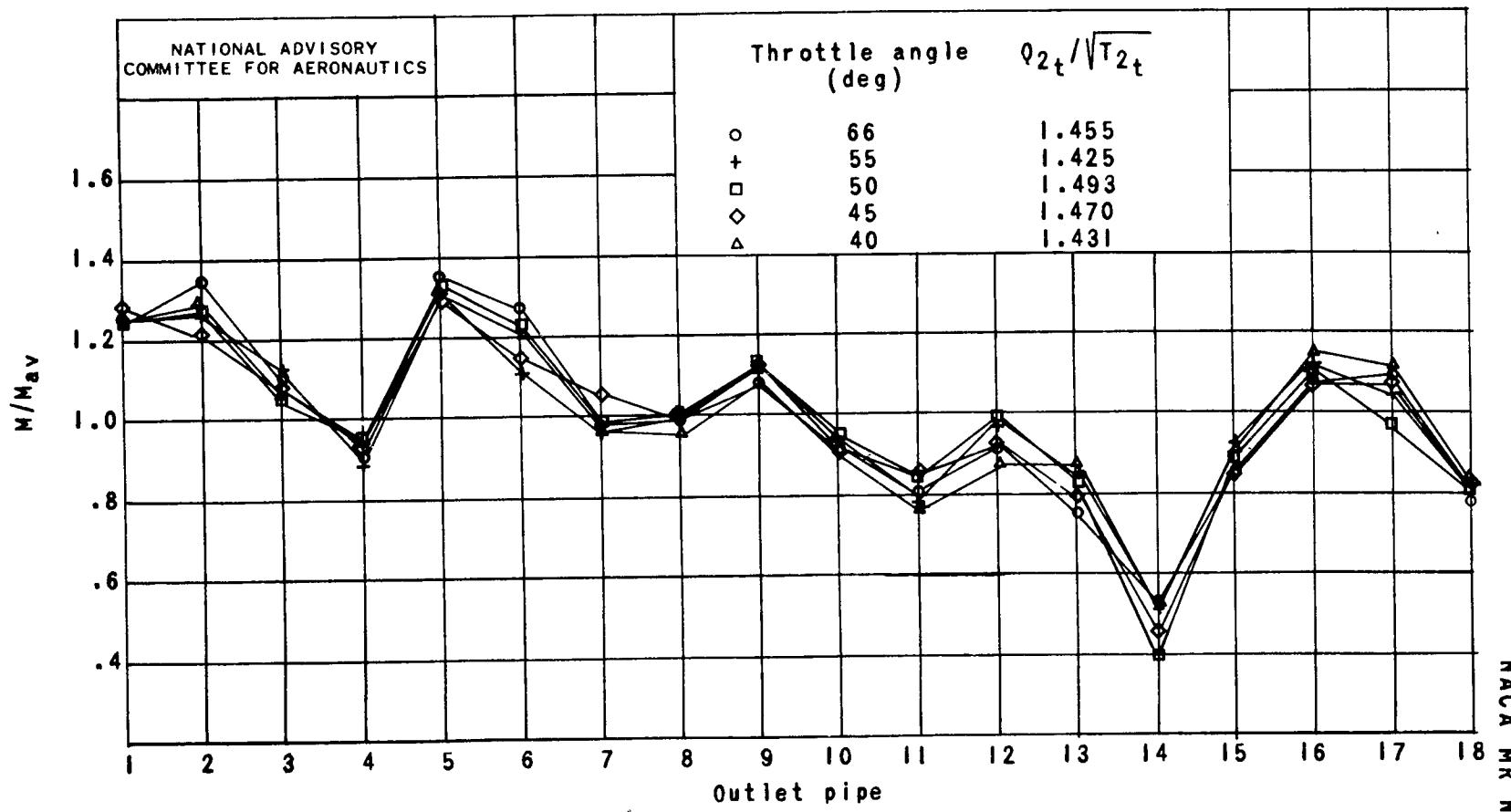
(d) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 1.5; engine speed, 2000 rpm.

Figure 8. — Concluded.

(a) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 2.0; engine speed, 2400 rpm.

(b) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 1.6; engine speed, 2400 rpm.
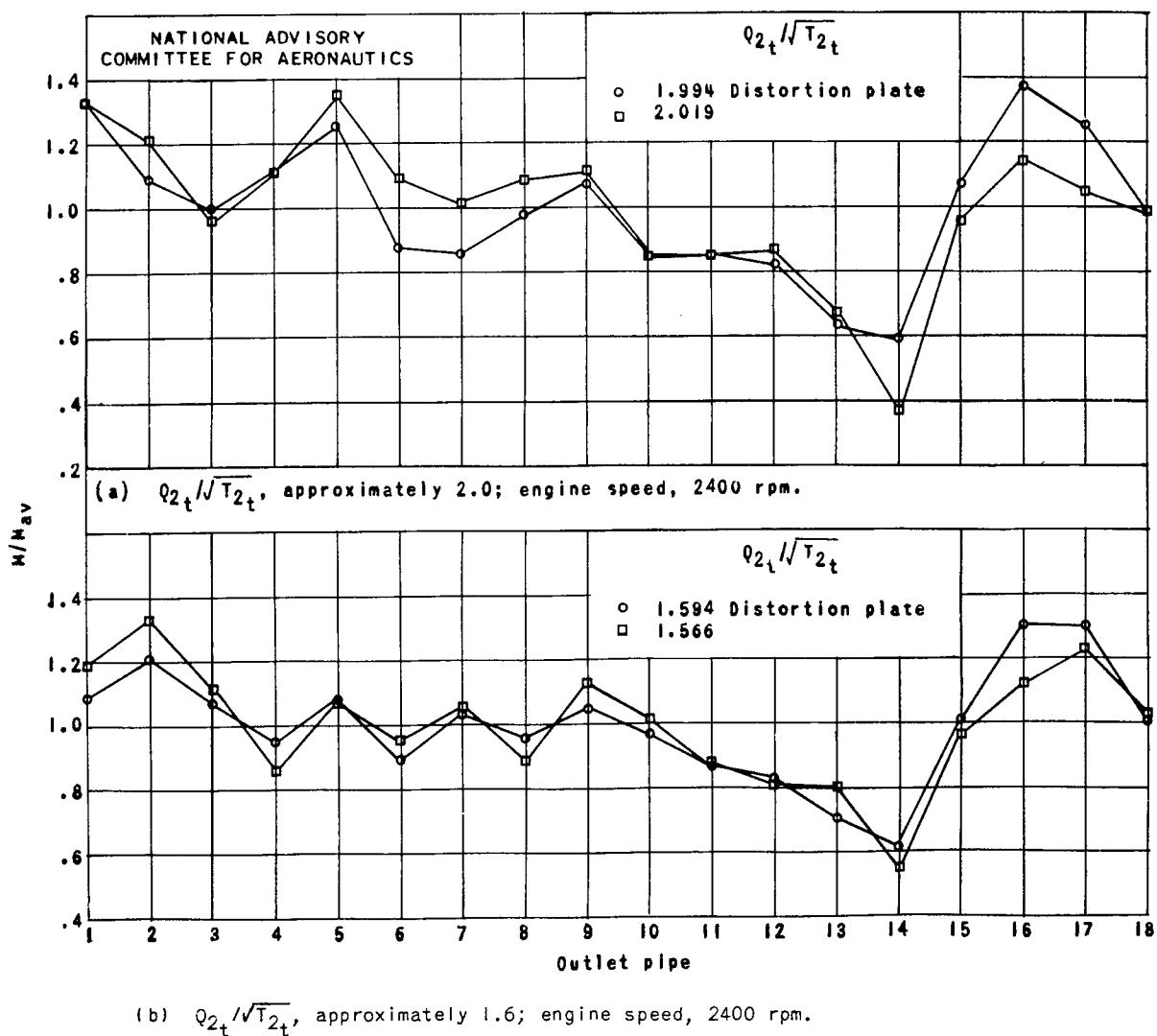
Figure 9. — Effect of distortion plate on air—flow distribution in outlets of engine—stage super-
charger of double—row radial engine; reference outlet pressure, 6 inches of mercury above
atmospheric; carburetor—throttle angle, 66°.

(c) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 2.0; engine speed, 2000 rpm.

(d) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 1.4; engine speed, 2000 rpm.

Figure 9. - Concluded.

(a) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 2.5.

(b) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 1.8.
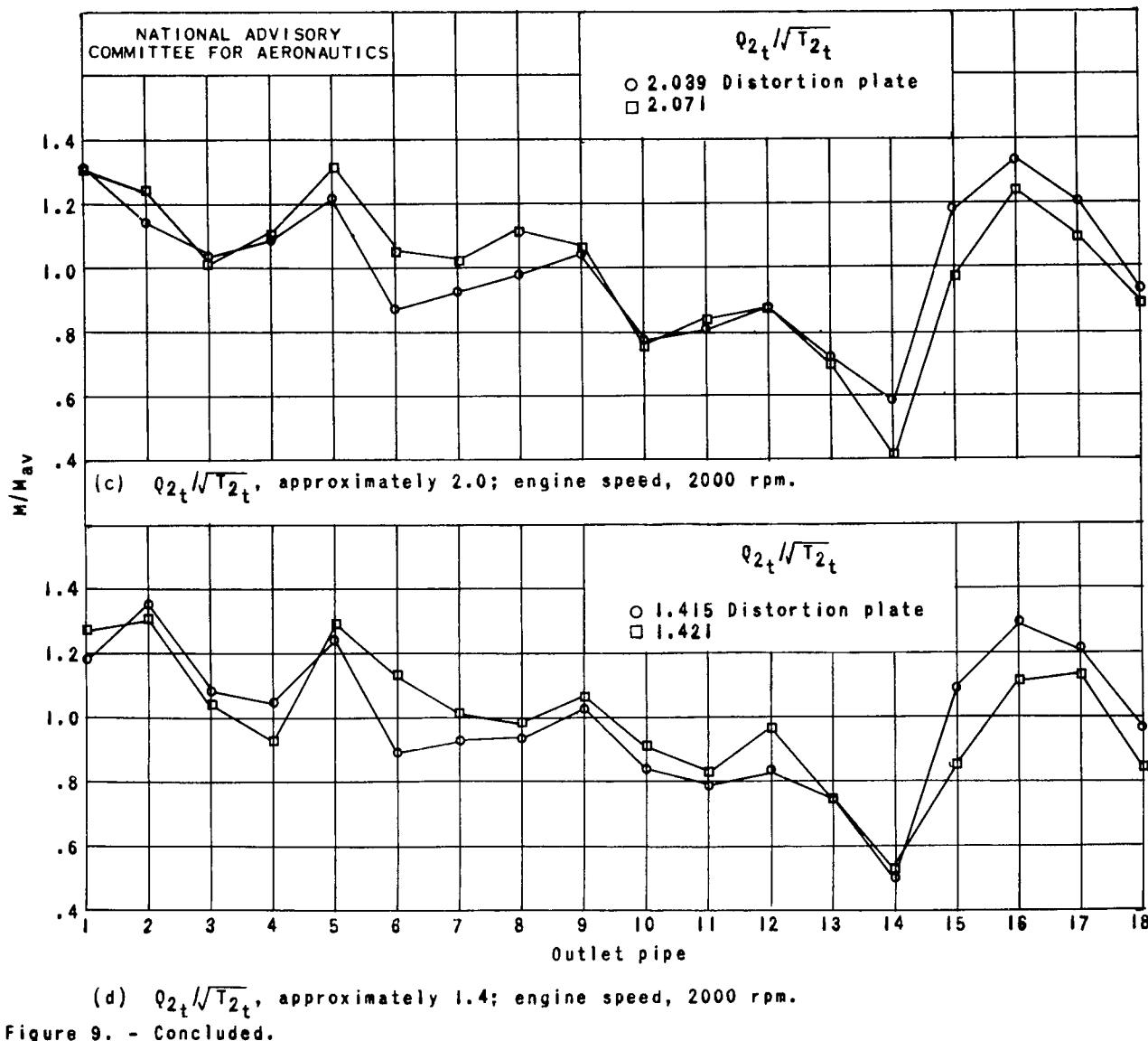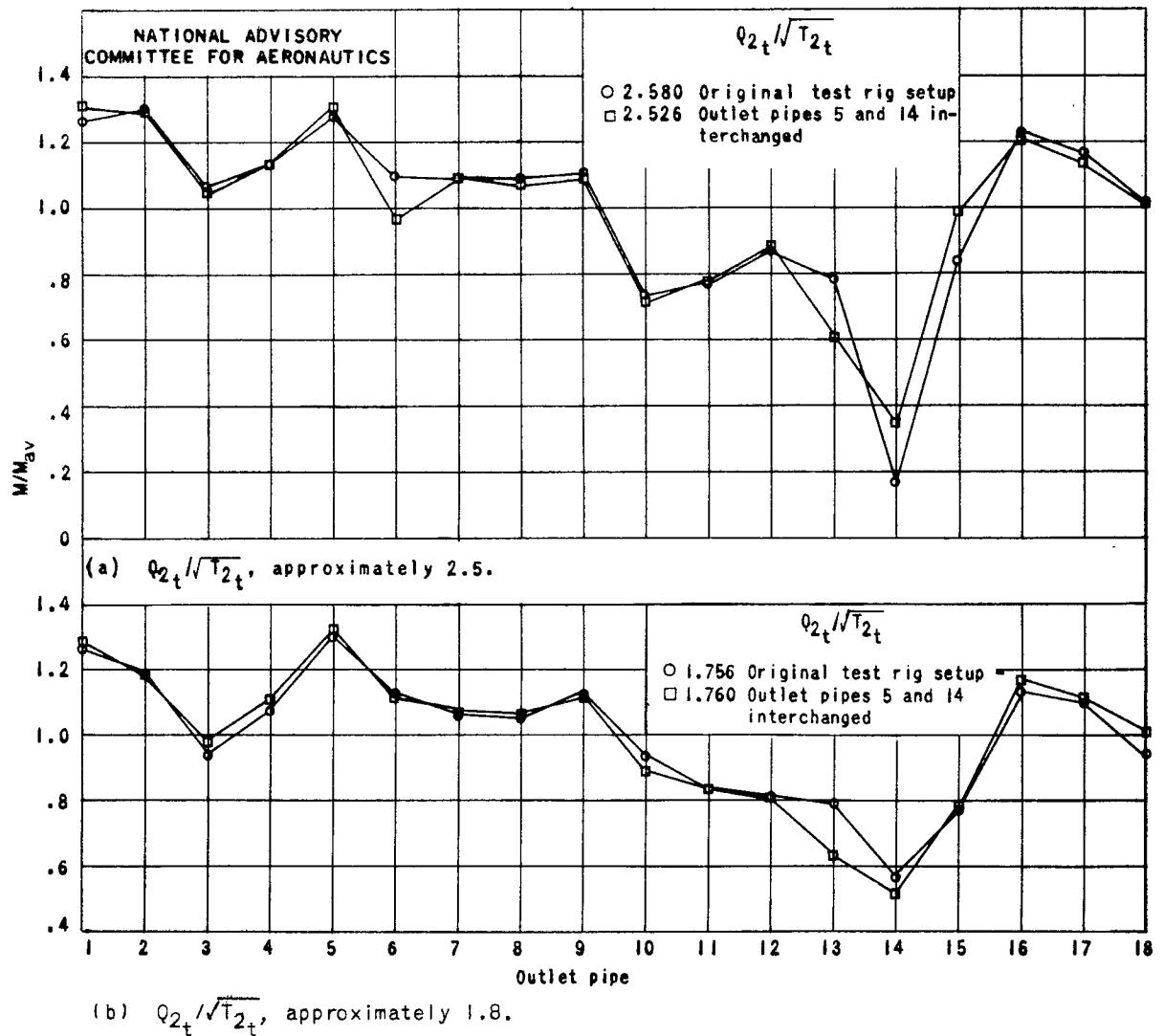
Figure 10. – Effect of outlet-pipe uniformity on air-flow distribution in outlets of engine-stage supercharger of double-row radial engine; engine speed, 2200 rpm; reference outlet pressure, 6 inches of mercury above atmospheric; carburetor-throttle angle, 66°.

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$Q_{2_t}/\sqrt{T_{2_t}}$

o 2.499 Orignal test rig setup
□ 2.452 Collector rotated 40°;
outlet pipes 5 and 14
interchanged

1.4

1.2

1.0

.8

.6

.4

.2

M/M_{av}

(a) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 2.5; engine speed, 2400 rpm.

1.4

1.2

1.0

.8

.6

.4

$Q_{2_t}/\sqrt{T_{2_t}}$

o 1.700 Original test rig setup
□ 1.685 Collector rotated 40°;
outlet pipes 5 and 14
interchanged

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Outlet pipe

(b) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 1.7; engine speed, 2400 rpm.
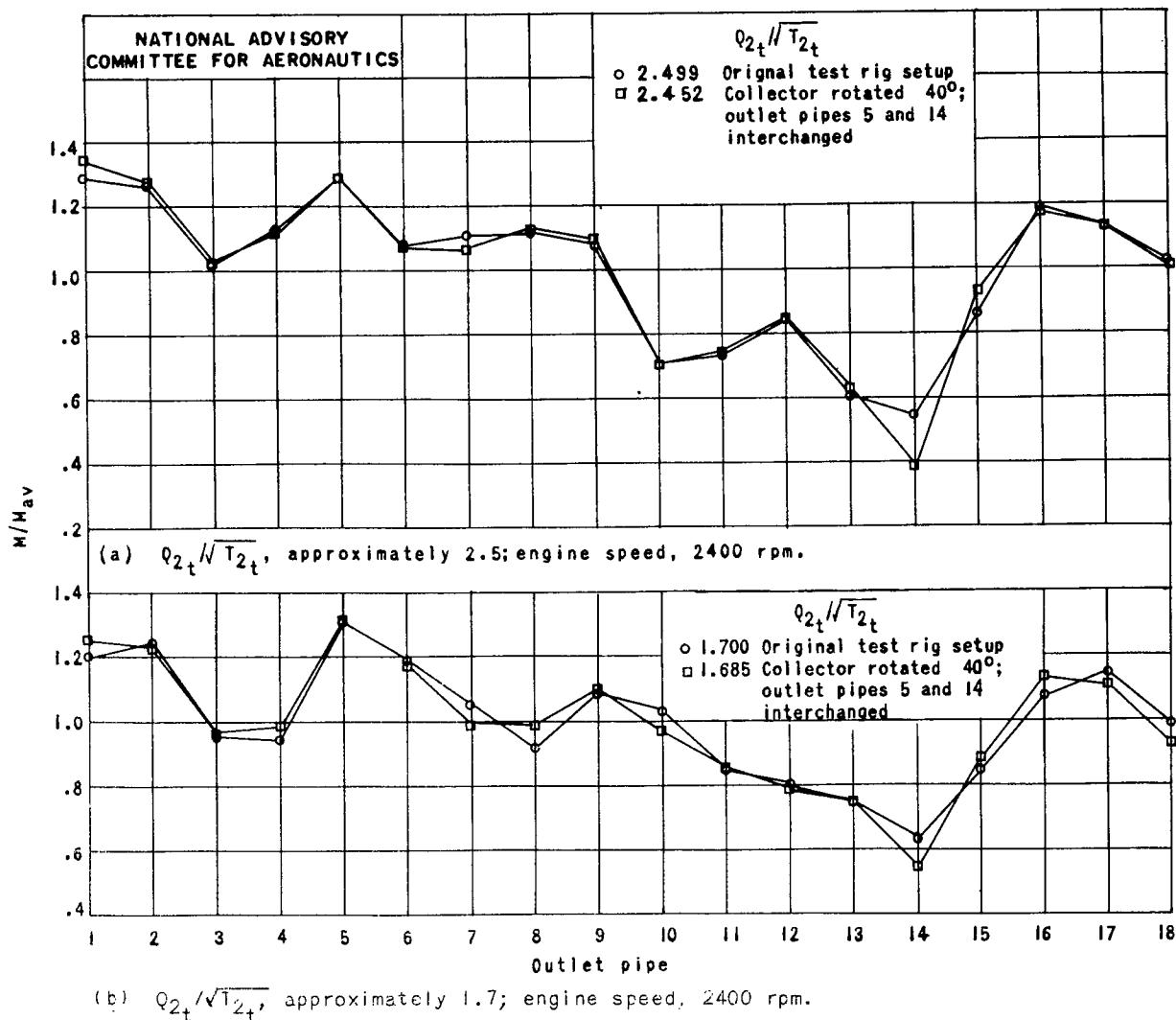
Figure 11. — Effect of collector-outlet location on air-flow distribution in outlets of engine-
stage supercharger of double-row radial engine; reference outlet pressure, 6 inches of mercury
above atmospheric; carburetor-throttle angle, 66°.

(c) $Q_{2_t}\sqrt{T_{2_t}}$, approximately 2.5; engine speed, 2200 rpm.

(d) $Q_{2_t}\sqrt{T_{2_t}}$, approximately 1.6; engine speed 2200 rpm.

Figure 11. - Concluded.

(a) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 2.0.

(b) $Q_{2_t}/\sqrt{T_{2_t}}$, approximately 1.6.
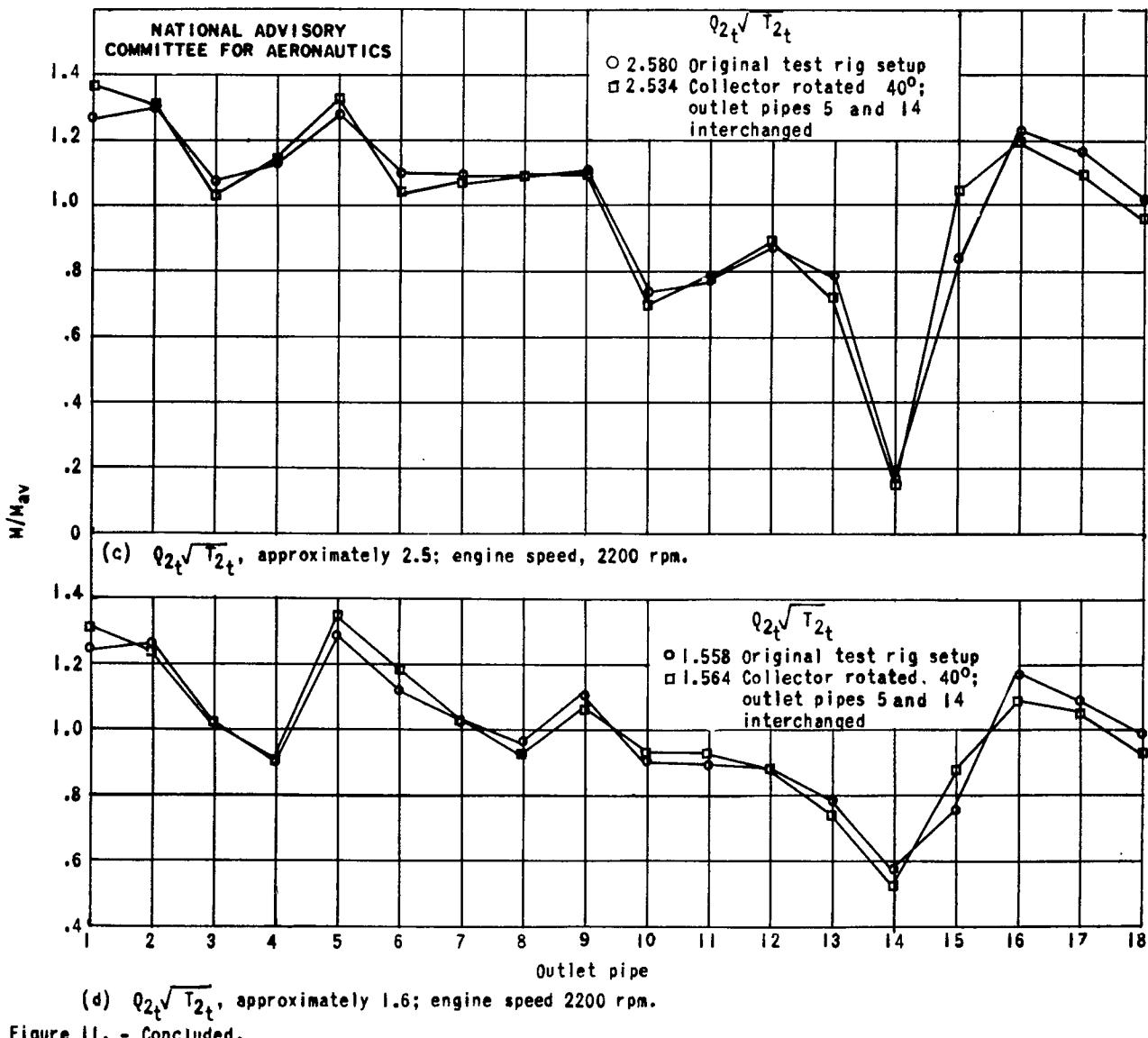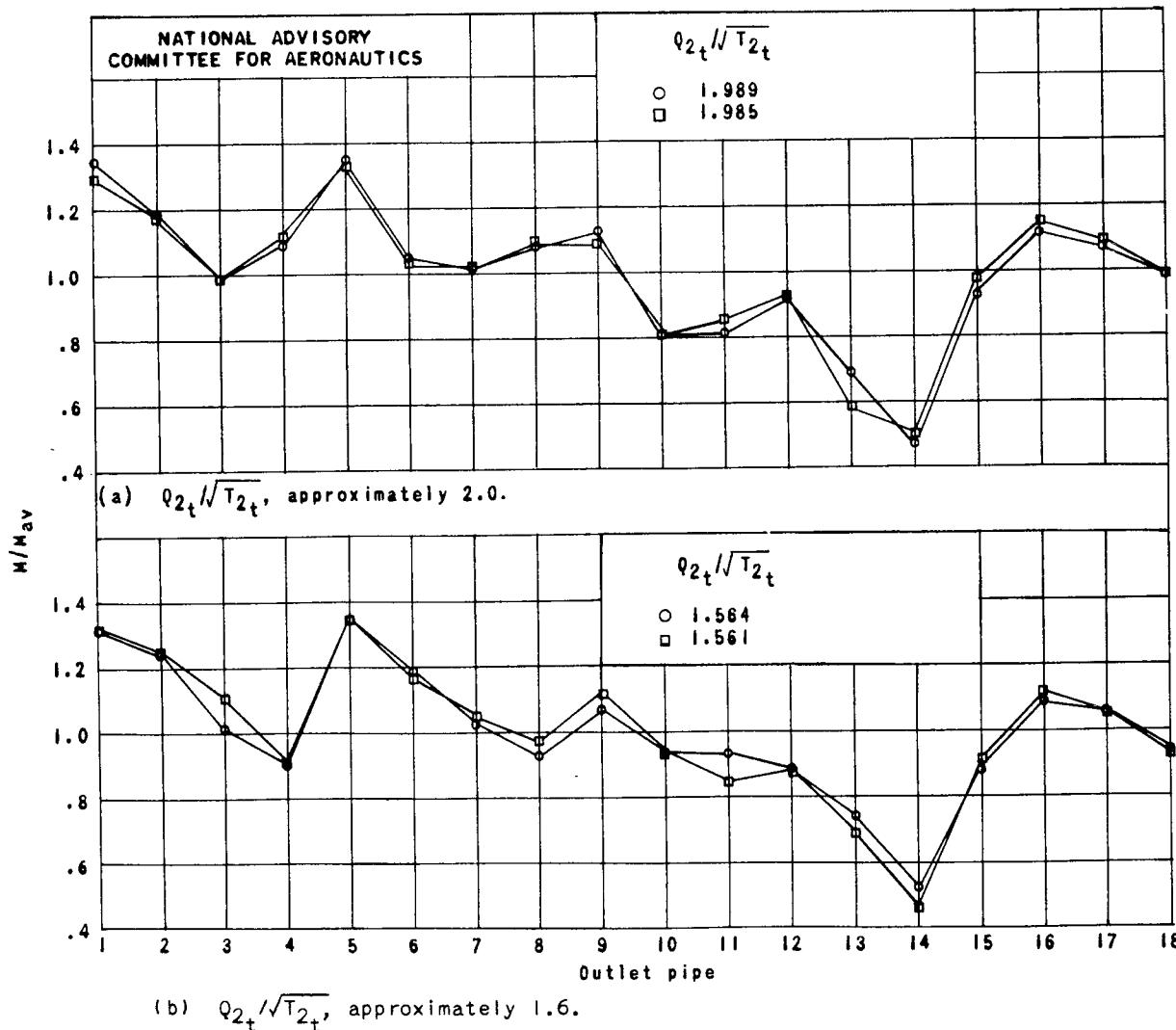
Figure 12. – Comparison of results for two approximately equal values of flow function on air-flow distribution in outlets of engine-stage supercharger of double-row radial engine; engine speed, 2200 rpm; reference outlet pressure, 6 inches of mercury above atmospheric; carburetor-throttle angle, 66°.

Impeller tip speed, V_T, fps

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Flow function, $Q_{2_t}/\sqrt{T_{2_t}}$
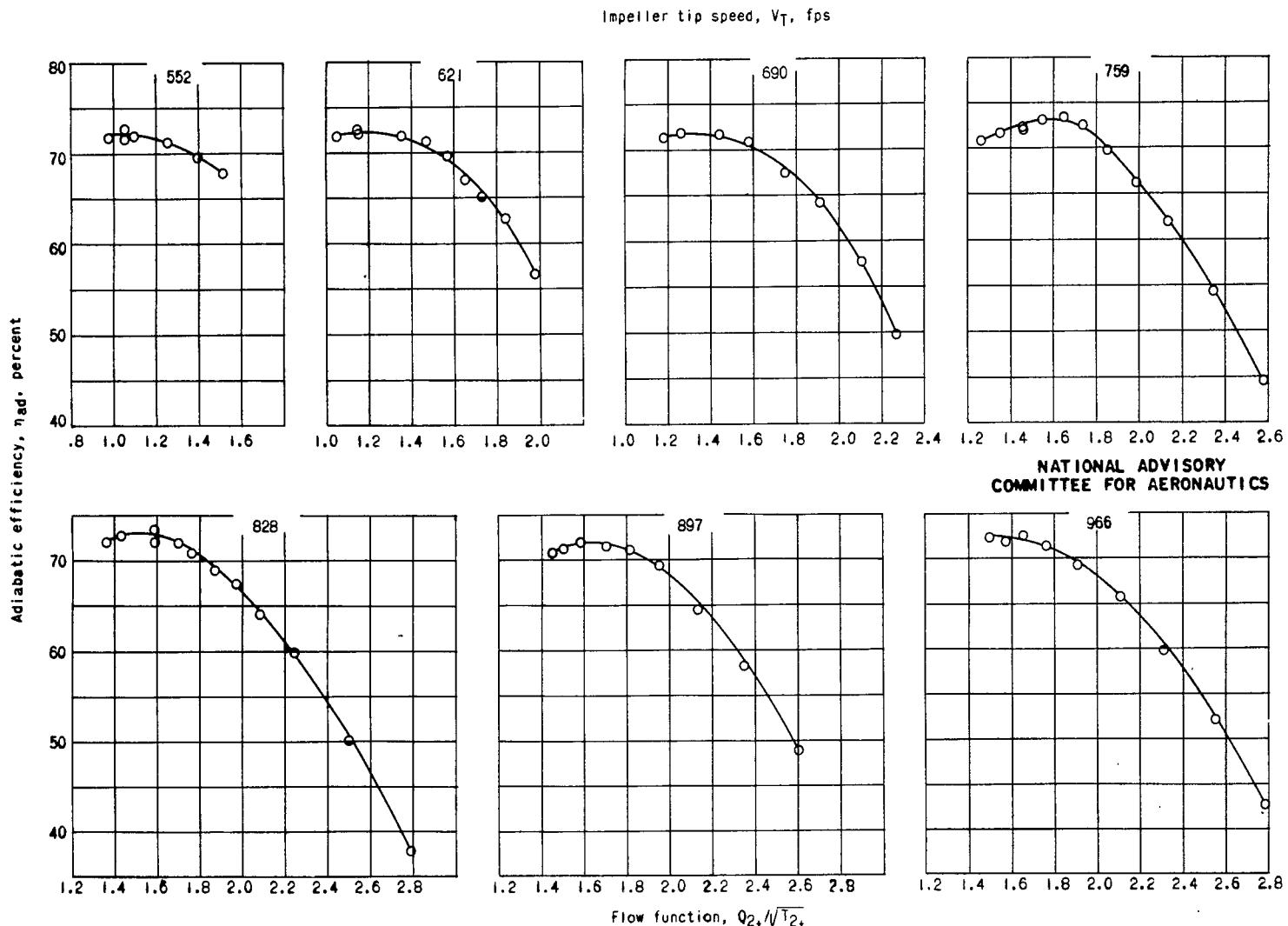
(a)   Adiabatic efficiencies.

Figure 13. – Engine–stage–supercharger performance of double–row radial engine at various impeller tip speeds; reference outlet pressure, 6 inches of mercury above atmospheric.

Impeller tip speed, V_T, fps

Pressure coefficient, q_{ad}, percent

Flow function, $Q_{2_t}/\sqrt{T_{2_t}}$
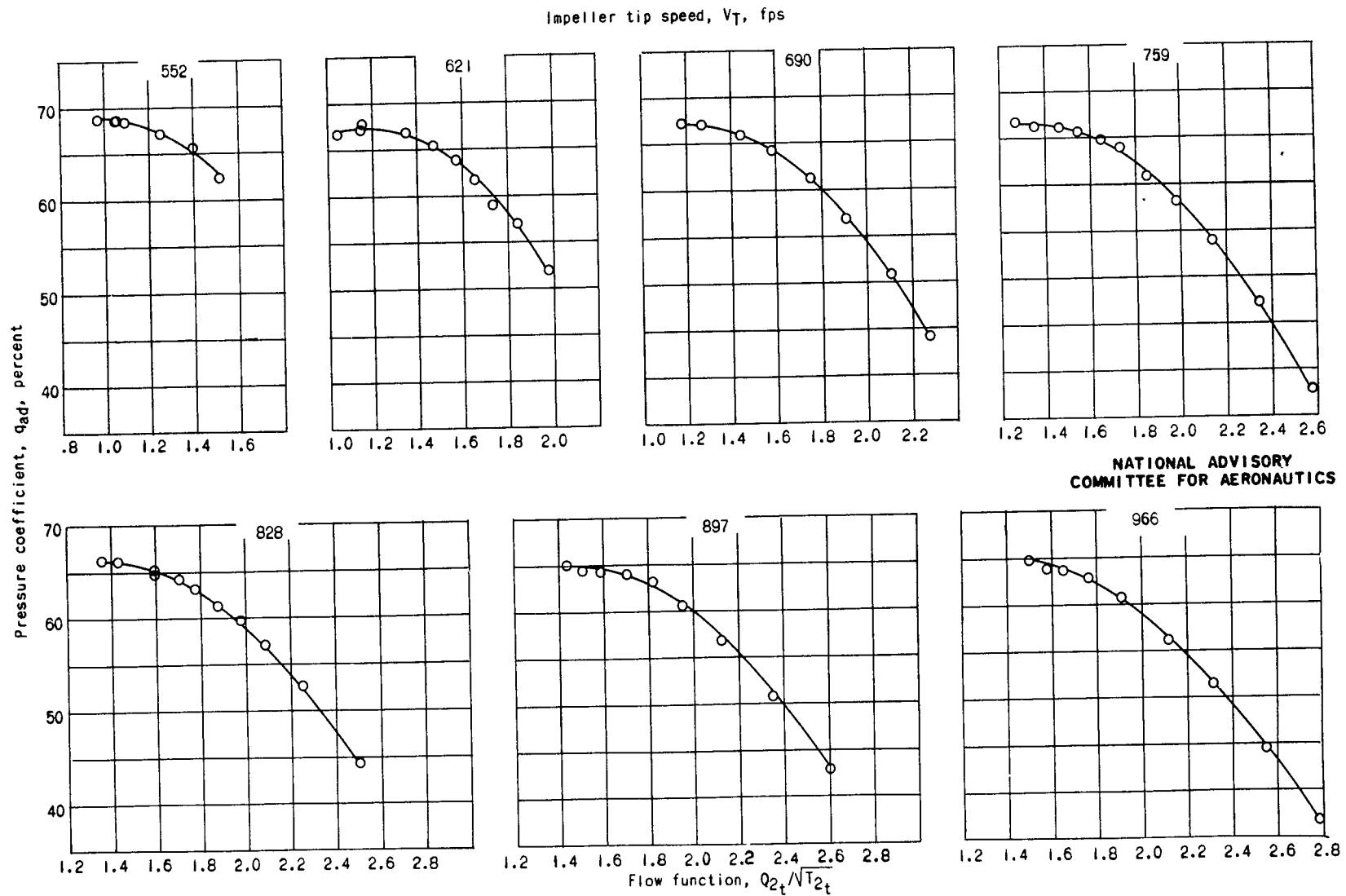
(b) Pressure coefficients.

Figure 13. – Concluded.