MEMO 12-21-58E

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## EXPERIMENTAL INVESTIGATION OF COAXIAL JET MIXING OF TWO SUBSONIC STREAMS AT VARIOUS TEMPERATURE, MACH NUMBER, AND DIAMETER RATIOS FOR THREE CONFIGURATIONS

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# EXPERIMENTAL INVESTIGATION OF COAXIAL JET MIXING OF TWO SUBSONIC STREAMS AT VARIOUS TEMPERATURE, MACH NUMBER, AND DIAMETER RATIOS FOR THREE CONFIGURATIONS

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## SUMMARY

An experimental investigation of the mixing of two coaxial gas streams was conducted over a range of subsonic jet Mach numbers and temperatures. Three configurations were investigated. One had no innerbody in the primary or inner pipe and was designed to give flat velocity profiles at the exit of the primary pipe. The other two configurations had innerbodies in the primary pipe. These were designed to give velocity profiles similar to those existing at the inlet of propulsive systems such as afterburners.

Curves of axial velocity and temperature profiles across the radius are presented at various axial stations. For the two configurations with the innerbody, data are shown at stations out to approximately 3 primary-pipe diameters from the exit of the primary pipe. For the flat-velocity-profile configuration, data are shown at distances extending downstream 22 primary-pipe diameters from the exit of the primary pipe.

## INTRODUCTION

The mixing of two subsonic coaxial jets occurs in many propulsive systems. Some of these systems are bypass engines, ejectors, afterburners, and air turborockets. At the point where the two streams begin to mix, the velocities and temperatures are at different levels. The amount of mixing can affect both the operating characteristics and the efficiency of propulsion systems.

Several analytical theories have been proposed to explain the phenomenon of jet mixing (refs. 1 to 3). Only a comparatively limited amount of experimental data has been obtained in connection with these theories. The majority of these experiments were for temperature ratios of 1 and were conducted on a relatively small scale; that is, the primary jets were approximately 1 inch in diameter.

The objects of this program therefore were (1) to extend the range of experimental data to a larger scale, (2) to extend the data to temperature ratios greater than 1, and (3) to simulate flow profiles that would be more nearly representative of those in propulsion systems. Data were obtained over a range of primary (inner pipe) to secondary (outer pipe) Mach number ratios from 1.00 to 3.00 and primary to secondary temperature ratios from 1.55 to 2.44 for three configurations. These configurations had primary to secondary diameter ratios ranging from 0.172 to 0.698.

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This report constitutes a data presentation of the results obtained from the investigation. The data are presented in the form of curves of velocity and temperature profiles across the radius for various stations along the mixing zone. No attempt is made to correlate with theory.

## SYMBOLS

D diameter

$M_p$ Mach number at primary exit

$M_s$ Mach number at secondary exit

p static pressure

T temperature

Subscripts:

p primary

s secondary

## APPARATUS

A schematic diagram of the coaxial jet-mixing setup is shown in figure 1. The 80° F inlet air was preheated by 135 combustor cans. The three configurations used during this investigation are shown in figures 2(a) to (c), and a detailed sketch of the innerbody is shown in figure 2(d). The flat-velocity-profile configuration consisted of a 3.61-inch-diameter primary pipe, the exit of which was tapered to the same sharp edge as the primary pipe with the innerbody configuration, and a 21-inch-diameter secondary pipe. The large plenum chamber located upstream of the primary pipe was designed to provide a flat velocity profile in the secondary stream at the primary exit. Innerbody configurations I and II each consisted of a 10.00-inch-diameter primary pipe containing an innerbody, and secondary pipes that were 21 and 14.32 inches in diameter, respectively.

Measurements of pressure and temperature were obtained by the use of remotely controlled, motor-driven, traversing probes (fig. 3(a)). A detailed sketch of one of these probes is shown in figure 3(b). The probe design was similar to that in reference 4. Both the static- and total-pressure measurements were accurate to within ±1 percent, and the measured temperature was lower than the true reading by less than 1 percent. Surveys across the radius of the mixing region were taken at 12-inch axial intervals beginning at the exit of the primary pipe and extending downstream. For the flat-velocity-profile configuration, the maximum axial distance was 22 primary-pipe diameters. With the two innerbody configurations, the maximum axial distance was 8 primary-pipe diameters.





## PROCEDURE

Data were obtained over a range of primary to secondary Mach number ratio $M_p/M_s$ of 1.00 to 3.00, and primary to secondary temperature ratio $T_p/T_s$ of 1.55 to 2.44 for three configurations. The range of variables is shown in table I. For all the configurations, the primary Mach number remained constant at 0.3, and the secondary stream Mach number was varied to obtain the desired ratio. This was accomplished by using altitude exhaust and high-pressure supply air. The static pressure at the beginning of mixing was varied from 21 to 29 inches of mercury absolute, depending on the conditions to be run. The temperature ratios for the flat-velocity-profile configuration were obtained by holding the secondary temperature constant at 540° R while the primary temperature was varied. For the two innerbody configurations, the primary temperature was maintained constant at 1710° R and the secondary temperature was varied.

Measurements of pressure and temperature across the radius were taken using one survey probe at a time. Since only three motor-driven actuators were used, they had to be removed and relocated at axial stations farther downstream in order to survey the entire length of mixing region. Total- and static-pressure probes were located at the exit of the primary pipe in both the primary and secondary streams. The pressures were then measured on U-tube manometers located in the control room. These manometers were used for setting the conditions before each survey. They were used also to indicate how accurate the conditions were maintained during each survey. With these manometers, the pressures were held constant to within ±0.25 pound per square inch absolute.

## RESULTS AND DISCUSSION

### Flat-Velocity-Profile Configuration

For the flat-velocity-profile configuration, variations of the velocity profile across the jet are shown in figure 4 for various axial distances downstream of the exit of the primary pipe. The corresponding temperature profiles are shown in figure 5. (In these and the following figures, the curves are divided into arbitrary groups for clarity of reading.)

The centerline velocity and temperature began to decay at an axial distance between 3.6 and 6.9 primary-jet diameters downstream of the end of the primary pipe for all Mach number and temperature ratios investigated. However, the centerline temperature decayed more rapidly than did the centerline velocity. The rate of centerline velocity and temperature decay was accelerated by increasing the difference between the primary-jet velocity and the secondary velocity. This trend occurred whether the velocity difference was obtained by varying the jet total pressure or the inner or outer jet temperature.

### Innerbody Configurations

Configuration I. - Variations of the velocity profile across the jet for innerbody configuration I are shown in figure 6 for various axial distances downstream of the exit of the primary pipe. The corresponding temperature profiles are shown in figure 7. A dip appears in the velocity profile near the centerline of the pipe and close to the primary exit. This dip, which is due to boundary-layer flow from the innerbody in the primary pipe (fig. 2), is typical of profiles often observed downstream of engine tailpipe innerbodies. In general, this dip disappeared by the time the flow had traveled 2.5 primary-pipe diameters downstream of the primary exit. The temperature profiles, which are much flatter than their corresponding velocity profiles, are similar to the temperature profiles of the flat-velocity-profile configuration.

Configuration II. - Variations of the velocity profile across the jet for innerbody configuration II are shown in figure 8 for various axial distances downstream of the exit of the primary pipe. The corresponding temperature profiles are shown in figure 9. The dip in these velocity profiles near the centerline of the pipe is also due to the presence of the innerbody. The velocity profile appears not to change much after the flow has reached a distance of 4.8 primary-pipe diameters downstream of the exit of the primary pipe. The temperature profiles, as with innerbody configuration I, are much flatter than their corresponding velocity profiles. It appears that the temperature profiles also do not change much after a distance of 4.8 diameters downstream of the primary exit.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, October 1, 1958

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2. Pai, S. I.: Axially Symmetrical Jet Mixing of a Compressible Fluid. Quarterly Appl. Math., vol. X, no. 2, July 1952, pp. 141-148.

3. Pai, S. I.: Two-Dimensional Jet Mixing of a Compressible Fluid. Jour. Aero. Sci., vol. 16, no. 8, Aug. 1949, pp. 463-469.

4. Gettelman, Clarence C., and Krause, Lloyd N.: Considerations Entering Into the Selection of Probes for Pressure Measurement in Jet Engines. Proc. Instr. Soc. Am., Paper No. 52-12-1, vol. 7, 1952, pp. 134-137.

TABLE I. - EXPERIMENTAL CONDITIONS

[Primary Mach number, $M_p$, 0.3.]

| Primary diam., $D_p$, in. | Secondary diam., $D_s$, in. | Primary temp., $T_p$, °R | Secondary temp., $T_s$, °R | $T_p/T_s$ | Secondary Mach number, $M_s$ | Primary-exit static pressure, $p_p$, in. Hg abs |
|---|---|---|---|---|---|---|
| Flat-velocity-profile configuration | | | | | | |
| 3.61 | 21.00 | 840 | 540 | 1.56 | 0.3 | 25 |
| | | | | | .2 | 27 |
| | | | | | .1 | 29 |
| | | 1040 | 540 | 1.93 | 0.3 | 25 |
| | | | | | .2 | 27 |
| | | | | | .1 | 29 |
| | | 1320 | 540 | 2.44 | 0.3 | 25 |
| | | | | | .2 | 27 |
| | | | | | .1 | 29 |
| Innerbody configuration I | | | | | | |
| 10.00 | 21.00 | 1710 | 1100 | 1.55 | 0.3 | 21 |
| | | | | | .2 | ↓ |
| | | | | | .1 | ↓ |
| | | | 900 | 1.90 | 0.3 | ↓ |
| | | | | | .2 | ↓ |
| | | | | | .1 | ↓ |
| | | | 700 | 2.44 | 0.3 | ↓ |
| | | | | | .2 | ↓ |
| | | | | | .1 | ↓ |
| Innerbody configuration II | | | | | | |
| 10.00 | 14.32 | 1710 | 1100 | 1.55 | 0.3 | 21 |
| | | | | | .2 | ↓ |
| | | | | | .1 | ↓ |
| | | | 900 | 1.90 | 0.3 | ↓ |
| | | | | | .2 | ↓ |
| | | | | | .1 | ↓ |
| | | | 700 | 2.44 | 0.3 | ↓ |
| | | | | | .2 | ↓ |
| | | | | | .1 | ↓ |

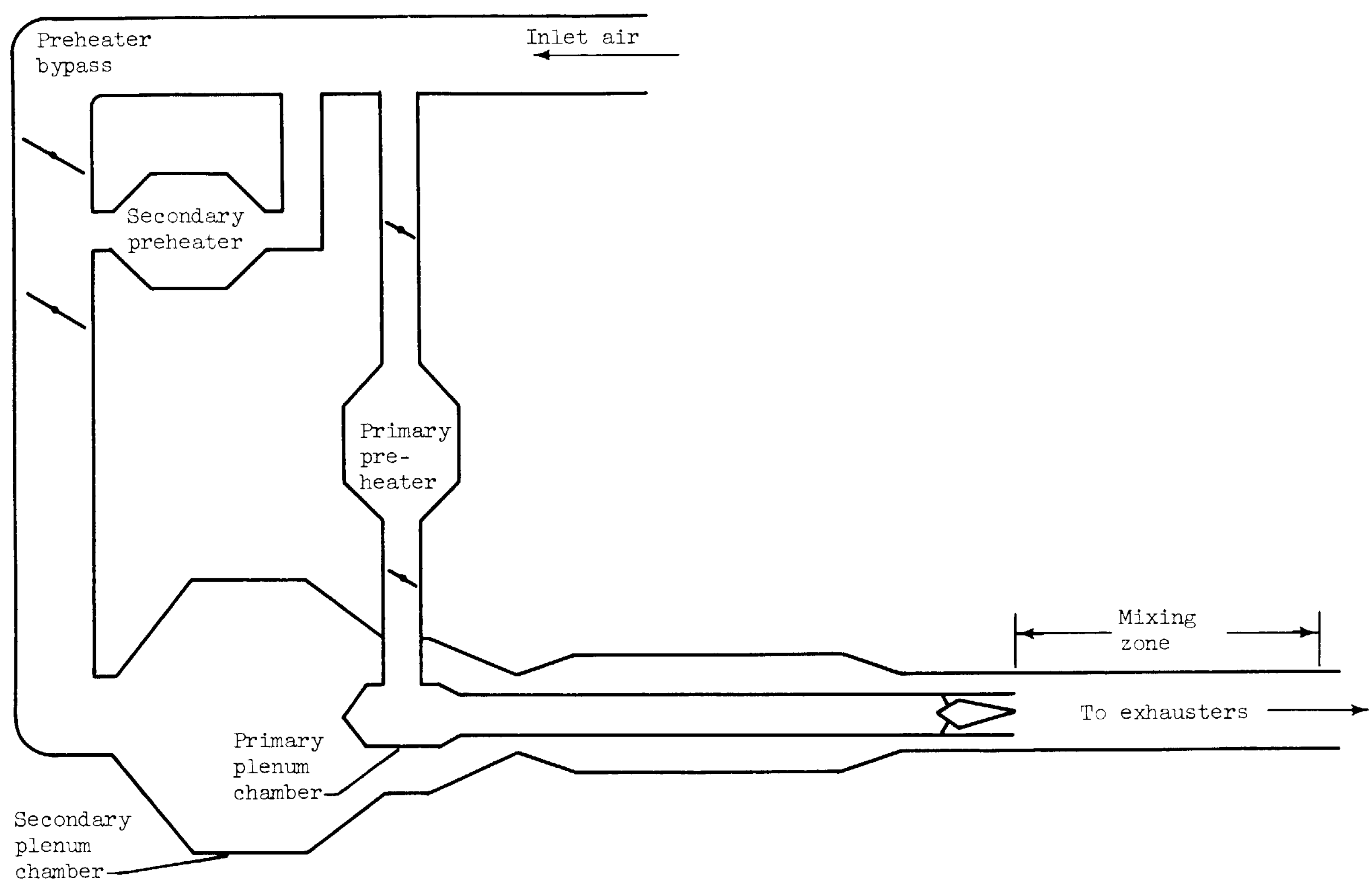
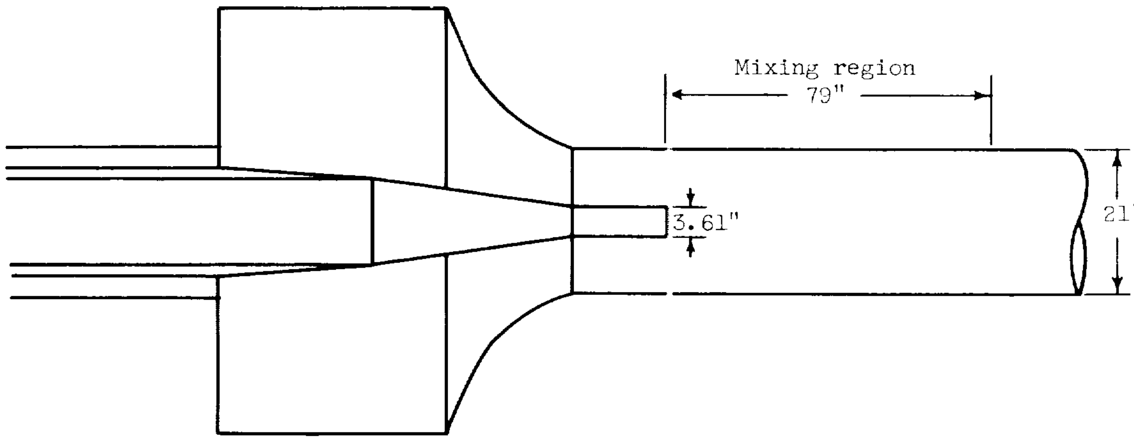
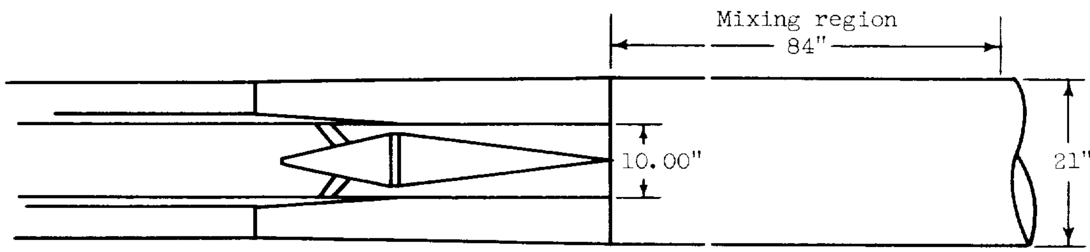


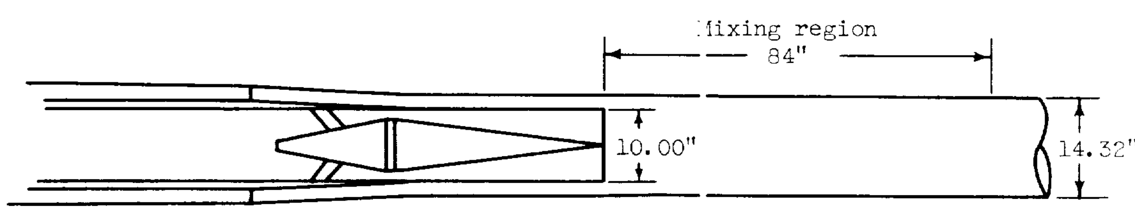

Figure 1. - Jet-mixing rig.




(a) Flat-velocity-profile configuration.




(b) Innerbody configuration I.




(c) Innerbody configuration II.

Figure 2. - Jet-mixing configurations.

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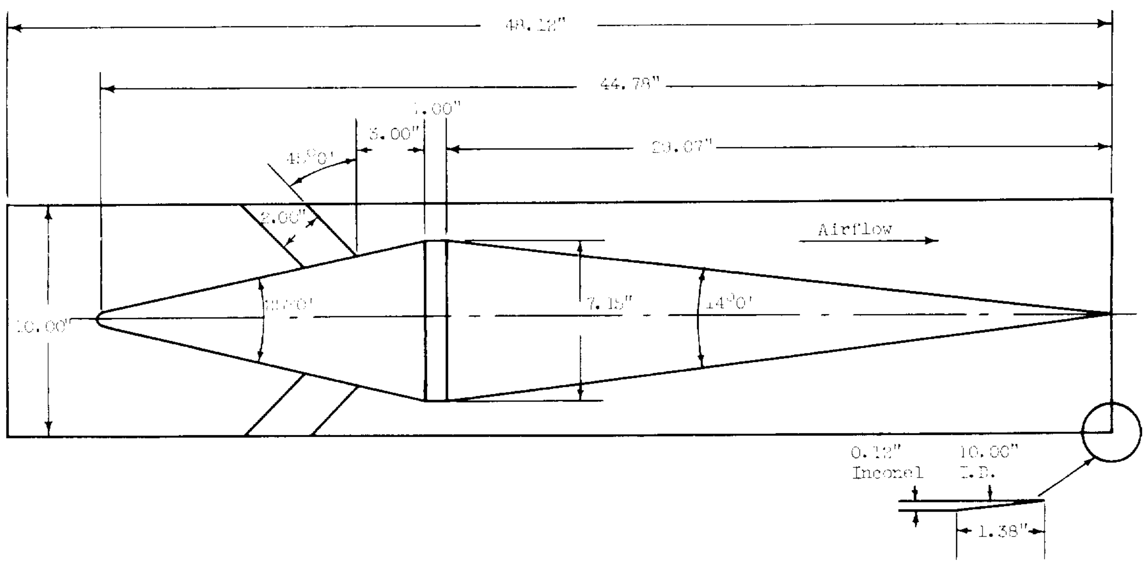
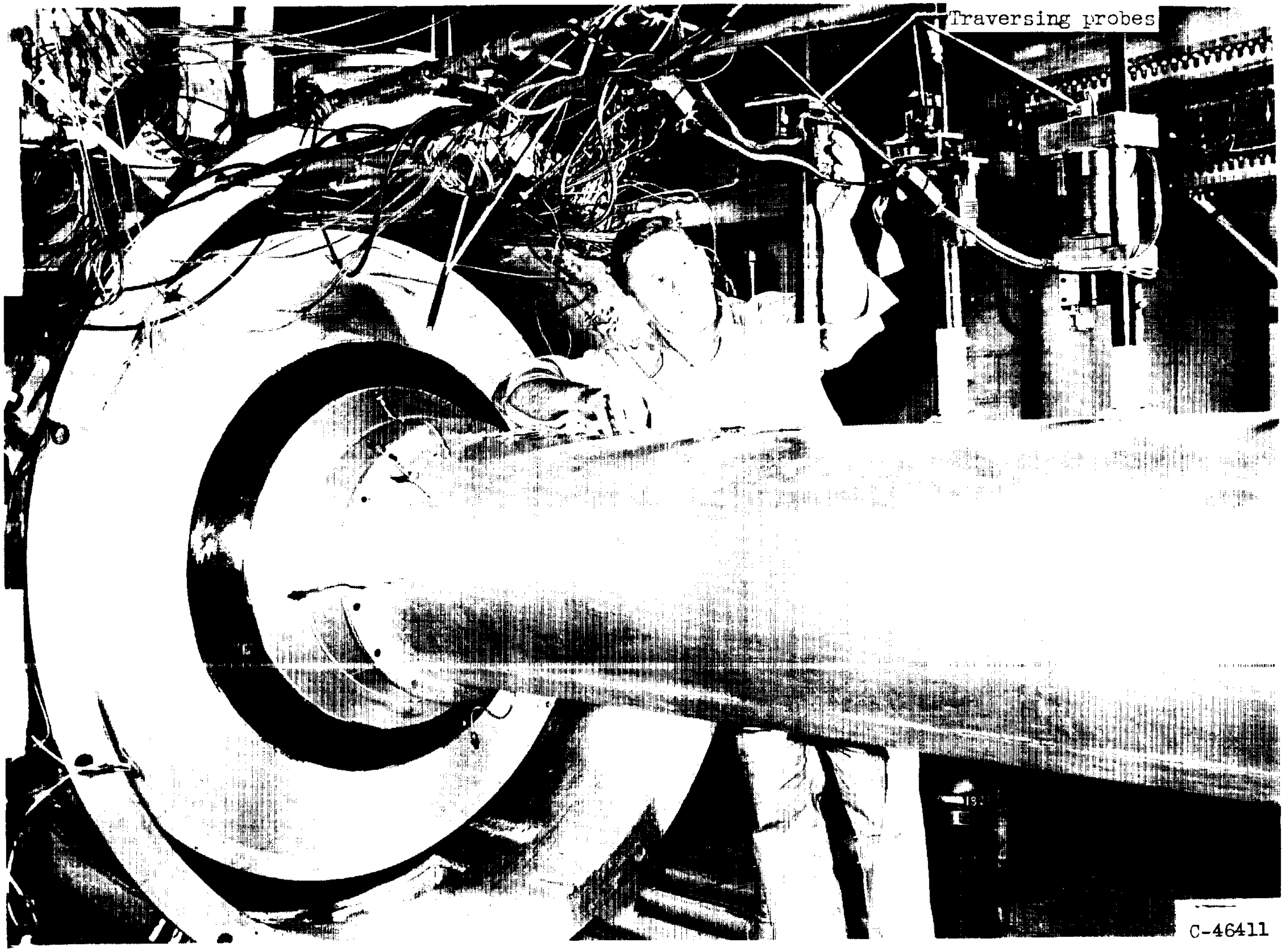



(d) Diffuser detail.

Figure 2. - Concluded. Jet-mixing configurations.




(a) Traversing probes installed in mixing rig.

Figure 3. - Traversing probes.

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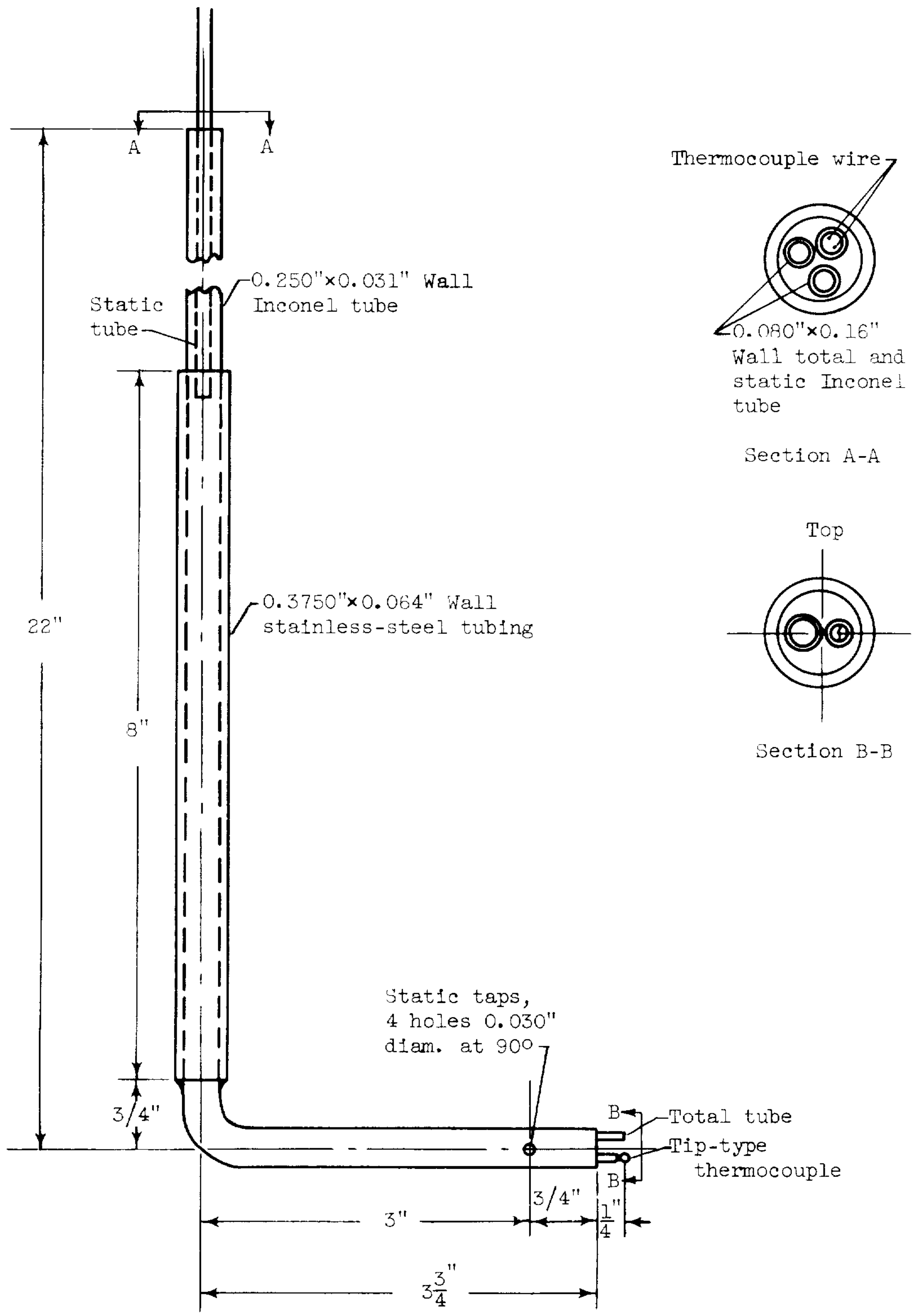
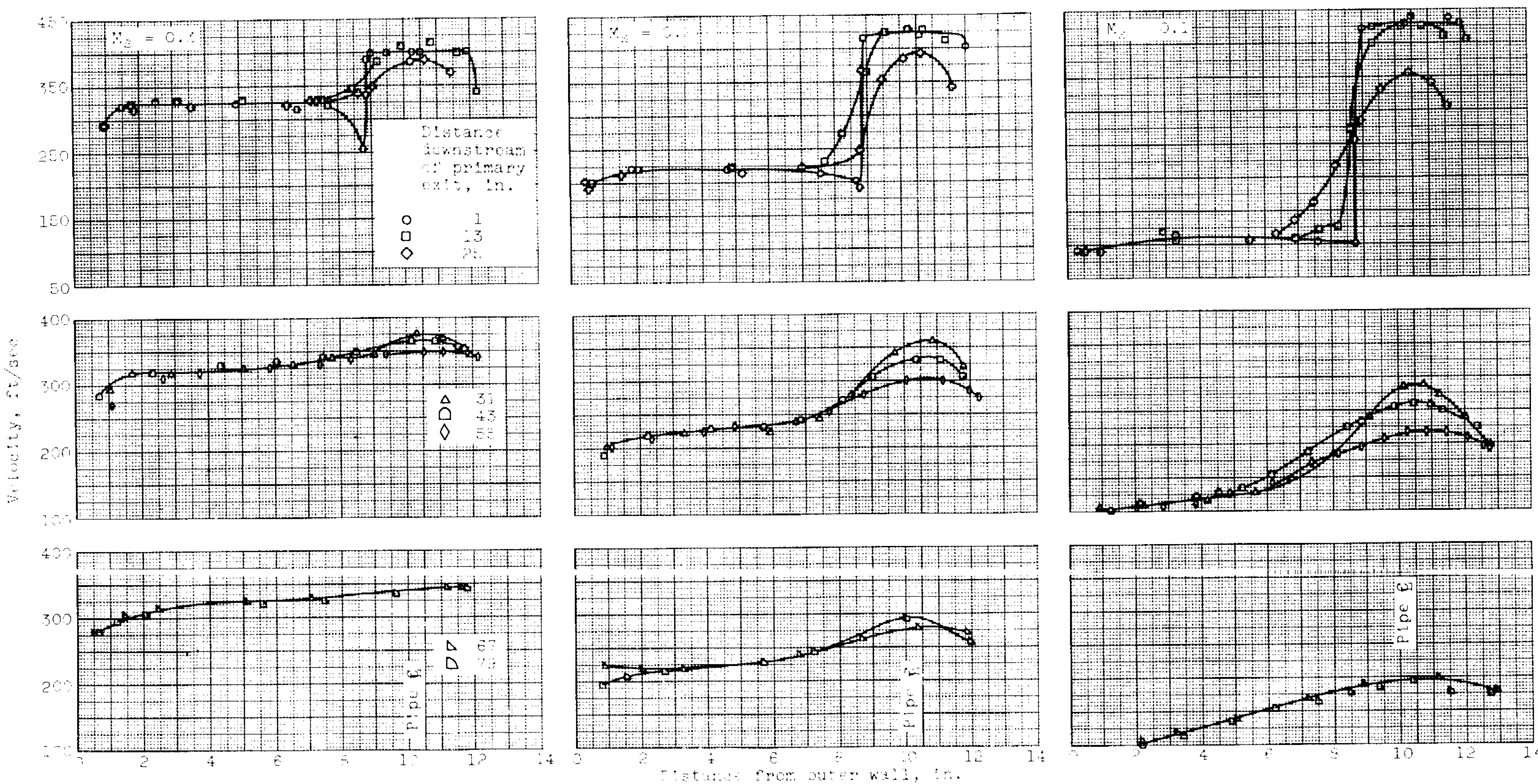
CR-2 back



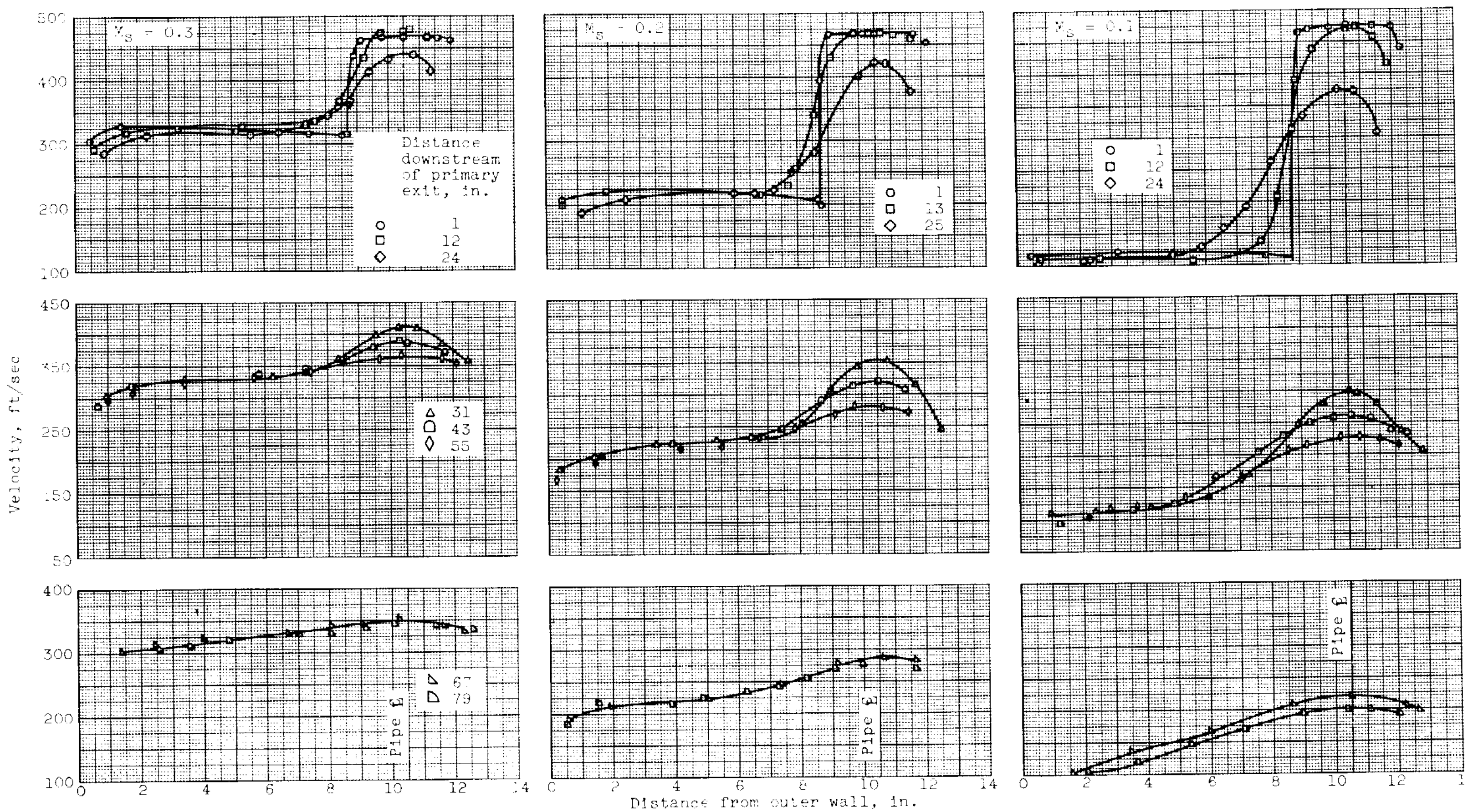

(b) Probe details.

Figure 3. - Concluded. Traversing probes.



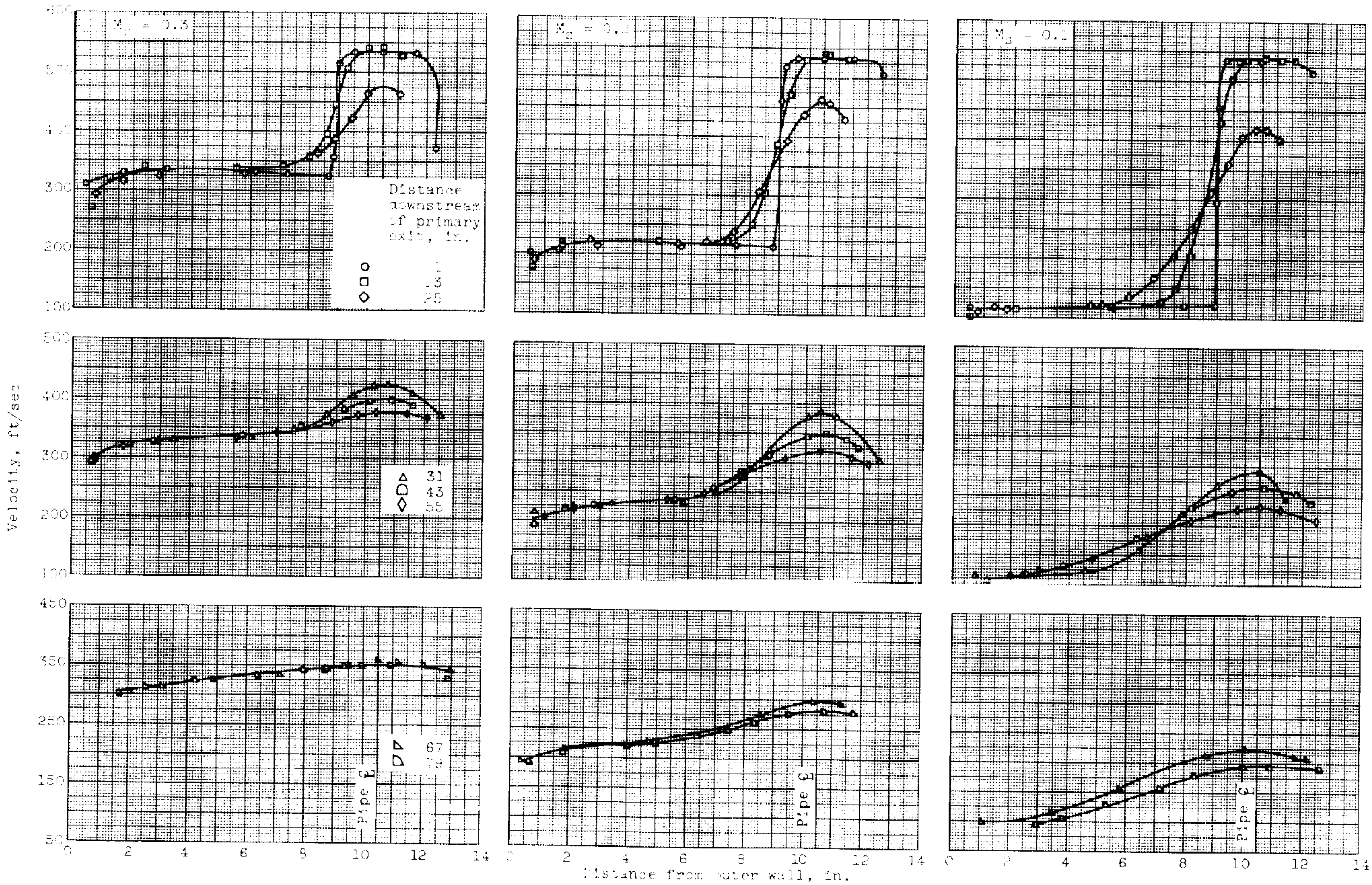

(a) Primary temperature, 540° R; ratio of primary to secondary temperature, 1.00.

Figure 4. - Radial velocity profiles for flat-velocity-profile configuration. Primary Mach number, 0.5; primary diameter, 5.61 inches; secondary diameter, 21.00 inches; secondary temperature, 540° R.



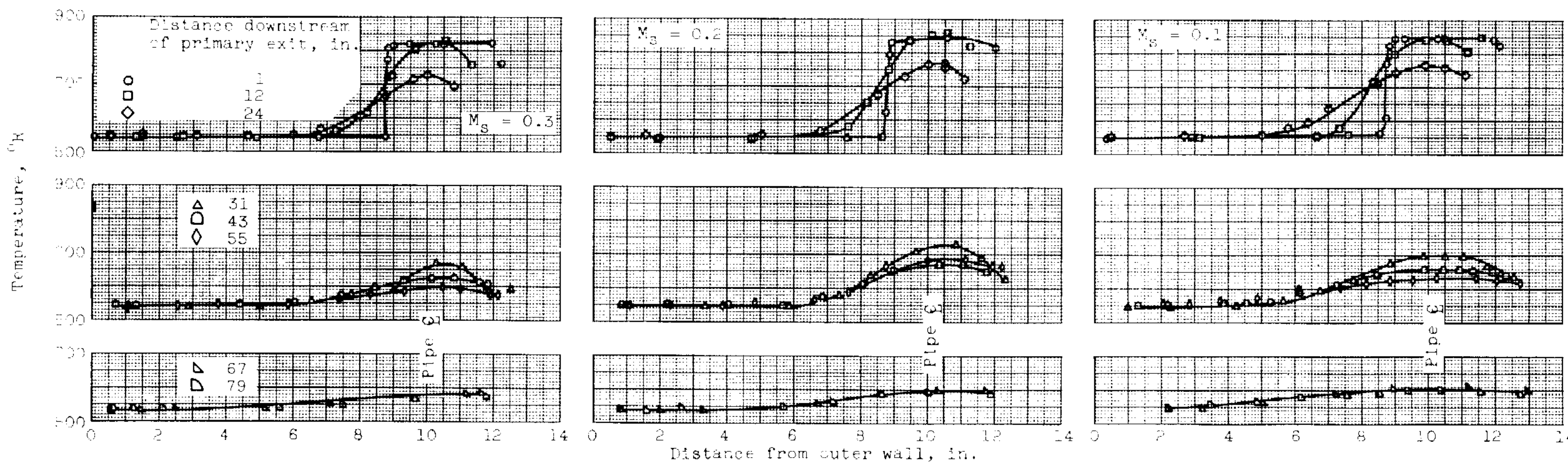

(b) Primary temperature, 1040° R; ratio of primary to secondary temperature, 1.93.

Figure 4. - Continued. Radial velocity profiles for flat-velocity-profile configuration. Primary Mach number, 0.3; primary diameter, 3.61 inches; secondary diameter, 21.00 inches; secondary temperature, 540° R.



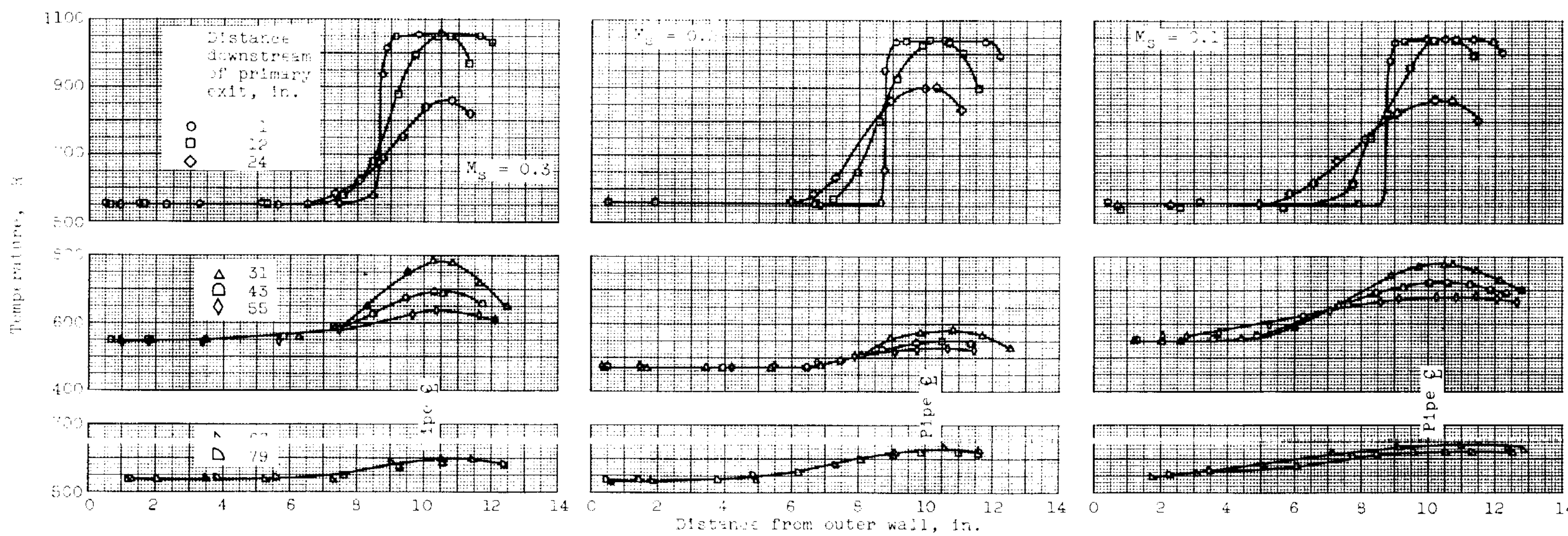

(c) Primary temperature, 1300° R; ratio of primary to secondary temperature, 2.44.

Figure 4. - Concluded. Radial velocity profiles for flat-velocity-profile configuration. Primary Mach number, 0.5; primary diameter, 3.81 inches; secondary diameter, 21.00 inches; secondary temperature, 540° R.



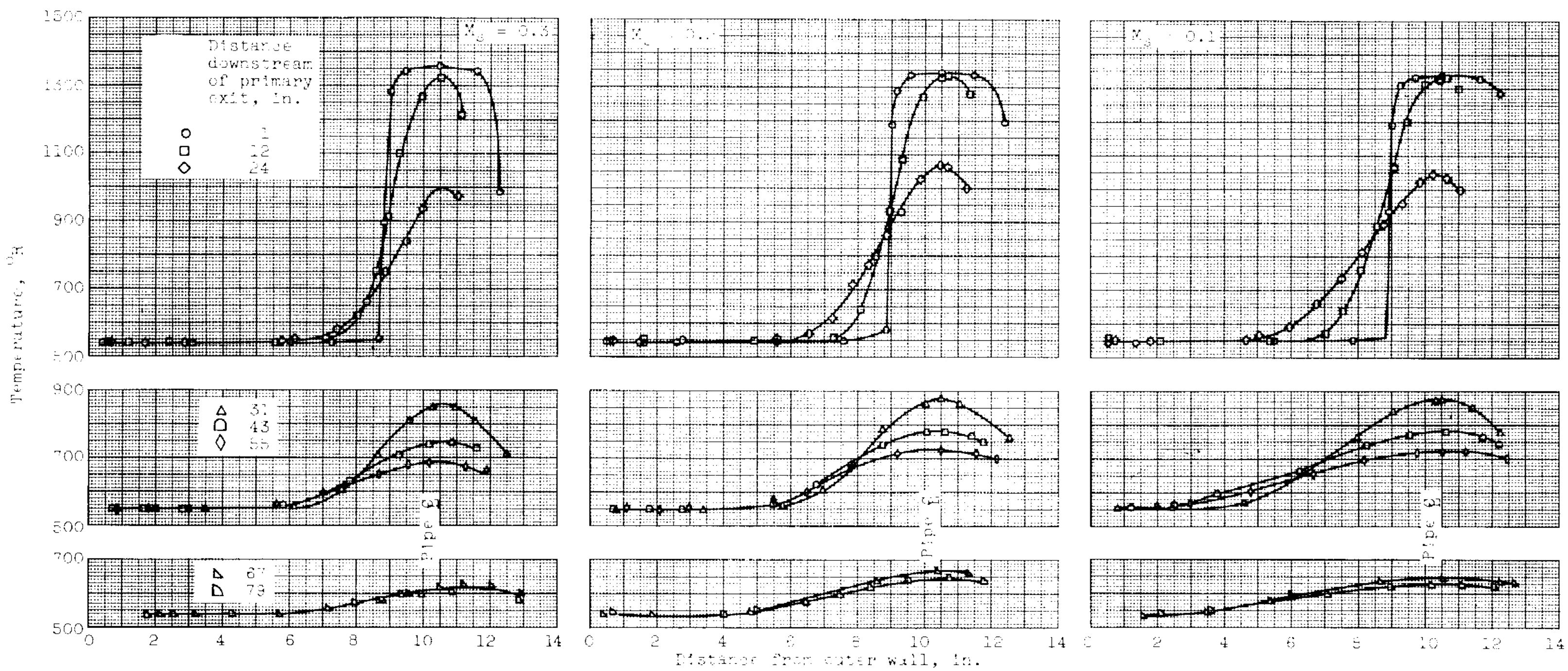

(a) Primary temperature, 840° R; ratio of primary to secondary temperature, 1.56.

Figure 5. - Radial temperature profiles for flat-velocity-profile configuration. Primary Mach number, 0.3; primary diameter, 3.61 inches; secondary diameter, 21.00 inches; secondary temperature, 540° R.



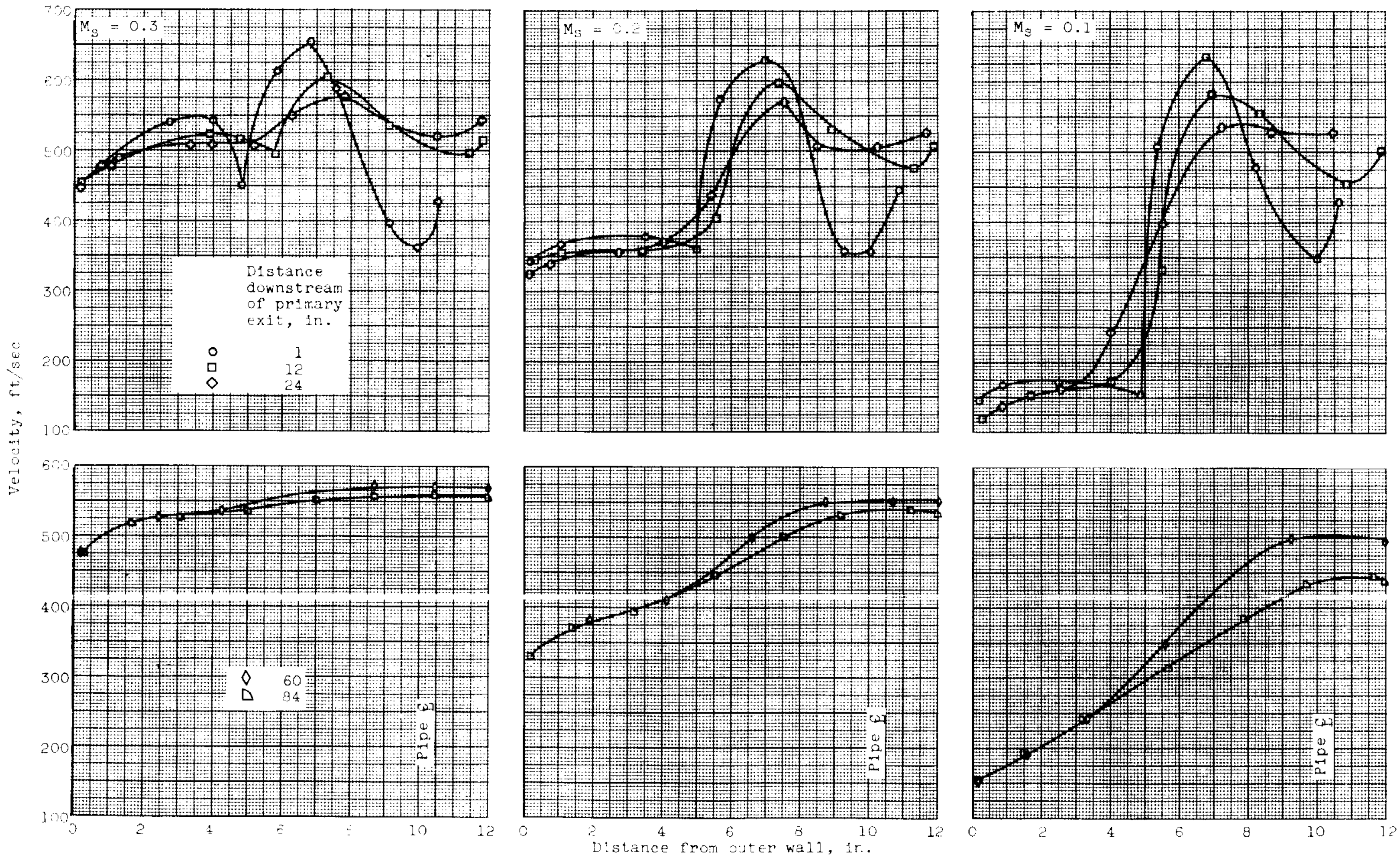

(b) Primary temperature, 1040° R; ratio of primary to secondary temperature, 1.93.

Figure 5. - Continued. Radial temperature profiles for flat-velocity-profile configuration. Primary Mach number, 0.3; primary diameter, 3.61 inches; secondary diameter, 21.00 inches; secondary temperature, 540° R.



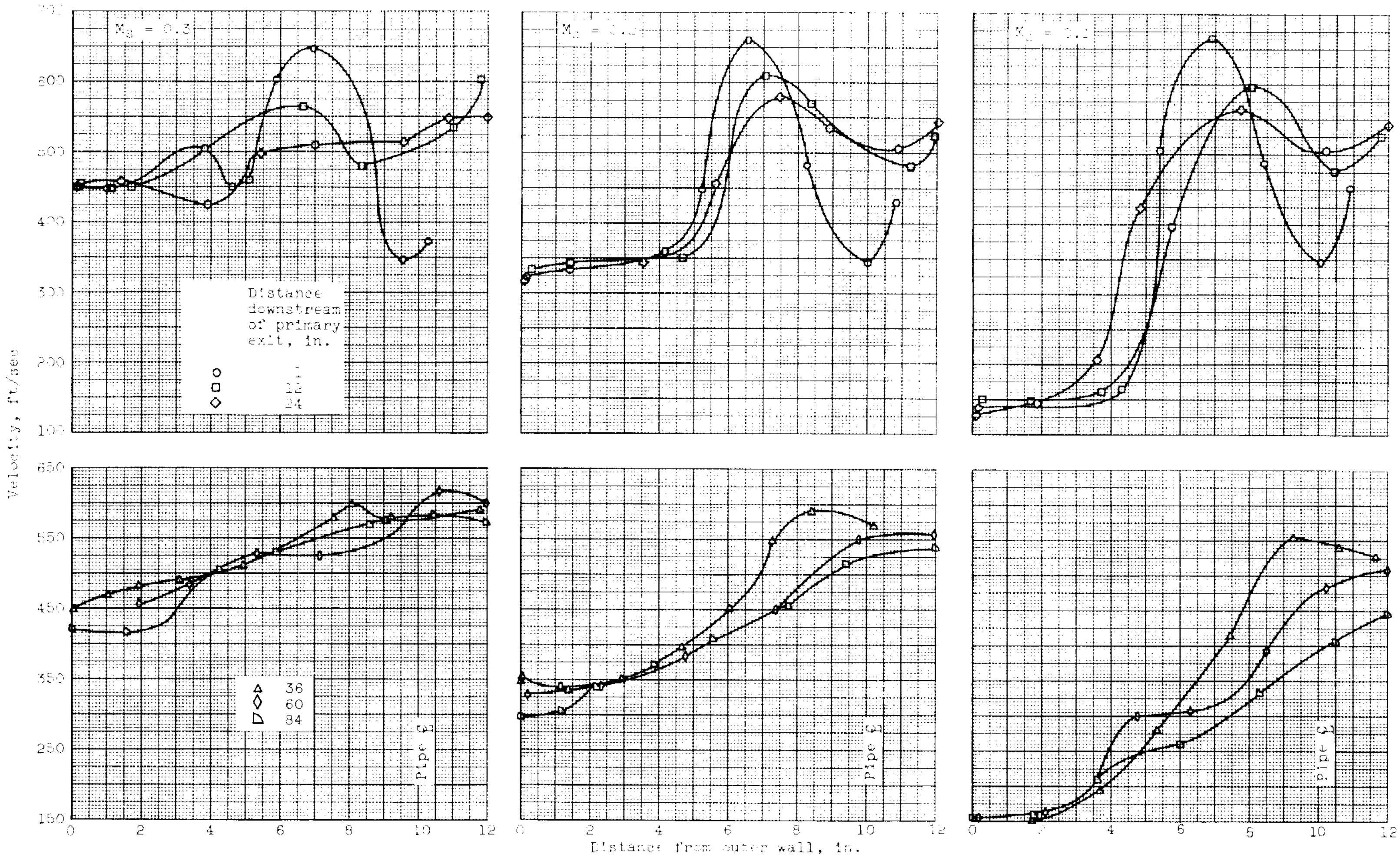

(c) Primary temperature, 1320° R; ratio of primary to secondary temperature, 2.44.

Figure 5. - Concluded. Radial temperature profiles for flat-velocity-profile configuration. Primary Mach number, 0.3; primary diameter, 3.61 inches; secondary diameter, 21.00 inches; secondary temperature, 540° R.



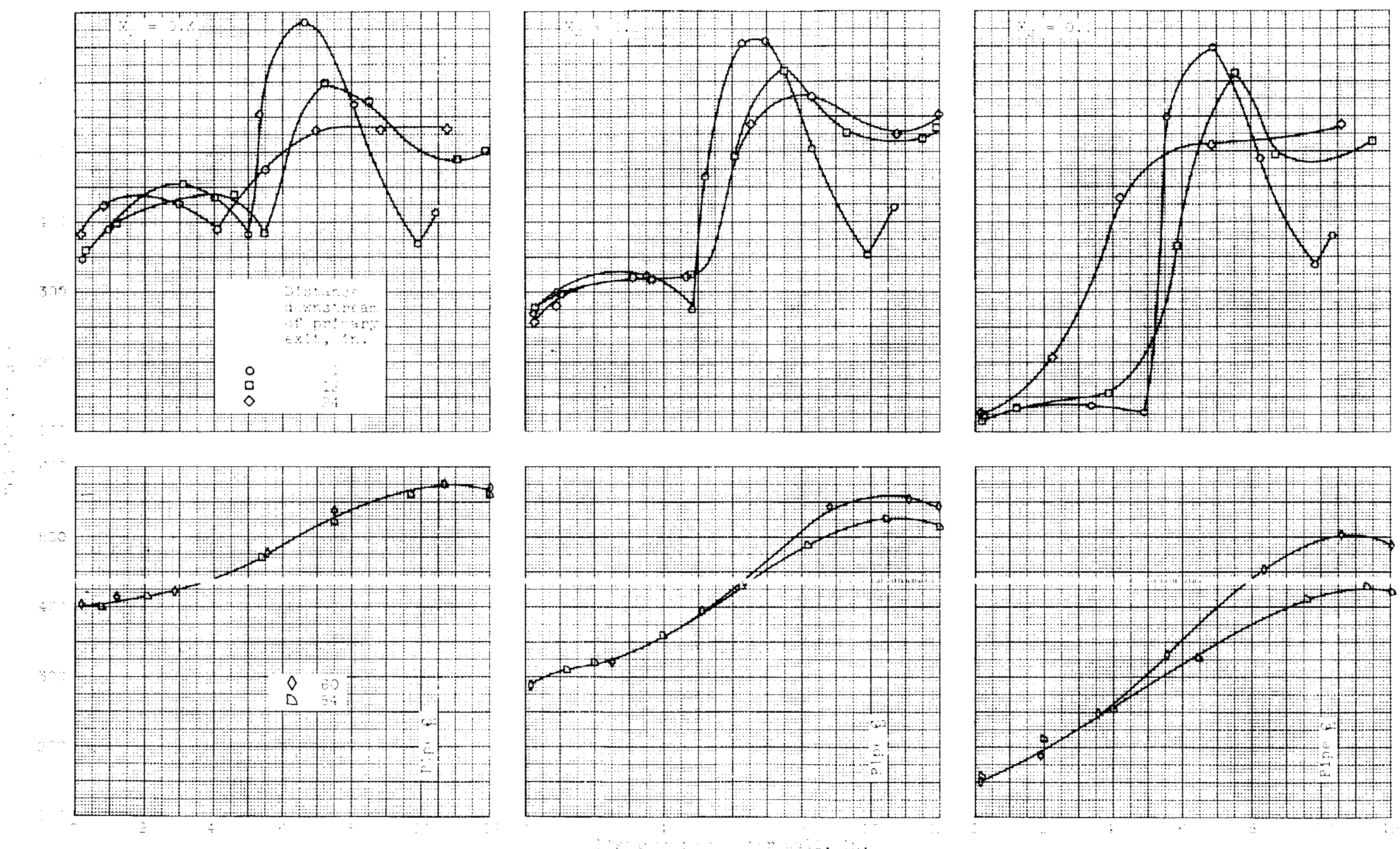

(a) Secondary temperature, 1100° R; ratio of primary to secondary temperature, 1.55.

Figure 6. - Radial velocity profiles for innerbody configuration I. Primary Mach number, 0.3; primary diameter, 10.00 inches; secondary diameter, 21.00 inches; primary temperature, 1710° R.



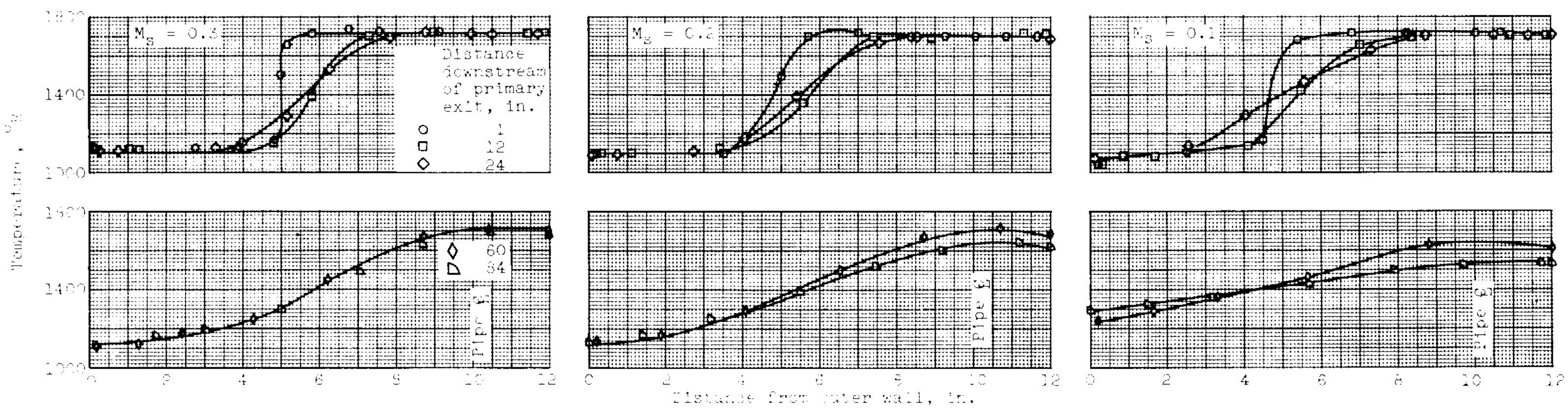

(b) Secondary temperature, 900° R; ratio of primary to secondary temperature, 1.90.

Figure 6. - Continued. Radial velocity profiles for Innerbody configuration I. Primary Mach number, 0.5; primary diameter, 10.00 inches; secondary diameter, 21.00 inches; primary temperature, 1710° R.



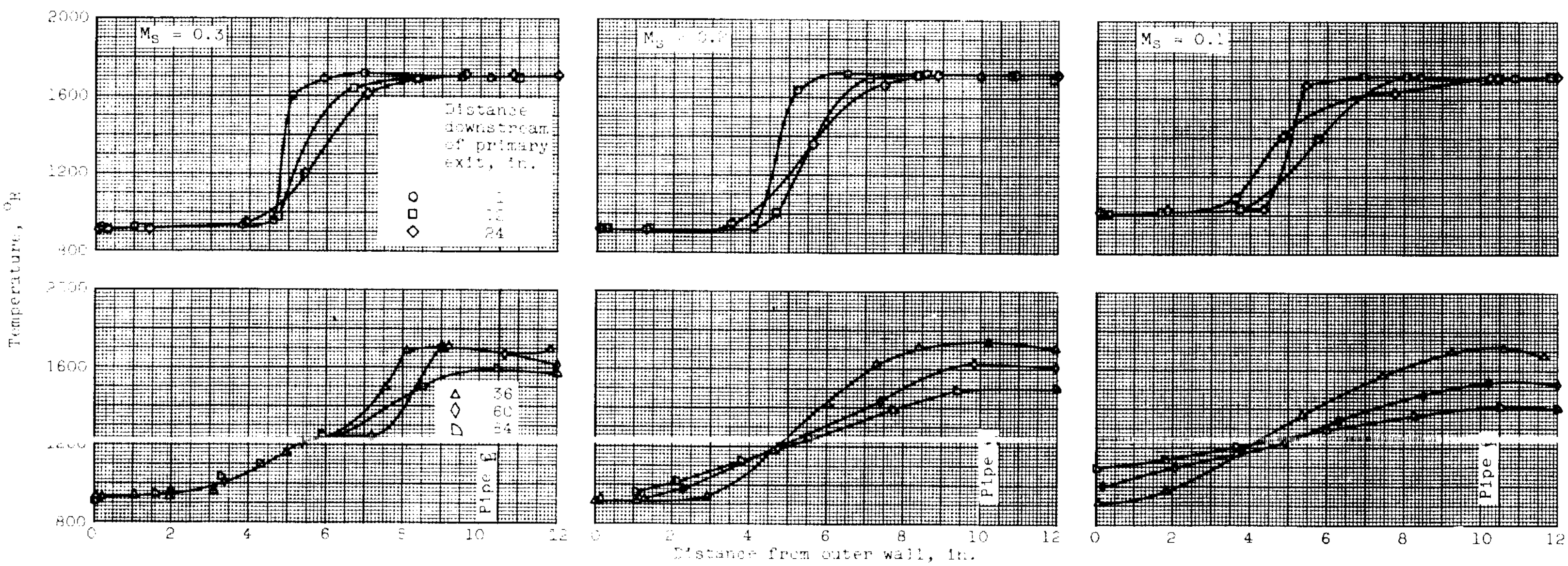

(b) [illegible] temperature, [illegible]; ratio of primary to secondary temperature, 2.44.

Figure 8. - Concluded. Radial velocity in [illegible] configuration I. Primary Mach number, 1.3; primary diameter, 10.00 inches; secondary diameter, [illegible] inches; primary temperature, [illegible].



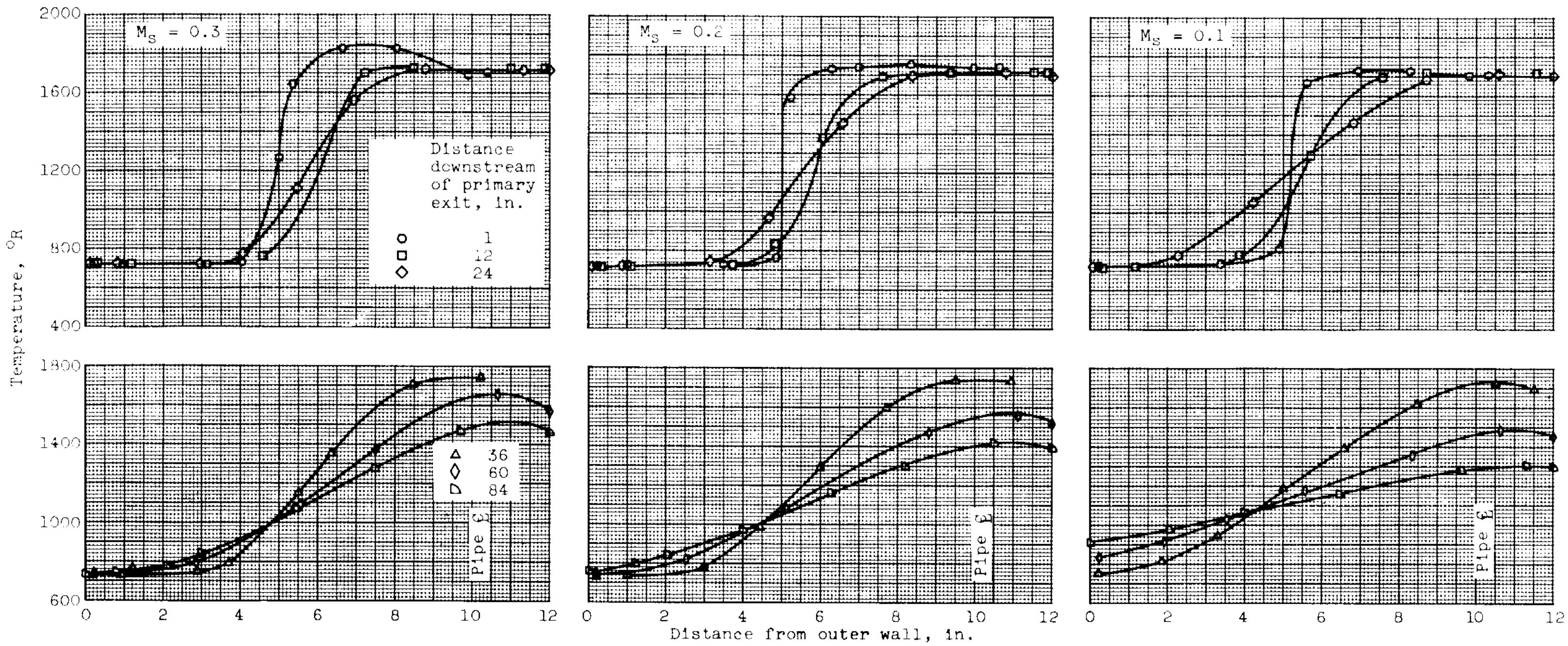

(a) Secondary temperature, 1100° R; ratio of primary to secondary temperature, 1.55.

Figure 7. - Radial temperature profiles for innerbody configuration I. Primary Mach number, 0.3; primary diameter, 10.00 inches; secondary diameter, 21.00 inches; primary temperature, 1710° R.




(b) Secondary temperature, 900° R; ratio of primary to secondary temperature, 1.90.

Figure 7. - Continued. Radial temperature profiles for innerbody configuration I. Primary Mach number, 0.3; primary diameter, 10.00 inches; secondary diameter, 21.00 inches; primary temperature, 1710° R.




(c) Secondary temperature, 700° R; ratio of primary to secondary temperature, 2.44.

Figure 7. - Concluded. Radial temperature profiles for innerbody configuration I. Primary Mach number, 0.3; primary diameter, 10.00 inches; secondary diameter, 21.00 inches; primary temperature, 1710° R.

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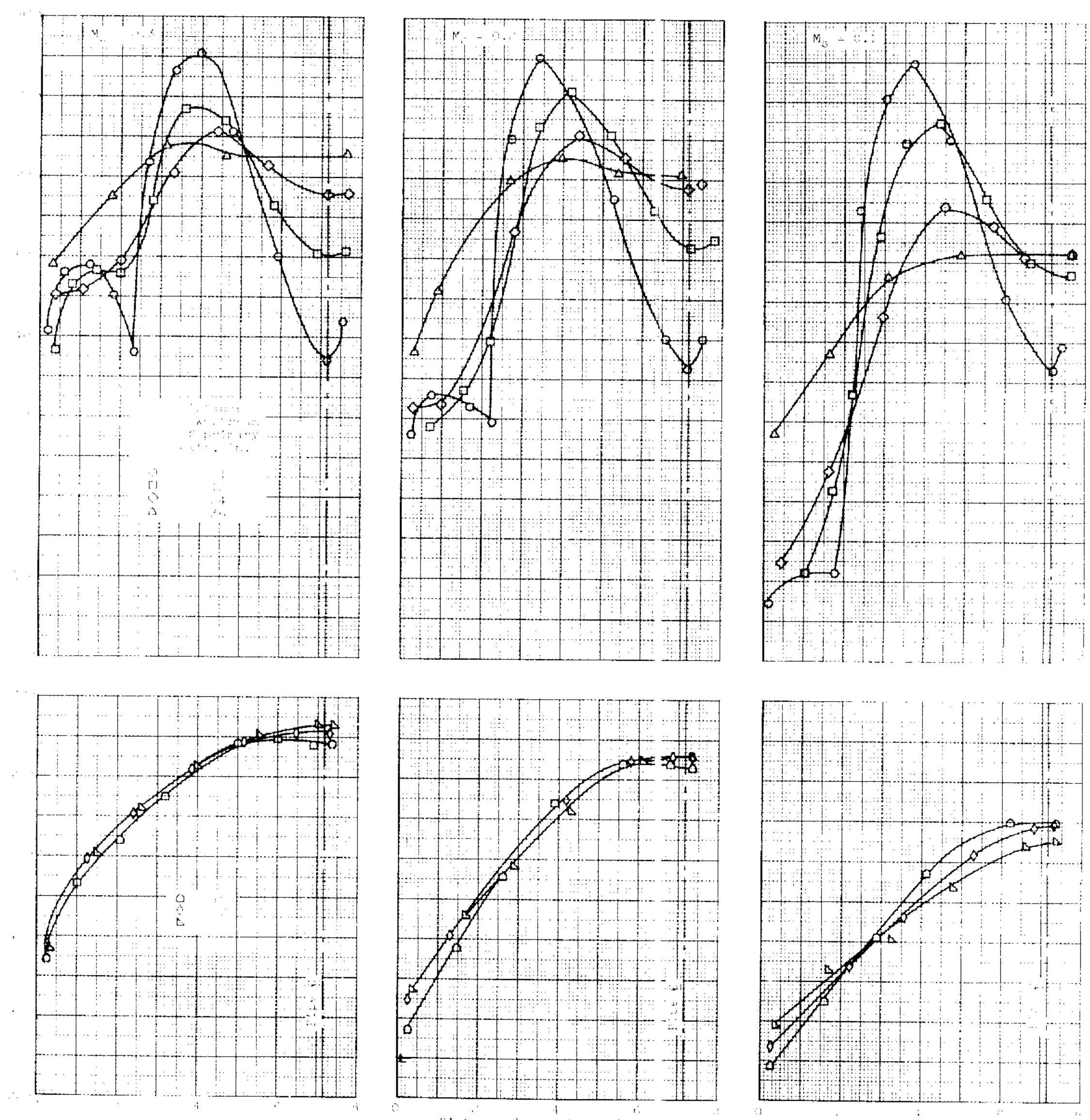

(a) Secondary temperature, 1100° R; ratio of primary to secondary temperature, 1.55.

Figure 8. - Radial velocity profiles for innerbody configuration II. Primary Mach number, 0.3; primary diameter, 10.00 inches; secondary diameter, 14.32 inches; primary temperature, 1710° R.

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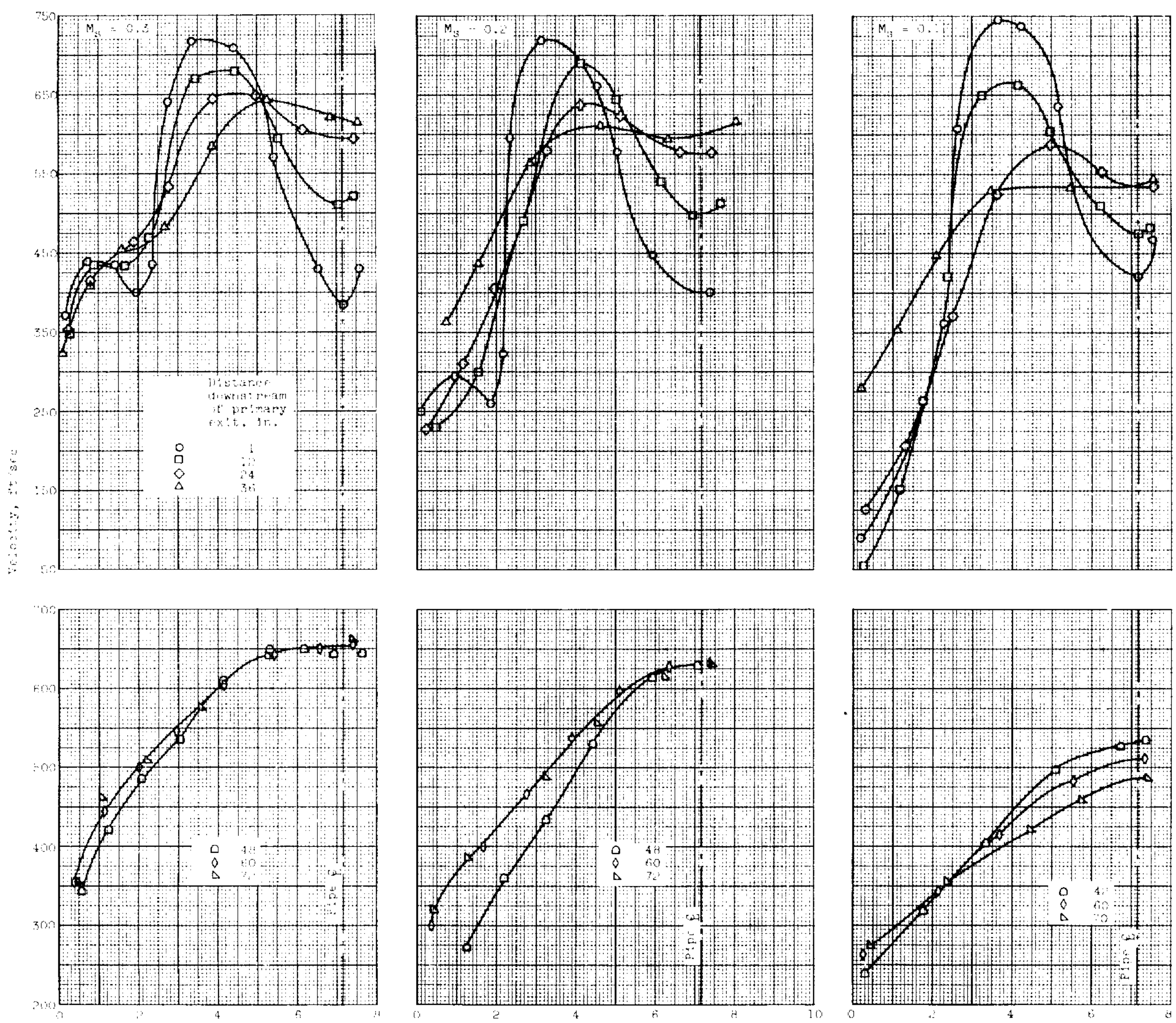
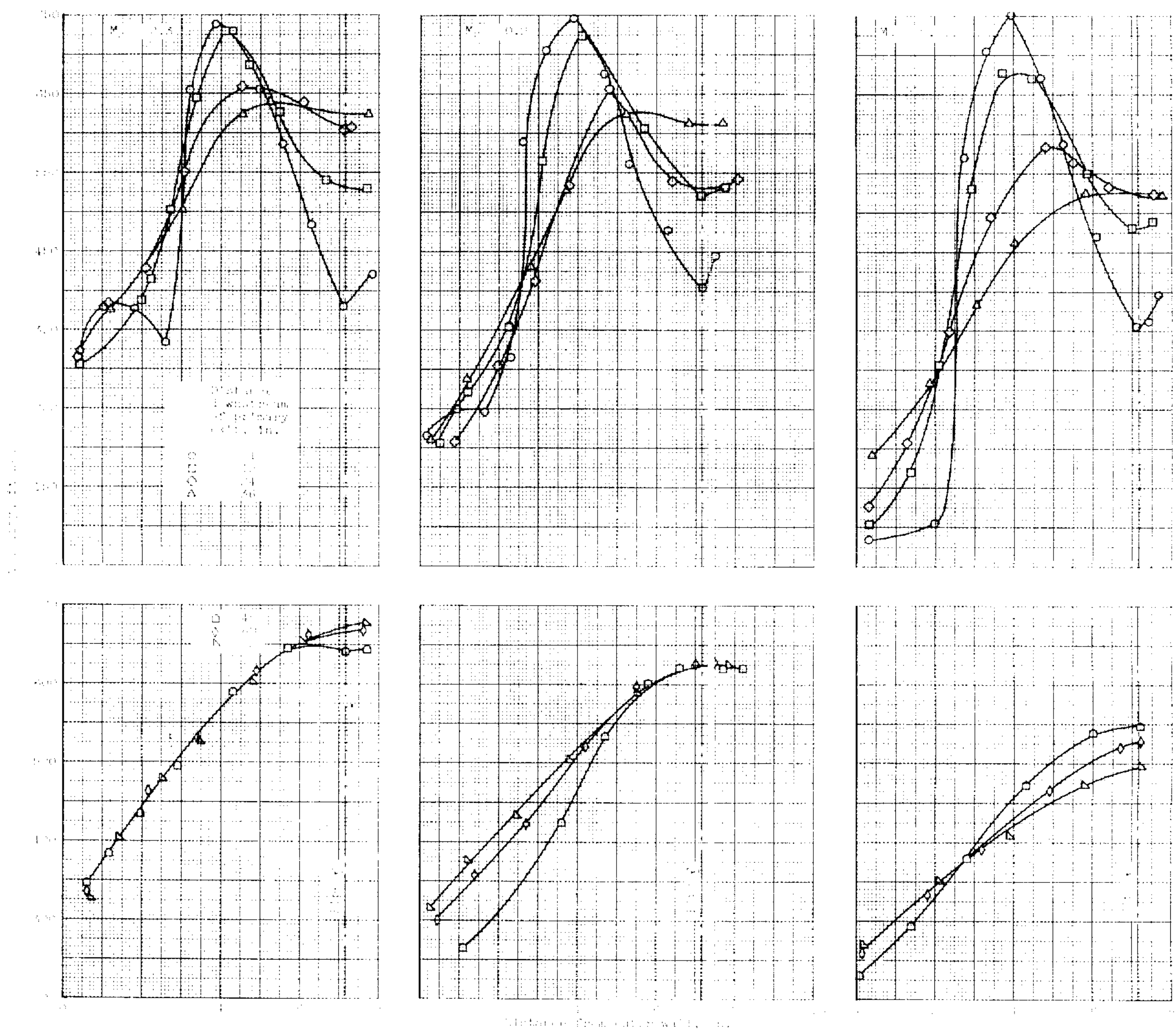


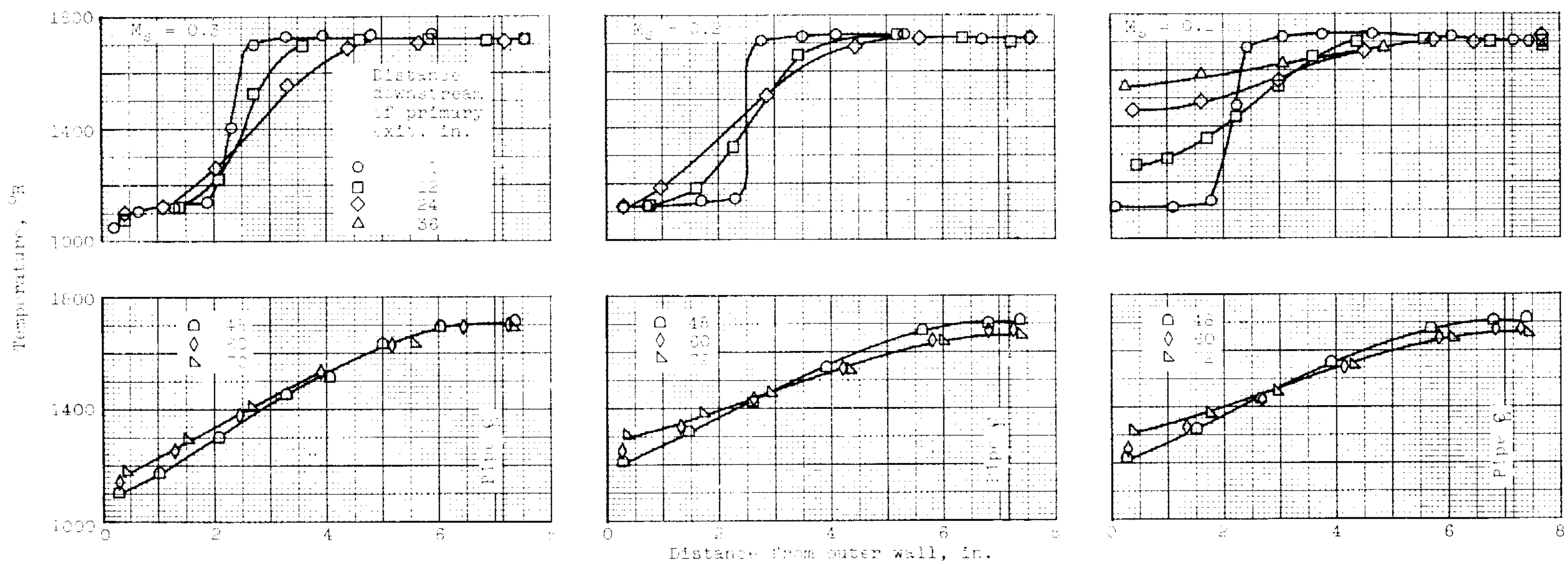
(b) Secondary temperature, 900° R; ratio of primary to secondary temperature, 1.90.

Figure 8. - Continued. Radial velocity profiles for innerbody configuration II. Primary Mach number, 0.3; primary diameter, 10.00 inches; secondary diameter, 14.32 inches; primary temperature, 1710° R.



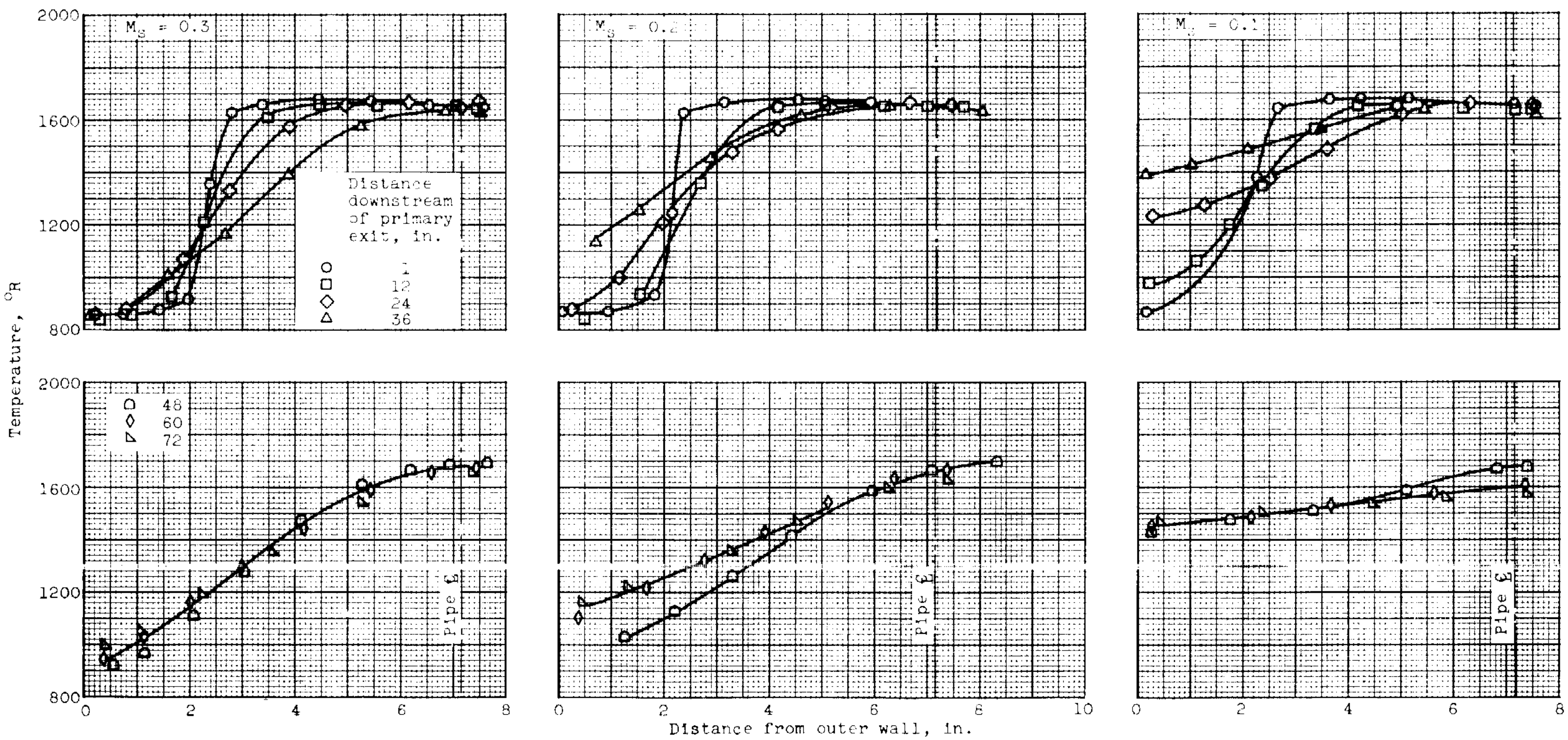
(c) Secondary temperature, 700° R; ratio of primary to secondary temperature, 2.44.

Figure 8. - Concluded. Radial velocity profiles for innerbody configuration II. Primary Mach number, 0.3; primary diameter, 10.00 inches; secondary diameter, 14.32 inches; primary temperature, 1710° R.



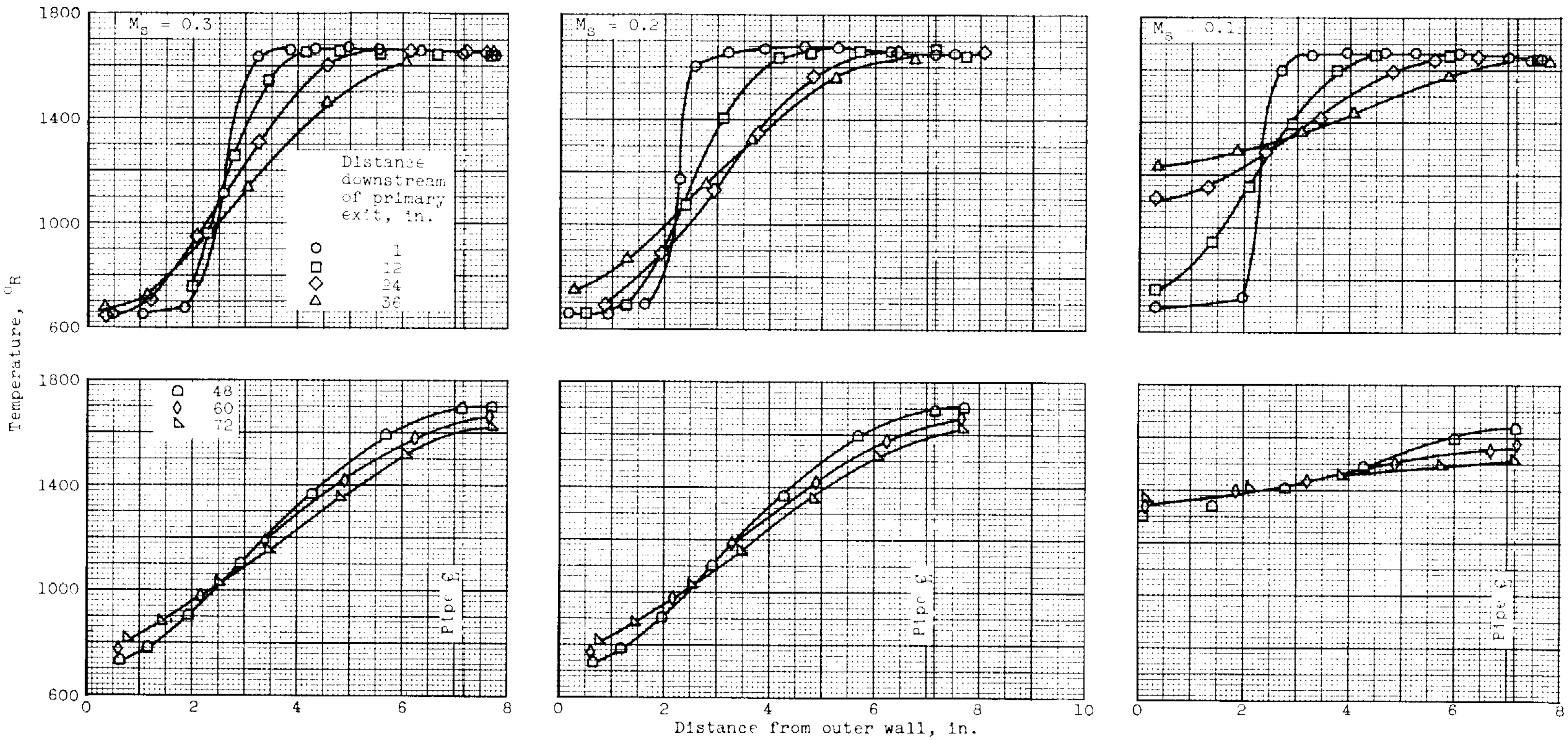

(a) Secondary temperature, 1100° R; ratio of primary to secondary temperature, 1.55.

Figure 9. - Radial temperature profiles for innerbody configuration II. Primary Mach number, 0.3; primary diameter, 10.00 inches; secondary diameter, 14.32 inches; primary temperature, 1710° R.




(b) Secondary temperature, 900° R; ratio of primary to secondary temperature, 1.90.

Figure 9. - Continued. Radial temperature profiles for innerbody configuration II. Primary Mach number, 0.3; primary diameter, 10.00 inches; secondary diameter, 14.32 inches; primary temperature, 1710° R.




(c) Secondary temperature, 700° R; ratio of primary to secondary temperature, 2.44.

Figure 9. - Concluded. Radial temperature profiles for innerbody configuration II. Primary Mach number, 0.3; primary diameter, 10.00 inches; secondary diameter, 14.32 inches; primary temperature, 1710° R.