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ANNULAR-JET EJECTORS

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SUMMARY

An experimental investigation of the entrainment and thrust-augmentation characteristics of ejectors which incorporate annular nozzles has been carried out at Stanford University.

The test results show that ejectors with annular nozzles and non-divergent mixing tubes have negligible thrust-augmentation capabilities, despite the possession of entrainment characteristics substantially identical with those of conventional ejectors with central nozzles. The augmentation deficiency is ascribed to inequality of the frictional forces experienced by the two types.

The combination of divergent mixing tubes with annular nozzles was found to result in very substantial improvement of both the entrainment and augmentation characteristics. While the augmentation so effected still falls short of that attainable with comparable central nozzles and straight mixing tubes, the corresponding entrainment characteristics are superior to any thus far demonstrated by central-nozzle types. This advantage is believed to originate in the suppression of flow separation from the walls of diffusers by the scouring action of annular jets.

Included in the report are the results of total-pressure surveys made at the downstream ends of the mixing tubes.

INTRODUCTION

The entrainment of adjacent fluid by that discharged from a nozzle or orifice has long been utilized in such familiar devices as steam injectors, aspirators, and jet pumps. More recently, it has been employed as the driving mechanism for high-speed wind tunnels of the induced-flow type. Currently, the entrainment of air by jets of exhaust gas is being used to augment cooling flow and exhaust-gas thrust in aircraft powered by reciprocating engines. Now, the intensive development of jet- and rocket-propelled aircraft and missiles has attracted interest to the possibility of utilizing controlled entrainment to increase their thrusts at low speeds with consequent improvement of performance and propulsive efficiency. Moreover, the demonstrated value of early induced-flow wind tunnels for high-speed testing appears to warrant much further investigation of the potentialities of such arrangements as tools for future aerodynamic research. These were the basic considerations which gave rise to the present investigation.

To one already familiar with the literature on these subjects, the field may appear already rather thoroughly covered. This is certainly true of many aspects. The theory of the simple ejector has been competently developed and, to a considerable extent, experimentally confirmed - notably by Keenan and Neumann (reference 1). The thrust-augmentation characteristics of the simple ejector - and various modifications thereof, particularly the Melot, or multistage arrangement - have been studied by several experimenters; the investigations of Jacobs and Shoemaker, Schubauer, and Morrison (references 2, 3, and 4) are outstanding. Substantially identical theories of thrust augmentation have been presented by Morrison and by Slatter and Bailey (reference 5). However, attention is now drawn to the fact that, with exception of some rather unpromising arrangements tested by Schubauer, all of the above-cited work pertains to nozzles of circular cross section located on the axes of circular-section mixing tubes. Thus the induced-flow wind tunnel constitutes the only well-known example of the ejector with an annular nozzle.

Relatively little information concerning the flow produced by discharging an annular jet along the wall of the circular tube is available and no calculations or measurements of the thrust of such an arrangement are known to have been made. The available data concerning the NACA induced-flow tunnels will be found in references 6 and 7, but the influence of the abrupt enlargement of section which characterizes the downstream limits of the test sections of these tunnels practically defies accurate appraisal. British experiments with a model tunnel of continuously varying cross-sectional area (reference 8) have furnished more comprehensive data with reference to mass flow ratios at relatively high pressures but in these experiments nontangential, and possibly nonuniform, jet discharge leaves the results open to some question. Some additional information relative to pressure-velocity relationships and wall pressure distribution in a model induced-flow tunnel has been given by Winter (reference 9).

Against this relatively meager background, the present investigation was planned with the intention of determining the entrainment, thrust augmentation, and mixing tube discharge characteristics of ejectors incorporating annular nozzles. Model dimensions and experimental conditions were so selected as to enable direct comparison of the test results with those reported in reference 4. This unhappy choice led to the use of some annular nozzles of extremely small slot width which experienced severe scale effects and thereby complicated interpretation of the results. Despite these difficulties, the major objectives of the investigation have been satisfactorily attained.

This investigation was conducted at Stanford University under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

SYMBOLS

D	minimum inside diameter of all mixing tubes (1.1250 in.)
D_1	diameter of secondary air passage, inches (table A)
D_2	outside diameter of primary nozzle lip, inches (table A)
x	slot width, inches (table A)
L	distance, slot to exit end of mixing tube, inches
A_m	minimum cross-sectional area of all mixing tubes (0.9940 in.^{2})
A_s	cross-sectional area of slot, square inches (table A)
A_j	cross-sectional area of conventional nozzle, square inches (fig. 21 only)
β	total divergence angle of mixing tube, degrees (table B)
ER	mixing tube expansion ratio $\left(A_{exit}/A_m\right)$
F	observed thrust, pounds
F_o	ideal thrust, pounds
W_1	observed mass flow rate, primary, pounds per second
W_{1i}	ideal mass flow rate, primary, pounds per second
W_z	mass flow rate corresponding to given flowmeter float position under calibration conditions (p_z, T_z), pounds per second
W_2	mass flow rate, secondary, pounds per second
F/W_1	specific thrust, observed, pounds per pound per second
$(F/W_1)_o$	specific thrust, unaugmented, pounds per pound per second
$(F/W_1)_i$	specific thrust, unaugmented, ideal, pounds per pound per second

C_d	primary nozzle discharge coefficient $\left(W_1/W_{1i}\right)$
k	thrust correction factor $\left(k = (F/W_1)_i/(F/W_1)_o\right)$
W_2/W_1	mass ratio
AR	augmentation ratio $(F/W_1)/(F/W_1)_o$
p_f	pressure at flowmeter entrance, pounds per square inch absolute
p_z	pressure at flowmeter entrance during calibration, pounds per square inch absolute
p_a	atmospheric (barometric) pressure, pounds per square inch absolute
p_c	pressure in plenum chamber, pounds per square inch absolute
p_t	pressure at orifice 3, figure 1, pounds per square inch absolute
p	total pressure of air discharged from mixing tube, pounds per square inch absolute
	Note: Primes (') are used to indicate gage pressures.
T_f	temperature at flowmeter entrance, $^{\circ}R$
T_z	temperature at flowmeter entrance during calibration, $^{\circ}R$
T_a	atmospheric temperature, $^{\circ}R$
T_c	temperature in plenum chamber, $^{\circ}R$
c_p	specific heat at constant pressure (For air, $c_p = 0.241$ Btu/lb/$^{\circ}R$)
γ	ratio of specific heats $\left(c_p/c_v\right)$ (For air, $\gamma = 1.400$)
R	gas constant (For air, $R = 53.33$ lb-ft/lb/$^{\circ}R$)
J	mechanical equivalent of heat (778.18 ft-lb/Btu)
g	gravitational acceleration (32.174 ft/sec^2)

ρ	mass density, slugs per cubic foot
μ	coefficient of viscosity, slugs per foot per second
N_R	Reynolds number $\left(\rho V x/\mu = W_1 x/12 g A_s \mu \right)$

MODELS

The models used in these experiments were formed by attaching various entry nozzles and mixing tubes of circular cross section to the opposite ends of a short, cylindrical pressure vessel. The forms and arrangement of the elements of a typical combination are illustrated by figure 1.

The steel pressure vessel consists of the body A and cover plate B. Compressed air is admitted to its interior through a pair of diametrically opposed ports GG and distributed by the action of the sheet-metal baffle H which extends close to the top and bottom of the main settling chamber. This air is discharged through the annular slot formed by the round-nosed bronze bushing C and the lip of the bell-mouthed entry nozzle D-E through which atmospheric air is drawn by entrainment. The mixture of primary and secondary streams is discharged, against atmospheric pressure, at the end of the mixing tube F. Interchangeable nozzles with lips of various outside diameters were used to change the slot area while the form of the passage downstream from the slot was varied by the substitution of mixing tubes which had different lengths and divergence angles.

Five bronze nozzles were built and tested; they were of equal axial length, had bellmouths of the same outside diameter, lips of equal thickness (0.010 in.) and identical profile radii r_2 and r_3. Their bores and outside lip diameters differed as indicated by the following table in which the slot widths x, slot areas $A_s = (\pi/4)(D^2 - D_2^2)$, and corresponding ratios of (minimum) mixing tube area $A_m = \pi D^2/4$ to slot area are also listed.

TABLE A

Nozzle	D_1 (in.)	D_2 (in.)	x (in.)	A_s (in.^{2})	A_m/A_s
1	1.0473	1.0673	0.0289	0.09935	10.005
2	1.0765	1.0965	.0143	.04973	19.988
3	1.0908	1.1108	.0071	.02494	39.856
4	1.0969	1.1169	.0041	.01426	69.707
5	1.1007	1.1207	.0022	.00758	131.14

(Note: The diameter D = 1.1250 in. in all models)

A noteworthy feature of the high-pressure-air passage is the provision for tangential discharge of the jet; it will be seen in figure 1 that for a distance of 0.125 inch upstream from the plane of efflux, both walls of the passage are parallel to the axis of the model.

As originally constructed, all four of the brass mixing tubes were of such length that $L/D = 10$ (see fig. 1); during the tests, the lengths were successively reduced by the amounts necessary to make $L/D = 8$, 6, 4, and 2. The various tubes are characterized by the following divergence angles:

TABLE B

Mixing tube	1	2	3	4
β(deg)	0	4	7	9

Great care was taken to match the bores and outside diameters of the upstream ends of these tubes to the corresponding dimensions of the bushing. The conical surfaces of the divergent tubes were so located as to intersect the cylindrical bores at a distance of 1.125 inches (1.0D) downstream from the slot. Smooth transitions from cylinder to cone were obtained by blueing and hand-scraping; this process was controlled by turning a groove of precalculated depth at the plane of discontinuity and then scraping to the bottom of that groove while confining the modification to an axial distance of 0.5D on either side of the groove.

Features of the models required for the determination of test conditions and performance are the pipe-tapped holes 2-2, into which copper tubes and a mercury thermometer were inserted for the measurement of plenum-chamber pressure and temperature, and the devious channel 1 which enabled observation of the static pressure at the orifice 3 in the straight wall of the secondary air passage. To enable the drilling of these passages, the nozzles were made of two pieces; after drilling the blank E and plugging the cross passage, elements D and E were joined by sweating and machined as a single unit.

The importance of concentricity, dimensional accuracy, and finish of the numerous interchangeable parts of these models will be apparent from the foregoing description. A major share of the credit for the success with which they were tested therefore belongs to their constructor, Mr. A. A. Rowe, of Stanford's Department of Mechanical Engineering. The skill and patience with which he carried out the exacting task of fabrication and fitting is, perhaps, best indicated by the fact that, whereas removal and replacement of the nozzles by hand was practically impossible, the exchange could be effected with the greatest of ease by use of a simple alinement fixture.

APPARATUS AND TECHNIQUE

The general arrangement of the apparatus which enabled determination of (a) thrust reaction, (b) weight of primary air discharged per unit time, (c) weight of secondary air entrained per unit time, and (d) distribution of total pressure at downstream end of mixing tube is illustrated by figure 2.

The model itself is partially visible at the extreme right of the picture. The beam balance used to measure reaction forces will be seen on the adjacent triangular steel frame. Pressures at various points of the primary and secondary paths, as well as total pressure at exit, were indicated by the easily recognizable multiple-tube manometer.[1] The tall, narrow, black case near the middle of the instrument panel encloses the tapered-tube flowmeter used for determination of the mass flow rate of primary (compressed) air. On the "data panel" at the upper left-hand corner of the cabinet, manually set pointers indicate test number, model configuration, temperatures, and barometric pressure. A gage tester, located below the data panel, was connected to the small pressure reservoir mounted on the left end of the cabinet and to one of the mercury columns of the manometer. Its primary function was the provision of a precise reference pressure which enabled the pressures on the other mercury columns to be determined by comparison of heights; its secondary function was to enable the control-valve operator to fix the primary air pressure at predetermined values. A double bell-jar balance (not visible in fig. 2) was used to impose a smaller reference pressure on one of the columns of lighter liquid.

All data were recorded photographically by means of a 35-millimeter camera; its field included the counter of the force-measuring balance, the manometer, flowmeter, data panel, and gage tester.

Details of the force-measuring system are revealed by figure 3. The model was attached to one end of a horizontal lever which consisted of a short length of 8-inch steel channel. An inclined tubular member bolted to the other end of this lever was connected to the balance beam by a short, vertical length of heavy piano wire. The lever itself was suspended from the lower vertex of the triangular steel frame (welded 8-inch channel) by a flexure knife-edge made of 0.015-inch clock-spring stock and clamped between rectangular steel blocks.

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[1]This manometer has a divided cistern which permits the simultaneous use of mercury for the measurement of large pressures and of a lighter liquid for smaller ones. It also incorporates two independent U-tubes — one for determination of the subatmospheric pressure in the secondary air passage and the other for measurement of the pressure drop between flowmeter and plenum chamber.

Special rider weights for the automatic, electrically operated balance were calibrated in place by suspending standard weights on the axis of the model. Under static conditions, force readings could be repeated with an accuracy of ±0.001 pound, the least count of the directly connected revolution counter.

Primary (compressed) air was supplied to the models by a pipe line in which were incorporated control valves, the flowmeter, and a flexible connection between that part of the line which is attached to the cabinet and the remainder which is mounted on the lever. In figure 2, the incoming line and control valves will be seen on the left side of the cabinet. The flowmeter has been identified previously and the flexible connection may be seen in figures 3 and 4. This highly unconventional connection consists of three thin-walled brass tubes which have their axes parallel to, and closely grouped around, the axis of the lever knife-edge; it was substituted for rubber hose when it was found that internal pressure caused the latter to exert considerable moments upon the lever. Closure of the globe valve beneath the lever enabled this extraneous effect to be measured in the absence of flow; it was completely eliminated by proper orientation of the metallic connection.

Determination of the mass flow rates of primary air was rendered comparatively simple by the use of a factory-calibrated flowmeter of the tapered-tube type.[2] The employment of a steel float for the measurement of large rates and of a Dowmetal one for small ones enabled good accuracy[3] to be obtained throughout the range of the experiments. Having the calibration curves, the only data required for determination of the mass flow rates were float position and temperature and pressure of the incoming air. The position of the float was, of course, directly readable from the photographic record; the auxiliary data were secured by installing a mercury thermometer and a manometer connection in the lower end-fitting of the flowmeter.

Mass rates of secondary (entrained) air flow were determined by using the bellmouth nozzles as metering devices. Knowledge of the temperature and pressure of the ambient air, of the static pressure at the wall orifice in the straight section of the nozzle (3 - fig. 1), and of the corresponding cross-sectional area sufficed for calculation of the flow rates by use of a standard compressible-flow equation.

Total-pressure surveys of the streams discharged from the mixing tubes were made by use of the rake which can be most clearly seen in figure 4. The rake is composed of 43 hypodermic tubes (0.020 by 0.010 in.) which are supported in a 0.5- by 0.125-inch brass bar. The central tube of the symmetrical rake lies on the axis of the duralumin ring to which the supporting bar is attached. Thus, by properly locating the fixture in which this ring is free to turn, the central tube of the rake can be made collinear with the mixing tube axis and directly comparable surveys

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[2]Fischer and Porter "Flowrator," size 8, $1\frac{1}{4}$ in.

[3]Guaranteed accuracy of calibration: ±1 percent.

along various diameters made by merely rotating the ring. The maximum number of rake tubes simultaneously connected to the manometer ranged from 15 to 21; the much larger number of tubes built into the rake enabled relatively uniform coverage of streams having various diameters. In making the surveys, the elevation of the supporting fixture was so adjusted as to place the tips of the rake tubes 0.1 inch above the end of the mixing tube. The total pressures actually encountered varied so widely that alcohol, carbon tetrachloride, and tetrabromoethane had to be used as manometer fluids in order to obtain satisfactorily measurable column heights under various testing conditions.

A résumé of the procedure followed in making a representative test would include the following steps: With the model elements assembled, test-number and model-configuration indicators set on the data panel, survey rake in position, and appropriate rake tubes connected to the manometer, a weight corresponding to the desired value of primary pressure would be placed on the gage tester and compressed air bled into the reservoir until the piston rose. With the piston rotating slowly under the action of a horizontal air jet upon the vanes attached to its under side, it would be elevated to the height of a fixed pointer by adjustment of the small sylphon on the end of the pressure reservoir. The primary air valve would then be opened and so adjusted as to depress the mercury column actuated by plenum-chamber pressure to the same height as that of the one connected to the gage tester. The balance would then be put into operation, data-board pointers set in accordance with barometer and preliminary temperature observations, and the shape of the discharge pressure pattern inspected. If asymmetry of the discharge was apparent, the rake would be rotated to minimize it insofar as possible. After the lapse of sufficient time for the manometer columns to attain equilibrium, final temperature readings would be set on the data board and the test completed by taking a photographic record.

TEST PROGRAM

Successive combination of the five nozzles with each of the four mixing tubes and repetition of this process for five lengths of each mixing tube furnished one hundred combinations of model elements. As each combination was tested at primary (plenum-chamber) pressures of 4, 8, 12, and 16 pounds per square inch (gage), the total number of tests made was 400.

All tests included the determination of thrust reaction, mass rates of primary and secondary air flows, and total-pressure distribution at efflux.

Auxiliary tests demonstrated that the presence of the survey rake at the mixing tube exit had no measurable effect upon the forces indicated by the balance.

Attempts to measure the unaugmented thrust of the annular nozzles by removing the mixing tube and clamping a disc over the entry bell-mouth were abandoned when it was found that the jet reaction forces were being neutralized to a considerable extent by the effects of accompanying reductions of pressure (as great as $0.05p'_c$) in the blocked entry passage.

REDUCTION OF DATA

The items of data which could be read directly from the photographic records are enumerated below and illustrated by the inclusion, in parentheses, of the actual values transcribed from the sample record which is reproduced as figure 5:

Test number – (295)

Model configuration – (nozzle 1, mixing tube 4, L/D = 8)

Nominal test (plenum-chamber) pressure – (8 lb/sq in., gage)[4]

Thrust reaction – (1.416 lb – counter reading)

Flowmeter float material and position – (steel,[5] 42.45 cm)

Barometric pressure – (30.06 in. Hg)

Ambient-air temperature – (75.5° F – scale D)

Temperature at flowmeter entrance – (78° F – scale F)

Plenum-chamber temperature – (78° F – scale C)

Manometer column heights were translated directly into absolute pressures or percentages of reference pressures by use of the projection-scaling apparatus which has been available for some time[6] in Stanford's Guggenheim Aeronautic Laboratory.

Mass rates of primary flow were calculated by use of the calibration curves and the following equation

$$W_1 = W_z \sqrt{\left(\frac{p_f}{p_z}\right)\left(\frac{T_z}{T_f}\right)} \qquad (1)$$

which defines the effects of deviations of the operating temperature and pressure from those which prevailed during calibration.

[4]Identifiable by distinctive silhouettes of gage tester weights used for different pressures.

[5]Identifiable by silhouette.

[6]Reference 10.

Mass rates of secondary flow were computed in accordance with the well-known relationship

$$\frac{W}{A} = p_1\sqrt{\frac{2g\gamma}{RT_1(\gamma - 1)}\left[\left(\frac{p_2}{p_1}\right)^{\frac{2}{\gamma}} - \left(\frac{p_2}{p_1}\right)^{\frac{\gamma+1}{\gamma}}\right]} \tag{2}$$

which, upon the substitution of appropriate subscripts and evaluation of the numerical constants, becomes

$$W_2 = 2.055\,\frac{A_m p_a}{\sqrt{T_a}}\sqrt{\left(\frac{p_t}{p_a}\right)^{1.429} - \left(\frac{p_t}{p_a}\right)^{1.714}} \tag{3}$$

The determination of thrust augmentation was complicated by two circumstances which were not fully appreciated when the investigation began. The first was the difficulty of measuring the unaugmented thrusts of the annular nozzles; this proved unsurmountable because any member used to block the secondary air passage was subjected to a large, and not readily determinable, pressure force which acted in the direction opposite to that of the thrust. The second was that the alternative of calculating the unaugmented thrusts by straightforward use of the idealized compressible-flow equations was precluded by extremely wide variation of the nozzle discharge coefficients.[7] It thus developed that some special method of conservatively calculating the unaugmented thrusts of annular nozzles under conditions of restricted discharge was prerequisite to any reasonable appraisal of the augmentation actually effected.

Details of the method finally evolved for this purpose are set forth in the appendix. There it is shown that if deviations of the actual velocity of efflux from the ideal, uniform one are confined to boundary layers in which the velocity distribution is parabolic, the relationship between actual and ideal unaugmented specific thrusts may be expressed as

$$\left(F/W_1\right)_o = \frac{1}{k}\left(F/W_1\right)_i \tag{4}$$

and that the value of the factor k depends only upon that of the discharge coefficient C_d. The fact that two equations are required to

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[7]The critical question in this connection is that of the distribution of efflux velocity across a radial element of the annular nozzle. For example, a parabolic radial distribution of velocity would result in a thrust reaction one-fourth greater than that corresponding to uniform discharge at the same mass rate. Thus, assumption of the latter condition when the former actually prevailed would cause the actual augmentation of thrust to be seriously overestimated.

define the relationship between k and C_d is a consequence of the existence of one type of velocity distribution across the slot when $C_d > 2/3$ and of another when $C_d < 2/3$.

In figure 6, k has been plotted as a function of C_d; methods are outlined below for evaluating $(F/W_1)_i$ and C_d from experimental data. Having this information, the unaugmented specific thrust was determined by reading the value of k which corresponds to the known value of C_d from figure 6 and substituting it, with that of $(F/W_1)_i$, in equation (4). The augmentation ratio, defined as

$$AR = \frac{F}{F_o} \tag{5}$$

was evaluated by dividing the observed specific thrust by the calculated value of the unaugmented specific thrust, that is,

$$AR = \frac{(F/W_1)}{(F/W_1)_o} \tag{6}$$

Use of the method described above necessitates the evaluation of C_d and $(F/W_1)_i$ for each test. Since

$$C_d = \frac{W_1}{W_{1i}} \tag{7}$$

its determination consists in dividing the observed primary mass flow rate by the ideal rate which corresponds to the known test conditions. The ideal value is given by

$$W_{1i} = 2.055\,\frac{A_s p_c}{\sqrt{T_c}}\sqrt{\left(\frac{p_t}{p_c}\right)^{1.429} - \left(\frac{p_t}{p_c}\right)^{1.714}} \tag{8}$$

when $p_t/p_c \geqslant 0.528$ and by

$$W_{1i} = 0.5319\,A_s p_c\Big/\sqrt{T_c} \tag{9}$$

when $p_t/p_c < 0.528$. The ideal unaugmented specific thrust, naturally predicated upon discharge against atmospheric pressure, is obtained from the equation

$$\left(\frac{F}{W_1}\right)_i = \sqrt{\frac{2c_pJT_c}{g}\left[1 - \left(\frac{p_a}{p_c}\right)^{0.2857}\right]} \qquad (10)$$

An unavoidable approximation in equation (8) is the use of p_t as the pressure at the annular slot. This is not strictly accurate because some reduction of pressure occurs between the static-pressure orifice (3 – fig. 1) and the slot. The immediate consequences of this approximation are the underestimation of W_{1i} and the corresponding overestimation and underestimation of C_d and k, respectively. Use of such a value of k in equation (4) leads to an erroneously large value of the unaugmented specific thrust which, when substituted in equation (6), causes the augmentation ratio to be somewhat conservatively evaluated. Quantitative determination of the error in primary nozzle pressure ratio was possible under only one condition; that is, choking of the secondary flow occurred when $p_t/p_a = 0.567$ approximately,[8] whereas the pressure ratio known to characterize this phenomenon is, of course, 0.528. The inconsequential effect of such a difference upon the value of W_{1i} (actually only 0.2 percent) would appear to preclude any serious doubt of the final results on this score.

Reduction of the discharge survey data consisted in translating the manometer column heights directly into numerical values of the pressure ratio p'/p'_c. The tabulated results are, actually, averages of the values determined at pairs of axially symmetric stations located on a common diameter.

RESULTS

Numerical values of the force and mass flow observations, together with those of the principal quantities computed therefrom, are given in tables 1 to 20; the discharge survey data will be found in tables 21 to 37. Auxiliary tables numbered 38 to 41 contain primary and secondary nozzle pressure ratios for all test conditions.

The majority of these results are presented graphically in figures 8 to 19. The variations of the discharge coefficients of the annular nozzles with plenum-chamber pressure and those of the corresponding loss coefficients with Reynolds number are illustrated by figures 8 and 9, respectively. Figures 10 to 14 show the effects of mixing tube length and plenum-chamber pressure upon the mass-flow and thrust-augmentation ratios for the various combinations of nozzle and mixing tube while typical

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[8] Apparent in figure 7.

radial distributions of total pressure at the ends of the mixing tubes are illustrated by figures 15 to 19.

Additional graphical interpretations of the basic results and comparisons with pertinent data from other sources will be presented in the following section.

DISCUSSION

Primary Nozzle Discharge Characteristics

Several features of the entrainment and thrust-augmentation characteristics which will be discussed later indicate their dependence upon the discharge characteristics of the primary nozzles. For this reason, attention is drawn, at the outset, to figures 8 and 9.

In figure 8, it will be seen that the discharge coefficients diminish in orderly fashion with pressure and slot width except in the case of nozzle 4. In figure 9, the resistance, or loss, coefficients for the five nozzles are plotted against Reynolds number. Although these independent line segments cannot be expected to define a single curve (because the profiles of the various primary nozzle passages are not geometrically similar) they do resemble progressive, but nonconsecutive, segments of the analogous curve of pressure-drop coefficients[9] for smooth pipes which is reproduced as figure 20. This similarity enables valuable deductions to be made with reference to the probable character of the nozzle boundary layers. Thus, since $\left(\frac{1}{C_d^2} - 1\right)$ varies with N_R^{-1} in the case of nozzle 5, the analogy suggests that the boundary layers of that nozzle remained laminar throughout the present tests. Similarly, the slope of the curve for nozzle 4 appears to correspond to a late stage of transition. And finally, continuance of the trend toward fully developed turbulent flow is strongly suggested by the progressive reduction of slope which characterizes the curves for nozzles 3, 2, and 1.

Thus variation of the ratio of mixing tube area to slot area, which was effected by interchanging nozzles, was accompanied by marked changes in the character of at least the boundary layers of the streams which they discharged. That this unforeseen circumstance appears to have exercised a marked influence upon the entrainment of secondary air and resulting thrust augmentation will become evident in later parts of the following discussion.

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[9]The relationship between the coefficients of figures 9 and 20 is $\left(\frac{1}{C_d^2} - 1\right) = \lambda l/r = 2\Delta p/\rho\bar{u}^2$, in which r is pipe radius, l is distance from entrance, Δp is pressure drop, and $\bar{u}$ is mean velocity.

Entrainment Characteristics

It is believed that insight into the performance of the tested ejectors can best be gained by considering the entrainment characteristics first and then attempting to correlate this information with the corresponding augmentation data. The first step will therefore be to examine the effects of primary pressure and model configuration upon the weight of air entrained per unit weight of air discharged by the annular nozzles.

Inspection of the upper charts of figures 10 to 14 will show that, with few exceptions, primary pressure has little effect upon the mass ratio obtained with a given model, that is, a particular combination of nozzle, mixing tube, and length of the latter. With nozzles 1 to 3 slight reductions of W_2/W_1 characterize the increase of p'_c from 4 to 16 pounds per square inch.[10] In the case of nozzle 4, a similar decline occurs in the range between 8 and 16 pounds per square inch but it will be noted that the mass ratios also diminish somewhat as p'_c is reduced from 8 to 4 pounds per square inch. The behavior of nozzle 5, however, is quite unlike that of the others; in this instance the relative magnitude of the secondary flow increases appreciably with primary pressure. With mixing tubes of small divergence, $\beta = 0^\circ$ and 4°, the increase continues only up to 12 pounds per square inch but with those having $\beta = 7^\circ$ and 9° it extends throughout the entire pressure range investigated.

Alterations of model configuration produce effects upon the entrainment characteristics which are, in general, more consistent than those just described. The reader will probably have noticed, already, that the influence of mixing tube length (L/D) upon mass ratio is a major one when the mixing tube is divergent but of relatively small importance when $\beta = 0^\circ$, and also that the values of W_2/W_1 for divergent tubes greatly exceed those for straight ones. Further examination of figures 10 to 14 will reveal that, within the range of these tests, the mass ratio increases continuously with L/D when the mixing tube is divergent but that it attains a maximum at an L/D value of the order of five when the mixing tube is straight. It will also be observed that the value of W_2/W_1 for a given mixing tube of fixed length increases in almost all cases – and by a considerable amount – as the slot width is reduced and the area ratio A_m/A_s increased.

As figures 10 to 14 are inconvenient for quantitative examination of the last effect referred to above and as it is one of major interest, reference is now made to figure 21 in which the two heavy-line curves define the variations of W_2/W_1 with A_m/A_s for mixing tubes 1 and 4 under the conditions $L/D = 10$ and $p'_c = 12$ pounds per square inch. These curves reveal the interesting fact, which was substantiated by

[10]The flattening of the right-hand portion of the curve for 16 pounds per square inch for mixing tube 4 in combination with nozzle 1 results from the attainment of sonic velocity of secondary flow when L/D exceeds 8.

plotting all of the mass-flow data in this form, that, for all four mixing tubes and at all values of L/D greater than 2, W_2/W_1 varies almost exactly with $(A_m/A_s)^{2/3}$ throughout most of the explored range of the latter.[11] While the reproduction of any large number of such curves in this report seemed superfluous, in view of their unvarying similarity and the availability of tabular data, it may be worth noting that another relationship of some value was deduced from these charts. It is that the ratio of corresponding ordinates of the curves for divergent and straight mixing tubes of equal L/D value is approximately equal to $(ER)^{2/3}$ – in which ER represents the expansion ratio of the divergent tube.[12]

The existence of a family of curves so related simply indicates that the mass ratio increased systematically with area ratio throughout the range which corresponds to nozzles 1 through 3 $(10 < A_m/A_s < 40)$ and at a diminishing rate – which in some instances fell to zero – as the slot width was further reduced and the turbulence of the nozzle boundary layers progressively suppressed.

It is of interest to compare the mass ratios obtained with these annular nozzles with those previously determined in tests made with central nozzles. The results from reference 1 appear to be reasonably consistent with the present ones whereas the curve taken from reference 4 is not only at variance with the other two but implies the attainment of values greater than those theoretically predicted for an incompressible fluid. Aside from this puzzling feature, the most interesting fact disclosed by the comparison is the apparent equivalence of central and peripheral jets as means of producing entrainment in a straight mixing tube.

In connection with the increase of mass ratio obtained by the use of divergent mixing tubes (see curve for mixing tube 4, fig. 21) it seems worth mentioning that the addition of divergent flares to straight mixing tubes was reported, in reference 4, to produce relatively small increases of mass ratio and to reduce augmentation. The ability to utilize divergent mixing tubes efficiently may not be possessed by ejectors of the central-nozzle type; intuition suggests that separation of flow from the

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[11] Whether or not this relationship be fortuitous, its discovery afforded a convenient means of identifying errors of transcription and computation which might have otherwise gone undetected. Slight upward convexity and a small increase of average slope distinguish the curves for $L/D = 2$.

[12] This result may be readily derived for an incompressible, inviscid fluid by assuming that all of the kinetic energy of the primary flow is conserved in a mixing process which results in a uniform velocity of efflux. The relationship given above is quite accurate for the tube with $\beta = 4^\circ$ but yields values which exceed the experimental ones by as much as 15 percent when $\beta = 9^\circ$.

walls would be less likely in the presence of the high-speed stream discharged from an annular jet than in the case of a stream having its maximum velocity along the axis. In any case, it will be noted that the mass ratios obtained with mixing tube 4 are very much larger than any thus far reported for conventional ejectors of comparable area ratio.

While not exactly descriptive of entrainment characteristics, attention is now called to the pressure-ratio curves of figure 7. They have been added to the basic charts to illustrate the relations between primary and secondary pressure ratios and to emphasize the attainment of choking conditions in the secondary channel. It is also believed that they may offer at least qualitative guidance in the design of small induced-flow wind tunnels.

Augmentation Characteristics

The effects of primary pressure upon thrust augmentation differed widely among the various configurations which were investigated. The relatively minor influence of this variable upon the maximum augmentation ratios attained with nozzles 1, 2, and 3 is evident in figures 10 to 12; these form a striking contrast with figures 13 and 14 which show that models incorporating nozzles 4 and 5 are extremely sensitive to variations of primary pressure.

A general tendency of the maximum augmentation ratio for a given combination of nozzle and mixing tube to increase with p'_c is apparent, but in some cases this disappears at 12 pounds per square inch and in one (nozzle 4, mixing tube 1) at 8 pounds per square inch. However, not all of the models share even this qualitative characteristic for it will be noted that, in the case of nozzle 3, apparently inconsistent reductions of maximum augmentation ratio occur with mixing tubes 1, 3, and 4 at $p'_c = 12$ pounds per square inch and that at this pressure the maximum value for mixing tube 2 falls below one which would be consistent with those for primary pressures of 4, 8, and 16 pounds per square inch.

Despite these exceptions, the general tendency for augmentation ratio to increase with primary pressure – at least until sonic velocity is attained by the jet – is noteworthy because it is contrary to the previously observed behavior of ejectors which incorporate central nozzles (see references 4 and 5). This dissimilarity of performance is emphasized by the fact that, with all but very small nozzles,[13] mass ratios diminish as primary pressure is increased, whether the nozzle be of the central or peripheral type. Thus, the experimental results obtained with annular nozzles present the anomaly of thrust augmentation increasing while mass ratio diminishes with increasing primary pressure.

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[13]Mass ratio increases with primary pressure until $p'_c = 8$ pounds per square inch in the case of nozzle 4 and at all values from 4 to 16 pounds per square inch in the case of nozzle 5. It appears probable that similar behavior would characterize conventional nozzles operating at very small Reynolds numbers.

The thrust-augmentation characteristics, like those of entrainment, are somewhat more consistently influenced by variations of model configuration than by those of primary pressure. There is, moreover, considerable resemblance between the entrainment and augmentation characteristics. Similarity is apparent in the superiority of both the mass and augmentation ratios for the divergent mixing tubes over those for the straight ones; it is also evident in the greater variation of both ratios for the divergent tubes. A striking difference becomes apparent, however, when the influences of mixing tube length (L/D) and area ratio (A_m/A_s) upon mass and augmentation ratios are compared.

In the case of the straight mixing tube, it will be seen that, although the mass ratios (for all nozzles) increase somewhat as L/D increases from 2 to 5 and thereafter remain nearly constant, the corresponding augmentation ratios attain well-defined maximums in the neighborhood of $L/D = 4.5$. With divergent mixing tubes, the mass ratios increase continuously with L/D whereas maximums of augmentation occur at length-diameter ratios which diminish from 8 or 9 to about 5 or 6 as the mixing tube divergence angle increases from 4° to 9°.

The relationships just described are qualitatively similar to those previously found in experiments on ejectors with central nozzles (see fig. 4, reference 4). With both arrangements, it appears that increasing the length-diameter ratio of the mixing tube beyond a certain value causes the friction forces to increase by greater amounts than do the pressure forces, with the consequence that the resultant upstream force is reduced. In this connection, it is noteworthy that maximum augmentation is obtained with $L/D = 5.5$ to 6.5 when a central nozzle is used but with $L/D = 4$ to 5 in the case of the peripheral one. In the absence of discharge survey data for the former type, it cannot be said with certainty whether this difference is the result of better mixing or greater frictional forces in the case of the annular type.

The general character of the influence of area ratio (A_m/A_s) upon thrust augmentation can be discerned by successively scanning the augmentation-ratio curves of figures 10 through 14. In accordance with theory and previous experimental work on conventional ejectors, these results show the augmentation ratio to increase with area ratio throughout the range covered by nozzles 1 to 4. The results obtained with nozzle 5, however, are completely at variance with both theory and previous experiment. Although the mass ratios for the models which incorporate nozzle 5 are, in practically all cases,[14] greater than those obtained with nozzles 1 to 4, the corresponding augmentation ratios fall far short of those for nozzles 1 to 4.

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[14] A few values for nozzle 4 at 4 and 8 pounds per square inch are greater.

This radical difference between the performance of nozzle 5 and that of all the others is more clearly portrayed by figure 22 which illustrates the variation of augmentation ratio with mass ratio at a primary pressure of 12 pounds per square inch. There the peculiarly low positions of the curves for nozzle 5 stand out in sharp contrast to the relatively systematic arrangement of those for the other nozzles. It is also noteworthy that, although the curves which correspond to straight and divergent mixing tubes are widely separated, a marked similarity of the effects of area-ratio variation is apparent in the two groups. Thus, the maximum augmentation ratio attained with the straight mixing tube diminishes as nozzles 2 and 3 are successively substituted for nozzle 1, rises again when nozzle 4 is used, and finally declines sharply in the case of nozzle 5; similar deviations from the continuously rising theoretical curve will be seen to characterize the curves for the divergent mixing tubes.

Figure 22 also shows that, although substantial augmentation is obtained with divergent mixing tubes, the combination of a straight mixing tube with an annular jet is practically worthless as a thrust augmenter. Moreover, it is apparent that the thrust augmentation obtained with annular nozzles and divergent mixing tubes is, at least at the Reynolds numbers of these experiments, much less than that produced by comparable combinations of central nozzles and straight mixing tubes.

Further comparison of the characteristics of ejectors with peripheral and central nozzles and analysis of the differences between them will be deferred until the discharge survey data have been examined.

Mixing Tube Efflux Characteristics

While total-pressure surveys were made under all test conditions, the spacing of the survey-rake tubes was not close enough to enable significant data to be obtained when $L/D = 2$. For that reason, only a few of those pressure records were even reduced to numerical form. The results of all other surveys are tabulated but only one set, that for 12 pounds per square inch, is graphically reproduced in this report. These curves will be found in figures 15 to 19. Examination of the data will show that the ordinates of corresponding curves for other pressures differ from those in the figures by substantially uniform, small percentages.

Since a total-pressure tube with its tip in the mouth of the primary nozzle would, under ideal conditions, experience a pressure $p' = p'_c$, perhaps the most surprising feature of the discharge survey curves is the small order of the maximums which they attain. The highest value plotted will be found in figure 15; it occurs in the case of nozzle 1 with mixing tube 1, $L/D = 4$, and barely exceeds 0.13. The values of the maximums for the other nozzles and mixing tubes (of the same length) will be seen to diminish both as slot width decreases and as mixing tube divergence angle increases. For example, the maximum value of p'/p'_c observed with nozzle 5 and mixing tube 4 $(L/D = 4)$ was only 0.0022.

The most significant information conveyed by these charts is, of course, that which illustrates the progress of the transfer of energy from the primary stream to the secondary one. Since total pressures were measured with reference to that of the undisturbed air, the determination of a positive value[15] of p'/p'_c at any point is evidence of the existence there of energy obtained from the primary stream. Interpretation of figures 15 to 19 on this basis brings to light at least three facts of fundamental importance.

First, it is evident that, in the case of the straight mixing tube, the transfer of energy, with resulting substantially uniform distribution over the whole of the composite stream, is accomplished within a relatively short length. Second, it is equally clear that the introduction of mixing tube divergence retards energy transfer to the secondary stream; thus, even at the end of a mixing tube of $L/D = 10$, the total pressure (p'/p'_c) on the axis is but a small fraction of that close to the wall. Third, the area ratio (A_m/A_s) has little apparent effect upon the uniformity of total-pressure distribution in the case of the straight mixing tube, but a very obvious one when divergence is present. In the latter case it is particularly noteworthy that the reduction of slot area is conducive to energy transfer; that is, the radial distribution of total pressure approaches uniformity as the area ratio is increased.

To define, precisely, the boundaries within which no transfer of energy has occurred is practically impossible because the curves of p'/p'_c against r approach zero asymptotically. However, the following table, which was obtained by cross-fairing, will serve to define, with fair accuracy, the values of L/D at which the total pressure on the axis attains one-tenth of the maximum value which occurs in the same transverse section.

TABLE C

Mixing tube \ Nozzle	1	2	3	4	5
	L/D				
1	4.0	4.2	4.0	3.8	3.2
2	9.5	9.3	8.4	7.7	5.3
3	---	---	---	---	7.5
4	---	---	---	---	9.5

The blanks in the table indicate values greater than 10.

[15] Some very small negative values are tabulated. These are believed to result either from inaccuracies of record reduction or from taking records before manometer equilibrium had been attained. In a few instances, substantial negative values characterize the central region of the discharged stream; these were observed during tests in which sonic velocities of secondary flow occurred and are therefore believed to be evidence of shock losses.

A somewhat clearer picture of typical survey results may be obtained from figure 23 in which the curves for $L/D = 8$, from figures 15 to 19, have been replotted in semilogarithmic coordinates. In the chart for mixing tube 1, the similarity of the relative variations of total pressure along the radius is clearly evident. The charts for the other mixing tubes illustrate the progressive increase of nonuniformity of radial pressure distribution which occurs as mixing tube divergence angle increases. They also emphasize the previously mentioned effect of area ratio upon energy transfer in divergent tubes.

Other things being equal, the survey results might be taken to indicate that maximum augmentation should be expected to occur with the straight mixing tube because the energy distribution at discharge is most nearly uniform in that case. Such a view is untenable, however, because the influences of two important factors are thus ignored. The primary one is the inequality of the mass ratios for comparable ejectors with straight and divergent mixing tubes; on this score, the advantage of the divergent tube tends to neutralize that of the more uniform energy distribution in the straight one. Thus, even the basic pressure forces – which, in the absence of friction, would constitute the entire augmenting force – are not uniquely determined by either uniformity of energy distribution or mass ratio, but by their combined effects. In this connection it is worth noting that the improved uniformity of energy distribution effected by the reduction of slot area enhances the effectiveness of the large mass ratios obtained with divergent mixing tubes. The secondary factor is the undetermined, but probably relatively large, difference between the frictional forces on straight and divergent mixing tubes when both operate at the same mass ratio; there can be little doubt that the divergent tube has the advantage in this respect as well.

Reconciliation

At the opening of this discussion, attention was called to the discharge characteristics of the primary nozzles and it was implied that they strongly influenced the character of the test results. All of the facts thus far reviewed are believed to be consistent with this view and it will now be attempted to bring them together in its substantiation.

Figure 21 showed that the entrainment characteristics of nozzles 1 to 3, and perhaps even 4 – when combined with the straight mixing tube – approach the theoretical values about as closely as do the results of tests on conventional (central-nozzle) ejectors. It therefore appears that some special characteristic of nozzle 5 must be responsible for its lack of conformity with the others. The facts that its maximum discharge coefficient barely exceeds 2/3 (see fig. 8 and appendix) and that the slope of its loss-coefficient curve is –1 (fig. 9) strongly suggest the existence of laminar boundary layers which fully occupy the entire radial width of the slot. If the other nozzles do not share this characteristic (and there is no evidence that any do, with possible exception of nozzle 4 – but in that case only at low pressures) it would appear logical to ascribe the relatively small mass ratios which characterize this nozzle to the unique properties of the stream which it discharges.

The mere reduction of mass ratio by some 25 percent of that fraction of the theoretical values attained by the others is, however, insufficient to explain the great deficiency of the augmentation ratios for nozzle 5. The only other source of such deficiency would appear to be disproportionately large skin-friction forces; it is believed that such forces do exist in this case. Moreover, it is believed that consideration of the probable variation of the skin-friction forces which act on the mixing tubes offers a satisfactory explanation of the inferiority of the augmentation produced by peripheral nozzles, as compared with that previously found with the central type. Finally, acceptance of this basis of analysis enables explanation of the irregularity of augmentation which occurs in the range between nozzles 2 and 4 (see fig. 22).

In figure 20, the pressure-drop coefficient for smooth pipes is shown to diminish steadily in the laminar range, rise sharply at transition, and then decline slowly as the boundary layer becomes fully turbulent. Remembering that the major portion of the skin-friction force experienced by the mixing tube is concentrated on the region which, located just downstream from the nozzle slot, is subjected to the highest velocity, it may be assumed that the character of the boundary layer issuing from the slot remains substantially unchanged within this critical region. As the boundary layer discharged by nozzle 5 is believed to be laminar, the source of the "disproportionately large skin-friction forces" is recognized in the large pressure-drop (and drag) coefficients which characterize the smaller Reynolds numbers in figure 20.[16]

If the boundary layer discharged along the mixing-tube wall by nozzle 4 happens to correspond to the left side and bottom of the valley at the beginning of transition in figure 20,[16] the accompanying frictional forces would be smaller than any likely to occur until a very large "equivalent pipe Reynolds number" has been attained. Under this condition, a large gain of augmentation by nozzle 4, over that for nozzle 5, would be expected.

Coming now to nozzle 3, it may be assumed that the corresponding segment of figure 20 is some distance to the right of the peak which follows transition. The pressure-drop (and drag) coefficients in this

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[16]Note that although in figure 8 the Reynolds number ranges for nozzles 5 and 4 are contiguous, the lack of geometric similarity of the nozzles may widely separate the corresponding ranges of Reynolds number in figure 20.

range are somewhat greater than those ascribed to nozzle 4 so it is reasonable to expect the augmentation obtained with nozzle 3 to drop proportionately further below the theoretical curve than did that of nozzle 4.

With the progressive development of turbulent boundary layers in the cases of nozzles 2 and 1, a gradual reduction of frictional forces would be expected, as would the approach of their augmentation ratios toward the theoretical curve.

It is the writer's opinion that the foregoing analysis, qualitative only though it must be, is in substantial agreement with all of the known facts and that it therefore merits at least tentative acceptance.

Turning now to the broader question of the relative merits of ejectors incorporating central and peripheral nozzles, reason for expectation of the inferiority of the latter type is seen in the larger frictional forces arising from exposure of the walls of its mixing tubes to the high velocity of the primary stream. This situation was appreciated when the investigation was proposed but it was not then known that both types possess substantially identical entrainment characteristics when they incorporate straight mixing tubes. In view of the demonstration of this equivalence, it appears unlikely that an ejector with peripheral slot can produce as great thrust augmentation as a comparable one of the central-jet type.

However, for use as a simple ejector or jet pump, the peripheral type offers advantages in its apparent ability to utilize divergent mixing tubes more effectively for the development of low throat pressures and large mass ratios than is the case with the central nozzle.

CONCLUSIONS

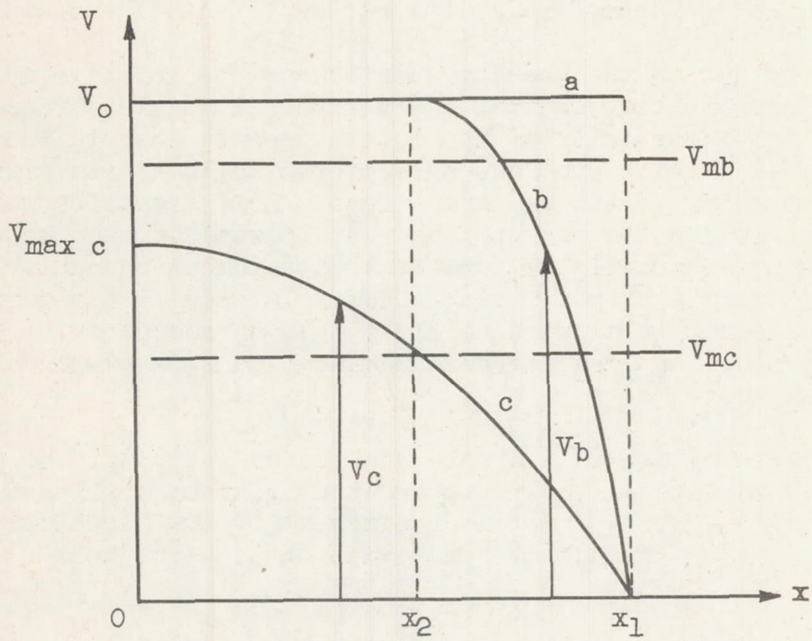
Tests of ejectors with annular nozzles and nondivergent mixing tubes have shown this arrangement to have negligible thrust-augmentation capabilities, despite the possession of entrainment characteristics substantially identical with those of the conventional ejector with central nozzle. The augmentation deficiency is ascribed to inequality of the frictional forces experienced by the two types.

The combination of divergent mixing tubes with annular nozzles was found to result in very substantial improvement of both entrainment and augmentation characteristics. While the augmentation so effected still falls short of that attainable with comparable central nozzles and straight mixing tubes, the corresponding entrainment characteristics are superior to any thus far demonstrated by central-nozzle types. This advantage is believed to originate in the suppression of flow separation from the walls of diffusers by the scouring action of annular jets.

Stanford University
Stanford University, Calif., September 15, 1947

APPENDIX

As the apertures of the annular nozzles used in these experiments are characterized by very large ratios of mean radius to width, the flow in radial sections thereof may, for the present purpose, be treated as two dimensional. The diagram below illustrates three hypothetical distributions of velocity across a two-dimensional slot of total width $2x_1$; all are symmetrical and of parabolic form where nonuniform.



Distribution a represents the ideal case in which the uniform velocity of efflux is V_o.

Distribution b represents a flow characterized by boundary layers of thickness $x_1 - x_2$.

Distribution c represents a more severely retarded flow in which the boundary layers have merged; they not only occupy the entire width of the slot but the maximum velocity in this case is less than V_o.

In case b, the mass rate of flow (lb/sec) per unit slot length is

$$W_b = 2\rho g V_{mb} x_1 \tag{A1}$$

in which V_{mb} is the mean velocity. Since the corresponding discharge coefficient is $C_{db} = V_{mb}/V_o$

$$W_b = 2\rho g C_{db} V_o x_1 \tag{A2}$$

The thrust (time rate of momentum discharge) in this case is

$$F_b = 2\rho\left(V_o^{\,2}x_2 + \int_{x_2}^{x_1} V_b^{\,2}\,dx\right) \tag{A3}$$

Now, between x_2 and x_1

$$V_b = V_o\left[1 - \left(\frac{x - x_2}{x_1 - x_2}\right)^2\right] \tag{A4}$$

Therefore

$$\int_{x_2}^{x_1} V_b^{\,2}\,dx = V_o^{\,2}\int_{x_2}^{x_1}\left[1 - \left(\frac{x - x_2}{x_1 - x_2}\right)^2\right]^2 dx = \frac{8}{15}V_o^{\,2}(x_1 - x_2) \tag{A5}$$

Substituting this value in equation (A3), the expression for the thrust becomes

$$F_b = 2\rho V_o^{\,2}x_1\left[\frac{x_2}{x_1} + \frac{8}{15}\left(1 - \frac{x_2}{x_1}\right)\right] \tag{A6}$$

The specific thrust is, therefore,

$$\frac{F_b}{W_b} = \frac{V_o}{gC_{db}}\left[\frac{x_2}{x_1} + \frac{8}{15}\left(1 - \frac{x_2}{x_1}\right)\right] \tag{A7}$$

Under ideal conditions (i.e., with the distribution a) the specific thrust would be

$$\left(\frac{F}{W}\right)_i = \frac{2\rho V_o^{\,2}x_1}{2\rho g V_o x_1} = \frac{V_o}{g} \tag{A8}$$

and the ratio of actual to ideal specific thrust is

$$\frac{F_b/W_b}{(F/W)_i} = \frac{\left[\frac{x_2}{x_1} + \frac{8}{15}\left(1 - \frac{x_2}{x_1}\right)\right]}{C_{db}} = \frac{1}{k_b} \tag{A9}$$

The fact that C_{db} is, itself, a function of x_2/x_1 enables the definition of k_b in terms of C_{db}. To do so, it is noted, first, that the mean ordinate of the parabolic segment between x_2 and x_1 is $2/3\ V_o(x_1 - x_2)$. Making use of this fact, the mean velocity is obtained as

$$V_{mb} = \frac{V_o x_2 + \frac{2}{3} V_o(x_1 - x_2)}{x_1} = V_o\left[\frac{x_2}{x_1} + \frac{2}{3}\left(1 - \frac{x_2}{x_1}\right)\right] \tag{A10}$$

The discharge coefficient may now be expressed as

$$C_{db} = \frac{V_{mb}}{V_o} = \frac{x_2}{x_1} + \frac{2}{3}\left(1 - \frac{x_2}{x_1}\right) \tag{A11}$$

and, from equation (A11)

$$\frac{x_2}{x_1} = 3C_{db} - 2 \tag{A12}$$

The substitution of this value for x_2/x_1 in equation (A9) yields the desired relationship

$$k_b = \frac{C_{db}}{\left[\frac{x_2}{x_1} + \frac{8}{15}\left(1 - \frac{x_2}{x_1}\right)\right]} = \frac{5C_{db}}{7C_{db} - 2} \tag{A13}$$

The applicability of equation (A13) is limited to the range $1 > C_d > 2/3$ because $C_{db} = 2/3$ when $x_2/x_1 = 0$. This lower limit for case b thus corresponds to the condition in which the two boundary layers just fill the slot and the ideal velocity is attained only at the midpoint.

With still greater frictional retardation of the discharged stream, the velocity distribution is assumed to degenerate into the form c, in which the ideal velocity is not attained at any point, and the following relationships therefore exist when $C_d \leqslant 2/3$.

The mass flow per unit slot length is, by analogy with equation (A2),

$$W_c = 2\rho g C_{dc} V_o x_1 \tag{A14}$$

and the thrust is

$$F_c = 2\rho \int_o^{x_1} V_c^2 \, dx \tag{A15}$$

The velocity V_c is defined by the equation

$$V_c = V_{max\ c}\left[1 - \left(\frac{x}{x_1}\right)^2\right] \tag{A16}$$

However, $V_{max\ c}$ may be expressed in terms of V_o and C_{dc}, that is,

$$V_{max\ c} = \frac{3}{2} V_{mc} = \frac{3}{2} C_{dc} V_o \tag{A17}$$

whence

$$V_c = \frac{3}{2} C_{dc} V_o \left[1 - \left(\frac{x}{x_1}\right)^2\right] \tag{A18}$$

Therefore

$$F_c = \frac{9}{2} \rho C_{dc}^2 V_o^2 \int_o^{x_1} \left[1 - \left(\frac{x}{x_1}\right)^2\right] dx = \frac{12}{5} \rho C_{dc}^2 V_o^2 x_1 \tag{A19}$$

and the specific thrust is

$$\frac{F_c}{W_c} = \frac{6 C_{dc} V_o}{5g} \tag{A20}$$

Thus the ratio of the ideal specific thrust V_o/g to the unaugmented thrust which corresponds to distribution c is

$$k_c = \frac{(F/W)_i}{F_c/W_c} = \frac{V_o}{g}\left(\frac{5g}{6C_{dc}V_o}\right) = \frac{5}{6C_{dc}} \qquad \text{(A21)}$$

and this relationship is applicable whenever $C_d \leqslant 2/3$.

Equations (A13) and (A21) were used to determine the curve shown in figure 6. Acceptance of the assumption of parabolic velocity distribution in the nozzle boundary layers enables evaluation of the unaugmented specific thrusts by use of this curve in conjunction with the relationships given in the section REDUCTION OF DATA.

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TABLE 1.- FORCE AND MASS FLOW DATA. NOZZLE 1; MIXING TUBE 1

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.644	0.03450	0.06844	1.984	20.22	0.9409	1.026	0.947
8	.662	.03451	.06817	1.975	20.22	.9407	1.026	.973
6	.675	.03427	.07150	2.086	20.31	.9364	1.028	.997
4	.692	.03435	.06870	2.000	20.33	.9399	1.027	1.018
2	.662	.03387	.05505	1.625	20.42	.9372	1.028	.984
p'_c (nominal) = 8 lb/sq in.								
10	1.232	.04800	.09300	1.938	26.89	.9434	1.025	.979
8	1.260	.04780	.09645	2.018	26.87	.9413	1.026	1.007
6	1.290	.04771	.09902	2.075	26.96	.9396	1.026	1.029
4	1.301	.04785	.09395	1.963	26.96	.9432	1.025	1.034
2	1.257	.04756	.07379	1.552	27.10	.9450	1.024	.999
p'_c (nominal) = 12 lb/sq in.								
10	1.736	.05792	.1106	1.910	31.18	.9453	1.024	.961
8	1.781	.05800	.1121	1.932	31.18	.9469	1.023	1.008
6	1.826	.05749	.1130	1.966	31.25	.9409	1.026	1.042
4	1.834	.05730	.1079	1.883	31.27	.9379	1.028	1.052
2	1.778	.05747	.0853	1.484	31.43	.9447	1.024	1.008
p'_c (nominal) = 16 lb/sq in.								
10	2.221	.06670	.1236	1.853	34.31	.9477	1.022	.992
8	2.281	.06650	.1250	1.880	34.29	.9446	1.024	1.024
6	2.328	.06661	.1267	1.902	34.38	.9483	1.022	1.039
4	2.338	.06660	.1194	1.793	34.38	.9480	1.022	1.043
2	2.259	.06627	.0949	1.432	34.54	.9473	1.023	1.010

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TABLE 2.– FORCE AND MASS FLOW DATA. NOZZLE 1; MIXING TUBE 2

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.811	0.03630	0.1452	4.000	20.30	0.9404	1.026	1.129
8	.809	.03600	.1286	3.572	20.32	.9450	1.024	1.133
6	.794	.03502	.1079	3.081	20.32	.9345	1.029	1.148
4	.753	.03478	.09147	2.630	20.29	.9384	1.027	1.096
2	.690	.03385	.06279	1.855	20.42	.9337	1.030	1.028
p'_c (nominal) = 8 lb/sq in.								
10	1.478	.0490	.1942	3.963	26.89	.9453	1.021	1.146
8	1.495	.0486	.1752	3.605	26.93	.9399	1.027	1.173
6	1.467	.04827	.1486	3.079	26.99	.9415	1.025	1.164
4	1.401	.04827	.1240	2.569	26.91	.9442	1.024	1.104
2	1.293	.04751	.0850	1.789	27.11	.9434	1.025	1.029
p'_c (nominal) = 12 lb/sq in.								
10	2.024	.05791	.2272	3.923	31.21	.9461	1.024	1.147
8	2.065	.0579	.2031	3.508	31.19	.9453	1.024	1.170
6	2.049	.05812	.1756	3.021	31.28	.9440	1.024	1.154
4	1.967	.05760	.1405	2.439	31.19	.9406	1.026	1.122
2	1.829	.05741	.0982	1.711	31.47	.9448	1.024	1.036
p'_c (nominal) = 16 lb/sq in.								
10	2.532	.0665	.2522	3.792	34.34	.9454	1.024	1.136
8	2.605	.0665	.2270	3.414	34.32	.9454	1.024	1.175
6	2.590	.06654	.1932	2.904	34.39	.9481	1.022	1.157
4	2.502	.06663	.1559	2.340	34.35	.9476	1.022	1.117
2	2.333	.06607	.1069	1.618	34.61	.9471	1.023	1.037

TABLE 3.– FORCE AND MASS FLOW DATA. NOZZLE 1; MIXING TUBE 3

L/D	F (lb)	W_1 $\left(\frac{\text{lb}}{\text{sec}}\right)$	W_2 $\left(\frac{\text{lb}}{\text{sec}}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{\text{lb}}{\text{lb/sec}}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.807	0.03820	0.1892	4.953	20.14	0.9479	1.022	1.072
8	.831	.03705	.1640	4.426	20.28	.9465	1.023	1.151
6	.823	.03583	.1354	3.779	20.32	.9394	1.026	1.159
4	.779	.03540	.1057	2.986	20.18	.9419	1.026	1.118
2	.706	.03412	.06729	1.972	20.47	.9399	1.026	1.037
p'_c (nominal) = 8 lb/sq in.								
10	1.373	.04970	.2461	4.952	26.76	.9489	1.022	1.056
8	1.475	.04910	.2145	4.369	26.95	.9447	1.024	1.142
6	1.507	.04859	.1816	3.737	26.99	.9413	1.025	1.178
4	1.457	.04856	.1413	2.910	26.84	.9435	1.025	1.146
2	1.325	.04751	.09186	1.933	27.15	.9430	1.025	1.053
p'_c (nominal) = 12 lb/sq in.								
10	1.815	.05824	.2789	4.789	31.05	.9465	1.023	1.027
8	1.992	.05780	.2514	4.349	31.26	.9458	1.024	1.128
6	2.074	.05757	.2128	3.696	31.31	.9439	1.025	1.179
4	2.025	.05774	.1649	2.856	31.15	.9417	1.025	1.154
2	1.867	.05724	.1079	1.885	31.47	.9433	1.025	1.063
p'_c (nominal) = 16 lb/sq in.								
10	2.154	.06670	.2920	4.378	34.16	.9436	1.025	.969
8	2.468	.06650	.2730	4.105	34.39	.9472	1.023	1.104
6	2.605	.06664	.2350	3.526	34.43	.9505	1.021	1.159
4	2.563	.06679	.1825	2.732	34.28	.9485	1.022	1.144
2	2.375	.06617	.1175	1.776	34.61	.9487	1.022	1.060

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TABLE 4.– FORCE AND MASS FLOW DATA. NOZZLE 1; MIXING TUBE 4

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.754	0.03880	0.2058	5.304	20.19	0.9492	1.022	0.984
8	.808	.03770	.1829	4.851	20.31	.9481	1.022	1.075
6	.836	.03620	.1506	4.160	20.33	.9397	1.026	1.166
4	.798	.03522	.1168	3.316	20.36	.9378	1.027	1.143
2	.719	.03423	.07363	2.151	20.44	.9395	1.026	1.048
p'_c (nominal) = 8 lb/sq in.								
10	1.254	.04960	.2678	5.399	26.81	.9488	1.022	.964
8	1.416	.04910	.2408	4.904	26.97	.9452	1.024	1.095
6	1.497	.04870	.2016	4.139	27.01	.9414	1.025	1.166
4	1.452	.04821	.1540	3.194	27.05	.9401	1.026	1.142
2	1.342	.04763	.09698	2.036	27.11	.9432	1.025	1.065
p'_c (nominal) = 12 lb/sq in.								
10	1.568	.05810	.2921	5.028	31.08	.9458	1.024	.889
8	1.879	.05780	.2728	4.720	31.27	.9463	1.023	1.064
6	2.051	.05782	.2341	4.049	31.33	.9483	1.022	1.157
4	2.050	.05732	.1843	3.215	31.34	.9406	1.026	1.171
2	1.884	.05722	.1134	1.982	31.45	.9425	1.025	1.073
p'_c (nominal) = 16 lb/sq in.								
10	1.911	.0670	.2907	4.339	34.21	.9492	1.022	.852
8	2.268	.0664	.2890	4.352	34.39	.9458	1.023	1.016
6	2.543	.06649	.2568	3.862	34.45	.9490	1.022	1.134
4	2.577	.06636	.1986	2.993	34.47	.9474	1.023	1.152
2	2.402	.06586	.1251	1.899	34.59	.9438	1.024	1.079

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TABLE 5.- FORCE AND MASS FLOW DATA. NOZZLE 2; MIXING TUBE 1

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.277	0.01589	0.05163	3.249	20.21	0.8775	1.060	0.914
8	.286	.01590	.05286	3.326	20.30	.8780	1.060	.939
6	.297	.01590	.05432	3.416	20.31	.8746	1.062	.977
4	.298	.01587	.05325	3.355	20.26	.8741	1.062	.984
2	.291	.01571	.04305	2.740	20.28	.8780	1.060	.954
p'_c (nominal) = 8 lb/sq in.								
10	.545	.02240	.07182	3.206	26.90	.8872	1.054	.953
8	.564	.02250	.07336	3.260	26.97	.8917	1.052	.973
6	.577	.02252	.07465	3.306	26.93	.8900	1.053	1.002
4	.585	.02253	.07109	3.155	26.91	.8897	1.053	1.016
2	.565	.02232	.05803	2.600	27.02	.8888	1.054	.987
p'_c (nominal) = 12 lb/sq in.								
10	.788	.02752	.08602	3.126	31.25	.9037	1.045	.957
8	.818	.02730	.08768	3.212	31.28	.8954	1.050	1.006
6	.835	.02747	.08915	3.245	31.25	.8987	1.048	1.019
4	.841	.02754	.08463	3.073	31.15	.8990	1.048	1.027
2	.810	.02736	.06877	2.514	31.34	.8976	1.049	.991
p'_c (nominal) = 16 lb/sq in.								
10	1.026	.03170	.09715	3.065	34.44	.9057	1.044	.981
8	1.058	.03170	.09892	3.121	34.41	.9044	1.044	1.013
6	1.083	.03210	.1003	3.125	34.33	.9139	1.040	1.022
4	1.091	.03211	.09533	2.969	34.26	.9110	1.041	1.032
2	1.055	.03195	.07797	2.440	34.47	.9128	1.040	.996

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TABLE 6.- FORCE AND MASS FLOW DATA. NOZZLE 2; MIXING TUBE 2

L/D	F (lb)	W_1 $\left(\frac{\text{lb}}{\text{sec}}\right)$	W_2 $\left(\frac{\text{lb}}{\text{sec}}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{\text{lb}}{\text{lb/sec}}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.350	0.01625	0.1029	6.332	20.36	0.8784	1.059	1.120
8	.358	.01630	.09188	5.637	20.29	.8797	1.058	1.145
6	.348	.01640	.08042	4.983	20.26	.8774	1.060	1.126
4	.328	.01586	.06536	4.121	20.29	.8704	1.064	1.084
2	.302	.01584	.04792	3.025	20.35	.8740	1.062	.995
p'_c (nominal) = 8 lb/sq in.								
10	.675	.02280	.1436	6.298	27.06	.8946	1.050	1.149
8	.694	.02280	.1280	5.614	26.90	.8930	1.051	1.190
6	.675	.02270	.1123	4.947	26.89	.8909	1.052	1.164
4	.632	.02248	.0901	4.008	26.95	.8875	1.054	1.099
2	.586	.02259	.0654	2.896	26.99	.8949	1.050	1.009
p'_c (nominal) = 12 lb/sq in.								
10	.974	.02745	.1717	6.255	31.35	.9034	1.045	1.183
8	.987	.02750	.1520	5.568	31.20	.8995	1.048	1.205
6	.965	.02768	.1332	4.812	31.17	.9040	1.045	1.168
4	.913	.02743	.1075	3.919	31.25	.8982	1.048	1.116
2	.842	.02738	.0781	2.852	31.29	.8975	1.049	1.031
p'_c (nominal) = 16 lb/sq in.								
10	1.262	.03170	.1923	6.066	34.56	.9087	1.042	1.200
8	1.273	.03200	.1716	5.363	34.35	.9109	1.041	1.205
6	1.244	.03218	.1482	4.738	34.27	.9141	1.040	1.173
4	1.173	.03210	.1210	3.769	34.43	.9134	1.040	1.103
2	1.096	.03184	.0876	2.750	34.43	.9085	1.042	1.042

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TABLE 7.- FORCE AND MASS FLOW DATA. NOZZLE 2; MIXING TUBE 3

L/D	F (lb)	W_1 (lb/sec)	W_2 (lb/sec)	W_2/W_1	$(F/W_1)_i$ (lb/(lb/sec))	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.348	0.01670	0.1312	7.856	20.42	0.8876	1.054	1.076
8	.365	.01660	.1167	7.030	20.25	.8821	1.058	1.149
6	.364	.01619	.0957	5.914	20.18	.8700	1.064	1.185
4	.342	.01595	.0757	4.748	20.34	.8734	1.063	1.120
2	.308	.01512	.0518	3.296	20.32	.8681	1.066	1.068
p'_c (nominal) = 8 lb/sq in.								
10	.670	.02290	.1791	7.821	27.14	.8952	1.050	1.132
8	.703	.02290	.1614	7.048	26.89	.8893	1.054	1.204
6	.703	.02297	.1351	5.882	26.81	.8950	1.050	1.199
4	.658	.02248	.1045	4.649	27.01	.8864	1.054	1.143
2	.599	.02261	.0716	3.166	26.99	.8953	1.050	1.030
p'_c (nominal) = 12 lb/sq in.								
10	.940	.02748	.2088	7.598	31.46	.9066	1.044	1.135
8	.997	.02750	.1894	6.891	31.16	.8982	1.048	1.219
6	.997	.02788	.1602	5.746	31.09	.9085	1.042	1.198
4	.953	.02753	.1248	4.533	31.28	.9025	1.046	1.119
2	.863	.02755	.0859	3.119	31.28	.9024	1.046	1.047
p'_c (nominal) = 16 lb/sq in.								
10	1.194	.03170	.2360	7.445	34.60	.9097	1.042	1.135
8	1.276	.03200	.2145	6.703	34.32	.9098	1.042	1.211
6	1.280	.03207	.1793	5.591	34.23	.9098	1.042	1.215
4	1.221	.03203	.1403	4.380	34.44	.9123	1.040	1.150
2	1.111	.03204	.0956	2.985	34.38	.9133	1.040	1.049

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TABLE 8.- FORCE AND MASS FLOW DATA. NOZZLE 2; MIXING TUBE 4

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.344	0.01680	0.1458	8.679	20.41	0.8832	1.057	1.060
8	.369	.01680	.1293	7.696	20.15	.8844	1.056	1.151
6	.371	.01629	.1092	6.703	20.34	.8752	1.061	1.187
4	.344	.01594	.0822	5.159	20.37	.8692	1.065	1.128
2	.312	.01585	.0549	3.464	20.29	.8717	1.063	1.031
p'_c (nominal) = 8 lb/sq in.								
10	.644	.02300	.1975	8.587	27.11	.8874	1.054	1.089
8	.696	.02320	.1781	7.677	26.82	.8967	1.048	1.173
6	.708	.02297	.1496	6.513	27.00	.8983	1.048	1.196
4	.675	.02271	.1144	5.037	27.04	.8951	1.050	1.154
2	.607	.02261	.0749	3.312	26.96	.8934	1.051	1.047
p'_c (nominal) = 12 lb/sq in.								
10	.899	.02743	.2314	8.436	31.42	.9047	1.045	1.090
8	.977	.02770	.2095	7.563	31.11	.9035	1.045	1.185
6	1.003	.02763	.1759	6.366	31.31	.9058	1.044	1.210
4	.967	.02749	.1355	4.929	31.35	.9024	1.045	1.172
2	.876	.02742	.0889	3.241	31.25	.8973	1.048	1.071
p'_c (nominal) = 16 lb/sq in.								
10	1.126	.03170	.2598	8.196	34.56	.9092	1.042	1.071
8	1.236	.03210	.2329	7.255	34.24	.9110	1.041	1.170
6	1.285	.03181	.1979	6.221	34.43	.9077	1.043	1.224
4	1.244	.03196	.1525	4.772	34.47	.9132	1.040	1.174
2	1.127	.03205	.1004	3.133	34.38	.9133	1.040	1.064

TABLE 9.- FORCE AND MASS FLOW DATA. NOZZLE 3; MIXING TUBE 1

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.115	0.00729	0.03650	5.007	20.29	0.8015	1.110	0.863
8	.118	.00709	.03702	5.221	20.33	.7849	1.123	.919
6	.120	.00715	.03775	5.278	20.30	.7908	1.119	.937
4	.126	.00710	.03830	5.392	20.29	.7849	1.123	.982
2	.123	.00713	.03193	4.481	20.16	.7832	1.125	.963
p'_c (nominal) = 8 lb/sq in.								
10	.228	.01050	.05131	4.887	26.94	.8306	1.089	.878
8	.244	.01041	.05220	5.014	26.99	.8246	1.093	.972
6	.249	.01033	.05333	5.163	26.97	.8167	1.100	.983
4	.253	.01033	.05252	5.084	26.95	.8170	1.099	.999
2	.244	.01035	.04404	4.255	26.81	.8138	1.101	.968
p'_c (nominal) = 12 lb/sq in.								
10	.341	.01294	.06200	4.791	31.28	.8438	1.081	.911
8	.352	.01290	.06239	4.836	31.28	.8441	1.081	.943
6	.365	.01294	.06429	4.908	31.27	.8454	1.080	.974
4	.365	.01291	.06213	4.812	31.25	.8431	1.081	.978
2	.360	.01298	.05199	4.005	31.07	.8425	1.081	.965
p'_c (nominal) = 16 lb/sq in.								
10	.455	.01520	.07083	4.660	34.39	.8640	1.068	.930
8	.471	.01510	.07198	4.767	34.41	.8590	1.071	.971
6	.480	.01502	.07311	4.868	34.36	.8528	1.075	1.000
4	.483	.01501	.07003	4.666	34.38	.8528	1.075	1.006
2	.471	.01511	.05982	3.958	34.18	.8535	1.074	.979

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TABLE 10.- FORCE AND MASS FLOW DATA. NOZZLE 3; MIXING TUBE 2

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.154	0.00737	0.07186	9.750	20.39	0.8021	1.110	1.138
8	.150	.00716	.06465	9.029	20.32	.7859	1.123	1.158
6	.149	.00722	.05788	8.019	20.31	.7931	1.117	1.139
4	.138	.00715	.04768	6.670	20.32	.7875	1.121	1.065
2	.127	.00713	.03545	4.971	20.21	.7849	1.123	.990
p'_c (nominal) = 8 lb/sq in.								
10	.307	.01060	.1004	9.472	26.99	.8350	1.087	1.166
8	.305	.01041	.09044	8.688	27.03	.8212	1.096	1.188
6	.298	.01040	.07976	7.669	26.96	.8256	1.093	1.162
4	.275	.01040	.06526	6.275	26.97	.8225	1.095	1.073
2	.254	.01039	.04917	4.732	26.84	.8183	1.098	1.000
p'_c (nominal) = 12 lb/sq in.								
10	.441	.01304	.1200	9.202	31.32	.8541	1.074	1.160
8	.438	.01280	.1088	8.500	31.11	.8379	1.085	1.196
6	.431	.01294	.09449	7.302	31.27	.8450	1.080	1.150
4	.403	.01291	.07763	6.013	31.27	.8437	1.081	1.079
2	.373	.01298	.05810	4.476	31.08	.8420	1.082	1.001
p'_c (nominal) = 16 lb/sq in.								
10	.584	.01530	.1378	9.007	34.45	.8714	1.064	1.179
8	.585	.0150	.1245	8.297	34.42	.8535	1.074	1.217
6	.566	.01501	.1079	7.189	34.41	.8532	1.075	1.178
4	.532	.01502	.08808	5.864	34.39	.8540	1.074	1.105
2	.491	.01510	.06581	4.358	34.20	.8533	1.075	1.022

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TABLE 11.- FORCE AND MASS FLOW DATA. NOZZLE 3; MIXING TUBE 3

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.151	0.00745	0.09109	12.25	20.35	0.8084	1.105	1.101
8	.159	.00722	.07975	11.05	20.38	.7868	1.121	1.211
6	.159	.00722	.06916	9.584	20.35	.7888	1.128	1.222
4	.140	.00710	.05402	7.608	20.31	.7819	1.126	1.093
2	.136	.00714	.03908	5.473	20.25	.7839	1.124	1.057
p'_c (nominal) = 8 lb/sq in.								
10	.301	.01060	.1276	12.04	27.05	.8311	1.089	1.143
8	.320	.01046	.1137	10.87	27.02	.8228	1.095	1.240
6	.312	.01042	.09778	9.384	26.99	.8199	1.104	1.224
4	.293	.01036	.07557	7.294	26.99	.8180	1.098	1.151
2	.266	.01035	.05358	5.177	26.87	.8146	1.100	1.052
p'_c (nominal) = 12 lb/sq in.								
10	.439	.01304	.1513	11.60	31.34	.8534	1.075	1.155
8	.458	.01290	.1345	10.43	31.31	.8446	1.080	1.225
6	.452	.01292	.1146	8.870	31.29	.8443	1.081	1.209
4	.422	.01292	.08952	6.929	31.29	.8448	1.080	1.128
2	.381	.01295	.06249	4.825	31.14	.8424	1.082	1.022
p'_c (nominal) = 16 lb/sq in.								
10	.573	.01520	.1716	11.29	34.46	.8656	1.067	1.167
8	.599	.01490	.1532	10.28	34.44	.8486	1.078	1.258
6	.592	.01500	.1321	8.870	34.40	.8529	1.075	1.233
4	.554	.01500	.1020	6.800	34.43	.8537	1.074	1.151
2	.505	.01522	.0714	4.691	34.26	.8533	1.073	1.039

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TABLE 12.- FORCE AND MASS FLOW DATA. NOZZLE 3; MIXING TUBE 4

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.154	0.00746	0.1033	13.85	20.32	0.8036	1.109	1.127
8	.160	.00727	.08945	12.30	20.35	.7897	1.119	1.211
6	.160	.00722	.07720	10.69	20.35	.7886	1.128	1.227
4	.153	.00717	.05927	8.262	20.36	.7886	1.128	1.178
2	.135	.00712	.04171	5.859	20.26	.7832	1.125	1.053
p'_c (nominal) = 8 lb/sq in.								
10	.297	.01060	.1430	13.49	27.00	.8285	1.091	1.132
8	.318	.01049	.1262	12.03	27.04	.8229	1.095	1.227
6	.319	.01042	.1065	10.22	26.98	.8209	1.098	1.246
4	.300	.01039	.08218	7.910	27.00	.8212	1.096	1.172
2	.266	.01035	.05392	5.210	26.89	.8165	1.099	1.050
p'_c (nominal) = 12 lb/sq in.								
10	.429	.01305	.1690	12.95	31.30	.8537	1.075	1.129
8	.451	.01290	.1488	11.54	31.34	.8454	1.080	1.205
6	.455	.01294	.1258	9.722	31.30	.8458	1.079	1.212
4	.432	.01292	.0972	7.524	31.32	.8448	1.080	1.152
2	.388	.01295	.0656	5.066	31.17	.8431	1.081	1.039
p'_c (nominal) = 16 lb/sq in.								
10	.555	.01520	.1913	12.59	34.43	.8653	1.067	1.131
8	.591	.01500	.1697	11.31	34.47	.8551	1.073	1.226
6	.599	.01500	.1441	9.607	34.43	.8529	1.075	1.247
4	.566	.01500	.1105	7.367	34.43	.8537	1.074	1.176
2	.508	.01507	.07488	4.969	34.26	.8533	1.075	1.058

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TABLE 13.- FORCE AND MASS FLOW DATA. NOZZLE 4; MIXING TUBE 1

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.050	0.00357	0.02465	6.905	20.25	0.6904	1.218	0.843
8	.049	.00358	.02480	6.927	20.18	.6884	1.220	.828
6	.050	.00361	.02629	7.281	20.24	.6978	1.210	.836
4	.051	.00357	.02453	6.935	20.35	.6930	1.215	.852
2	.049	.00356	.02150	6.048	20.31	.6942	1.214	.824
p'_c (nominal) = 8 lb/sq in.								
10	.107	.00513	.03585	6.988	26.83	.7075	1.197	.931
8	.113	.00511	.03708	7.256	26.76	.7025	1.204	.995
6	.115	.00512	.03823	7.473	26.89	.7069	1.198	1.002
4	.121	.00506	.03738	7.392	27.00	.7020	1.204	1.067
2	.114	.00504	.03268	6.484	26.96	.6987	1.208	1.014
p'_c (nominal) = 12 lb/sq in.								
10	.167	.00656	.04568	6.963	31.11	.7462	1.158	.948
8	.173	.00654	.04678	7.153	31.05	.7410	1.163	.991
6	.177	.00654	.04720	7.217	31.21	.7456	1.158	1.004
4	.181	.00645	.04621	7.168	31.29	.7381	1.166	1.046
2	.173	.00643	.04036	6.277	31.27	.7344	1.170	1.007
p'_c (nominal) = 16 lb/sq in.								
10	.217	.00785	.05183	6.603	34.27	.7776	1.131	.912
8	.229	.00776	.05273	6.795	34.10	.7649	1.136	.983
6	.234	.00784	.05356	6.830	34.35	.7781	1.129	1.069
4	.239	.00767	.05225	6.811	34.43	.7637	1.138	1.033
2	.228	.00766	.04487	5.858	34.40	.7615	1.143	.989

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TABLE 14.- FORCE AND MASS FLOW DATA. NOZZLE 4; MIXING TUBE 2

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.062	0.00360	0.04588	12.74	20.21	0.6917	1.217	1.037
8	.064	.00361	.04225	11.70	20.09	.6897	1.219	1.076
6	.062	.00362	.03700	10.21	20.25	.6982	1.209	1.013
4	.058	.00356	.03067	8.610	20.33	.6910	1.218	.967
2	.052	.00358	.02383	6.658	20.31	.6942	1.214	.869
p'_c (nominal) = 8 lb/sq in.								
10	.150	.00516	.07214	13.98	26.86	.7095	1.195	1.293
8	.147	.00515	.06494	12.61	26.74	.7050	1.201	1.281
6	.140	.00512	.0571	11.15	26.90	.7053	1.201	1.217
4	.130	.00512	.04743	9.258	27.00	.7105	1.195	1.123
2	.120	.00510	.03624	7.100	26.96	.7079	1.197	1.044
p'_c (nominal) = 12 lb/sq in.								
10	.229	.00657	.08922	13.58	31.15	.7481	1.156	1.294
8	.226	.00655	.08096	12.36	30.98	.7413	1.163	1.296
6	.215	.00654	.07042	10.76	31.17	.7453	1.159	1.222
4	.202	.00645	.05822	9.031	31.29	.7378	1.166	1.167
2	.184	.00654	.04484	6.854	31.28	.7474	1.157	1.040
p'_c (nominal) = 16 lb/sq in.								
10	.295	.00776	.1002	12.81	34.29	.7694	1.136	1.260
8	.293	.00777	.09164	11.79	34.07	.7651	1.140	1.262
6	.283	.00782	.08047	10.29	34.28	.7746	1.131	1.194
4	.263	.00767	.06496	8.465	34.43	.7640	1.141	1.136
2	.243	.00787	.05025	6.382	34.40	.7828	1.125	1.009

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TABLE 15.- FORCE AND MASS FLOW DATA. NOZZLE 4; MIXING TUBE 3

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.059	0.00361	0.05916	16.39	20.16	0.6894	1.219	0.988
8	.063	.00359	.05254	14.64	20.36	.6935	1.214	1.046
6	.061	.00362	.04413	12.19	20.24	.6970	1.211	1.008
4	.056	.00356	.03511	9.851	20.33	.6888	1.220	.943
2	.055	.00359	.02627	7.313	20.30	.6957	1.212	.914
p'_c (nominal) = 8 lb/sq in.								
10	.148	.00518	.08893	17.18	26.79	.7085	1.197	1.276
8	.150	.00514	.08004	15.57	27.03	.7115	1.193	1.288
6	.142	.00513	.06860	13.37	26.90	.7064	1.199	1.239
4	.138	.00512	.05463	10.66	27.02	.7098	1.195	1.191
2	.125	.00510	.03928	7.696	26.98	.7076	1.197	1.087
p'_c (nominal) = 12 lb/sq in.								
10	.227	.00659	.1136	17.24	31.08	.7479	1.156	1.281
8	.233	.00651	.1017	15.62	31.35	.7459	1.158	1.322
6	.226	.00656	.08467	12.92	31.17	.7464	1.158	1.281
4	.213	.00645	.06555	10.16	31.30	.7378	1.166	1.229
2	.193	.00651	.04787	7.352	31.28	.7443	1.160	1.099
p'_c (nominal) = 16 lb/sq in.								
10	.295	.00780	.1287	16.50	34.21	.7705	1.135	1.255
8	.297	.00771	.1122	14.55	34.47	.7687	1.137	1.270
6	.297	.00792	.09614	12.14	34.31	.7849	1.123	1.227
4	.275	.00762	.07574	9.939	34.42	.7582	1.147	1.202
2	.248	.00783	.05393	6.886	34.40	.7787	1.128	1.038

TABLE 16.- FORCE AND MASS FLOW DATA. NOZZLE 4; MIXING TUBE 4

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.057	0.00361	0.06566	18.19	20.13	0.6864	1.223	0.959
8	.062	.00358	.05785	16.16	20.36	.6901	1.219	1.037
6	.063	.00362	.04907	13.54	20.28	.6955	1.212	1.039
4	.064	.00357	.03869	10.85	20.36	.6890	1.220	1.076
2	.051	.00361	.02713	7.526	20.32	.6980	1.209	.842
p'_c (nominal) = 8 lb/sq in.								
10	.140	.00529	.1026	19.40	26.99	.7135	1.191	1.180
8	.151	.00516	.08972	17.39	27.02	.7127	1.192	1.291
6	.154	.00514	.07664	14.90	26.88	.7076	1.198	1.330
4	.144	.00513	.05929	11.57	27.00	.7098	1.195	1.244
2	.124	.00507	.04112	8.104	26.98	.7023	1.205	1.091
p'_c (nominal) = 12 lb/sq in.								
10	.214	.00658	.1249	18.98	31.06	.7470	1.157	1.211
8	.230	.00649	.1106	17.15	31.33	.7435	1.160	1.312
6	.237	.00656	.09394	14.32	31.21	.7474	1.157	1.340
4	.220	.00645	.07292	11.30	31.29	.7380	1.166	1.270
2	.193	.00651	.05021	7.717	31.25	.7425	1.161	1.102
p'_c (nominal) = 16 lb/sq in.								
10	.281	.00774	.1378	17.80	34.18	.7649	1.140	1.211
8	.301	.00768	.1235	16.08	34.45	.7653	1.140	1.297
6	.308	.00780	.1063	13.63	34.26	.7720	1.134	1.308
4	.288	.00762	.08249	10.83	34.42	.7582	1.147	1.259
2	.251	.00774	.05647	7.299	34.37	.7685	1.137	1.073

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TABLE 17.- FORCE AND MASS FLOW DATA. NOZZLE 5; MIXING TUBE 1

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.010	0.00143	0.01046	7.315	20.10	0.5116	1.631	0.567
8	.010	.00142	.00942	7.063	20.21	.5154	1.622	.537
6	.009	.00143	.01042	7.282	20.22	.5205	1.602	.498
4	.011	.00142	.00978	6.885	20.33	.5192	1.608	.585
2	.010	.00143	.00766	5.359	20.22	.5197	1.605	.540
p'_c (nominal) = 8 lb/sq in.								
10	.030	.00235	.02001	8.515	26.72	.6075	1.373	.656
8	.030	.00344	.01979	8.494	26.80	.6045	1.379	.663
6	.030	.00236	.01990	8.447	26.85	.6122	1.361	.648
4	.031	.00232	.01978	8.541	26.98	.6050	1.378	.684
2	.034	.00238	.01741	7.318	26.87	.6178	1.350	.718
p'_c (nominal) = 12 lb/sq in.								
10	.053	.00309	.02688	8.699	30.97	.658	1.267	.702
8	.054	.00308	.02751	8.932	31.10	.6586	1.266	.714
6	.054	.00305	.02759	9.043	31.14	.6535	1.276	.725
4	.059	.00302	.02717	8.985	31.29	.6509	1.281	.799
2	.062	.00313	.02485	7.942	32.47	.6698	1.246	.760
p'_c (nominal) = 16 lb/sq in.								
10	.078	.00374	.03248	8.684	34.13	.694	1.214	.742
8	.082	.00373	.03251	8.716	35.09	.6935	1.215	.761
6	.083	.00370	.03306	8.930	34.27	.6893	1.220	.798
4	.080	.00368	.03224	8.763	34.40	.6886	1.220	.771
2	.083	.00377	.02821	7.483	34.26	.7022	1.204	.774

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TABLE 18.- FORCE AND MASS FLOW DATA. NOZZLE 5; MIXING TUBE 2

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.009	0.00142	0.01874	13.20	20.24	0.5120	1.631	0.511
8	.010	.00142	.01701	11.98	20.23	.5158	1.619	.564
6	.011	.00144	.01553	10.77	20.12	.5198	1.607	.690
4	.011	.00144	.01335	9.290	20.13	.5204	1.604	.610
2	.011	.00143	.00843	5.908	20.25	.5198	1.607	.584
p'_c (nominal) = 8 lb/sq in.								
10	.037	.00237	.03604	15.21	26.90	.6157	1.354	.786
8	.039	.00236	.03373	14.29	26.85	.6124	1.361	.838
6	.039	.00235	.03003	12.78	26.71	.6064	1.374	.854
4	.038	.00235	.02495	10.64	26.75	.6066	1.374	.832
2	.036	.00236	.01984	8.393	26.89	.6149	1.356	.773
p'_c (nominal) = 12 lb/sq in.								
10	.069	.00310	.05108	16.47	31.17	.664	1.255	.896
8	.070	.00309	.04667	15.10	31.10	.6607	1.262	.913
6	.070	.00307	.04048	13.17	30.98	.6542	1.274	.937
4	.068	.00307	.03393	11.05	30.96	.6541	1.274	.911
2	.064	.00309	.02653	8.594	31.18	.6613	1.260	.838
p'_c (nominal) = 16 lb/sq in.								
10	.104	.00374	.06157	16.51	34.30	.698	1.209	.980
8	.105	.00373	.05489	14.72	34.21	.6938	1.214	.999
6	.101	.00374	.04885	13.06	34.08	.6933	1.215	.962
4	.097	.00373	.04157	11.14	34.07	.6906	1.218	.930
2	.091	.00374	.03102	8.294	34.30	.6968	1.210	.858

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TABLE 19.- FORCE AND MASS FLOW DATA. NOZZLE 5; MIXING TUBE 3

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.010	0.00141	0.02297	16.29	20.26	0.5135	1.626	0.569
8	.011	.00142	.02085	14.68	20.23	.5164	1.616	.619
6	.012	.00143	.01803	12.57	20.19	.5202	1.605	.665
4	.010	.00143	.01543	10.77	20.18	.5203	1.605	.558
2	.010	.00144	.00934	6.480	20.22	.5241	1.593	.547
p'_c (nominal) = 8 lb/sq in.								
10	.039	.00236	.04522	19.16	26.90	.6136	1.359	.774
8	.039	.00233	.04120	17.68	26.88	.6059	1.375	.856
6	.040	.00237	.03569	15.08	26.81	.6125	1.361	.858
4	.038	.00234	.02912	12.50	26.78	.6054	1.377	.836
2	.037	.00236	.02189	9.291	26.83	.6115	1.363	.798
p'_c (nominal) = 12 lb/sq in.								
10	.074	.00309	.06269	20.29	31.20	.663	1.257	.965
8	.073	.00309	.05703	18.46	31.17	.6618	1.259	.954
6	.075	.00307	.05018	16.37	31.05	.6535	1.277	1.006
4	.069	.00306	.03970	12.96	31.04	.6535	1.277	.927
2	.069	.00312	.02908	9.323	32.03	.6668	1.250	.863
p'_c (nominal) = 16 lb/sq in.								
10	.104	.00373	.07768	20.83	34.31	.696	1.211	.923
8	.105	.00369	.06931	18.78	34.29	.6879	1.221	.984
6	.108	.00372	.05944	15.98	34.12	.6899	1.219	1.037
4	.101	.00369	.04779	12.96	34.13	.6847	1.225	.989
2	.096	.00378	.03373	8.923	34.21	.7031	1.203	.893

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TABLE 20.- FORCE AND MASS FLOW DATA. NOZZLE 5; MIXING TUBE 4

L/D	F (lb)	W_1 $\left(\frac{lb}{sec}\right)$	W_2 $\left(\frac{lb}{sec}\right)$	W_2/W_1	$(F/W_1)_i$ $\left(\frac{lb}{lb/sec}\right)$	C_d	k	AR
p'_c (nominal) = 4 lb/sq in.								
10	0.009	0.00141	0.02421	17.17	20.30	0.5077	1.645	0.517
8	.009	.00143	.02230	15.59	20.31	.5195	1.607	.470
6	.011	.00143	.01958	13.67	20.18	.5190	1.608	.612
4	.011	.00143	.01629	11.38	20.18	.5199	1.606	.584
2	.0118	.00144	.01032	7.179	20.29	.5233	1.595	.601
p'_c (nominal) = 8 lb/sq in.								
10	.038	.00236	.04844	20.53	26.91	.6139	1.358	.813
8	.036	.00232	.04460	19.22	26.91	.6033	1.382	.811
6	.041	.00234	.03927	16.82	26.79	.6046	1.378	.903
4	.039	.00233	.03122	13.39	26.81	.6047	1.378	.859
2	.037	.00236	.02190	9.268	26.94	.6149	1.356	.788
p'_c (nominal) = 12 lb/sq in.								
10	.067	.00309	.06591	21.33	31.23	.663	1.257	.873
8	.077	.00308	.06343	20.59	31.18	.6604	1.262	1.012
6	.078	.00305	.05493	17.99	31.08	.6522	1.279	1.051
4	.071	.00305	.04222	13.83	31.09	.6529	1.277	.968
2	.067	.00308	.03031	9.828	31.22	.6617	1.260	.877
p'_c (nominal) = 16 lb/sq in.								
10	.102	.00367	.08400	22.89	34.33	.685	1.225	.992
8	.105	.00372	.07595	20.42	34.31	.6934	1.215	.999
6	.109	.00370	.06539	17.65	34.20	.6887	1.220	1.050
4	.103	.00368	.05153	14.02	34.21	.6838	1.227	1.005
2	.096	.00374	.03538	9.467	34.34	.6976	1.209	.905

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TABLE 21.- DISCHARGE SURVEY DATA. MIXING TUBE 1

[$L/D = 10$; $r_{max} = 0.5625$ in.]

Nozzle	Pressure (lb/sq in.)	0	0.1	0.2	0.3	0.4	0.45	0.5	0.55
		p'/p'_c							
1	4	0.08760	0.08900	0.08960	0.09176	0.09168	0.08916	0.08088	0.05996
	8	.08056	.08150	.08324	.08542	.08622	.08428	.07740	.05792
	12	.07611	.07698	.07851	.07935	.08178	.08031	.07409	.05572
	16	.07386	.07495	.07609	.07844	.07971	.07868	.07276	.05507
2	4	.03709	.03749	.03816	.03920	.03908	.03777	.03383	.02499
	8	.03591	.03627	.03701	.03822	.03844	.03743	.03397	.02520
	12	.03425	.03460	.03534	.03655	.03678	.03605	.03285	.02456
	16	.03842	.03370	.03476	.03607	.03654	.03585	.03286	.02460
3	4	.01563	.01559	.01595	.01627	.01595	.01535	.01351	.00998
	8	.01600	.01620	.01636	.01676	.01654	.01596	.01426	.01054
	12	.01528	.01539	.01567	.01600	.01591	.01545	.01393	.01026
	16	.01548	.01565	.01584	.01618	.01613	.01566	.01417	.01048
4	4	.00648	.00676	.00660	.00672	.00648	.00608	.00532	.00376
	8	.00760	.00766	.00766	.00786	.00758	.00724	.00638	.00466
	12	.00770	.00782	.00786	.00797	.00780	.00750	.00661	.00489
	16	.00748	.00760	.00767	.00784	.00774	.00749	.00665	.00492
5	4	.00120	.00124	.00132	.00132	.00128	.00116	.00112	.00072
	8	.00196	.00200	.00206	.00216	.00220	.00212	.00192	.00136
	12	.00240	.00241	.00247	.00257	.00257	.00245	.00219	.00160
	16	.00243	.00247	.00261	.00275	.00284	.00274	.00250	.00185

TABLE 22.- DISCHARGE SURVEY DATA. MIXING TUBE 1

[$L/D = 8$; $r_{max} = 0.5625$ in.]

Radius (in.)		0	0.1	0.2	0.3	0.4	0.45	0.5	0.55
Nozzle	Pressure (lb/sq in.)	p'/p'_c							
1	4	0.07800	0.08028	0.08408	0.08996	0.09508	0.09512	0.09008	0.06828
	8	.07260	.07450	.07874	.08480	.09030	.09132	.08706	.06664
	12	.06741	.06966	.07450	.08088	.08668	.08770	.08391	.06386
	16	.06374	.06567	.07018	.07636	.08248	.08393	.08062	.06211
2	4	.03248	.03348	.03576	.03844	.04072	.04076	.03800	.02816
	8	.03192	.03284	.03514	.03794	.04044	.04072	.03828	.02886
	12	.03077	.03177	.03415	.03712	.03973	.04020	.03811	.02904
	16	.02910	.03007	.03257	.03552	.03818	.03870	.03685	.02814
3	4	.01457	.01522	.01594	.01706	.01790	.01766	.01618	.01189
	8	.01441	.01493	.01590	.01716	.01826	.01826	.01690	.01255
	12	.01379	.01423	.01517	.01641	.01748	.01756	.01641	.01217
	16	.01362	.01411	.01506	.01635	.01752	.01767	.01652	.01241
4	4	.00585	.00605	.00637	.00669	.00697	.00685	.00617	.00461
	8	.00692	.00712	.00734	.00770	.00770	.00756	.00694	.00516
	12	.00710	.00724	.00755	.00794	.00820	.00807	.00738	.00544
	16	.00676	.00697	.00725	.00770	.00404	.00800	.00734	.00543
5	4	.00120	.00120	.00124	.00124	.00132	.00132	.00132	.00076
	8	.00172	.00182	.00198	.00218	.00232	.00236	.00216	.00158
	12	.00221	.00231	.00247	.00269	.00291	.00288	.00268	.00203
	16	.00226	.00236	.00255	.00279	.00299	.00297	.00275	.00202

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TABLE 23.- DISCHARGE SURVEY DATA. MIXING TUBE 1

[L/D = 6; r_{max} = 0.5625 in.]

Radius (in.)		0	0.1	0.2	0.3	0.4	0.45	0.5	0.55
Nozzle	Pressure (lb/sq in.)	p'/p'_c							
1	4	0.05600	0.06176	0.07400	0.08840	0.10312	0.10936	0.10736	0.08488
	8	.05072	.05624	.06868	.08372	.09912	.10588	.10508	.08400
	12	.04693	.05216	.06419	.07843	.09336	.10021	.09987	.06699
	16	.04260	.04740	.05918	.07316	.08834	.09532	.09586	.07730
2	4	.02341	.02581	.03162	.03864	.04589	.04862	.04709	.03667
	8	.02216	.02468	.03046	.03754	.04472	.04768	.04668	.03660
	12	.02097	.02337	.02905	.03595	.04304	.04610	.04543	.03587
	16	.01986	.02231	.02819	.03528	.04255	.04566	.04512	.03570
3	4	.01080	.01176	.01380	.01636	.01908	.02008	.01936	.01468
	8	.00997	.00896	.01314	.01600	.01901	.02017	.01959	.01504
	12	.00953	.01049	.01275	.01577	.01889	.02015	.01979	.01530
	16	.00936	.01034	.01267	.01562	.01870	.01999	.01969	.01530
4	4	.00432	.00480	.00560	.00648	.00728	.00752	.00672	.00512
	8	.00536	.00568	.00656	.00756	.00856	.00880	.00844	.00648
	12	.00520	.00557	.00637	.00741	.00846	.00881	.00838	.00646
	16	.00500	.00532	.00616	.00724	.00830	.00872	.00834	.00644
5	4	.00080	.00088	.00104	.00124	.00144	.00144	.00140	.00088
	8	.00144	.00154	.00184	.00218	.00264	.00280	.00274	.00208
	12	.00179	.00192	.00223	.00261	.00311	.00327	.00317	.00240
	16	.00168	.00184	.00225	.00279	.00342	.00369	.00366	.00281

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TABLE 24.- DISCHARGE SURVEY DATA. MIXING TUBE 1

[L/D = 4; r_{max} = 0.5625 in.]

Radius (in.)		0	0.1	0.2	0.3	0.4	0.45	0.5	0.55
Nozzle	Pressure (lb/sq in.)	p'/p'_c							
1	4	0.01554	0.02322	0.04460	0.07127	0.11099	0.12869	0.13894	0.11275
	8	.01248	.01976	.04012	.07092	.10672	.12468	.13644	.11148
	12	.01024	.01712	.03691	.06699	.10224	.12027	.13245	.10901
	16	.00812	.01454	.03378	.06340	.09836	.11572	.13213	.11037
2	4	.00592	.00920	.01764	.03088	.04696	.05504	.05968	.04864
	8	.00489	.00767	.01610	.02896	.04517	.05334	.05869	.04863
	12	.00440	.00702	.01487	.02737	.04317	.05138	.05689	.04764
	16	.00398	.00650	.01421	.02648	.04223	.05052	.05634	.04748
3	4	.00368	.00496	.00856	.01392	.01988	.02268	.02380	.01836
	8	.00304	.00426	.00768	.01323	.01973	.02279	.02443	.01929
	12	.00232	.00343	.00669	.01221	.01903	.02233	.02432	.01945
	16	.00226	.00339	.00667	.01225	.01918	.02258	.02460	.01977
4	4	.00144	.00200	.00321	.00533	.00806	.01327	.00978	.00741
	8	.00204	.00270	.00432	.00652	.00918	.01036	.01078	.00846
	12	.00189	.00255	.00409	.00647	.00921	.01057	.01119	.00881
	16	.00154	.00206	.00359	.00600	.00897	.01044	.01126	.00905
5	4	.00020	.00024	.00040	.00072	.00124	.00164	.00204	.00160
	8	.00072	.00098	.00138	.00200	.00274	.00316	.00332	.00256
	12	.00096	.00121	.00172	.00247	.00328	.00368	.00388	.00305
	16	.00085	.00112	.00177	.00262	.00366	.00421	.00454	.00361

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TABLE 25.- DISCHARGE SURVEY DATA. MIXING TUBE 2

[L/D = 10; r_{max} = 0.916 in.]

Radius (in.)		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.85	0.90
Nozzle	Pressure (lb/sq in.)	p'/p'_c										
1	4	0.00915	0.00975	0.01192	0.01565	0.02195	0.03045	0.04096	0.05151	0.05625	0.05083	0.03723
	8	.00634	.00680	.00887	.01218	.01784	.02551	.03446	.04488	.05006	.04371	.03426
	12	.00600	.00637	.00776	.01068	.01581	.02331	.03257	.04259	.04887	.04483	.03404
	16	.00482	.00522	.00671	.00954	.01445	.02159	.03026	.04004	.04672	.04286	.03300
2	4	.00352	.00388	.00508	.00720	.01012	.01380	.01812	.02244	.02344	.02044	.01480
	8	.00264	.00306	.00438	.00658	.00968	.01362	.01820	.02298	.02478	.02202	.01608
	12	.00253	.00292	.00402	.00593	.00866	.01213	.01636	.02077	.02278	.02049	.01513
	16	.00200	.00234	.00345	.00533	.00803	.01157	.01553	.02000	.02225	.01984	.01495
3	4	.00186	.00222	.00279	.00380	.00497	.00654	.00824	.00990	.00966	.00824	.00574
	8	.00184	.00204	.00262	.00358	.00482	.00644	.00824	.01000	.01020	.00890	.00636
	12	.00136	.00155	.00204	.00292	.00412	.00572	.00755	.00937	.01002	.00903	.00641
	16	.00140	.00162	.00211	.00300	.00421	.00584	.00770	.00952	.01023	.00929	.00663
4	4	.00072	.00112	.00116	.00164	.00212	.00272	.00348	.00404	.00380	.00320	.00220
	8	.00136	.00158	.00184	.00230	.00278	.00350	.00422	.00472	.00434	.00360	.00260
	12	.00125	.00139	.00160	.00199	.00252	.00321	.00404	.00473	.00465	.00409	.00288
	16	.00100	.00114	.00139	.00182	.00135	.00305	.00389	.00466	.00469	.00410	.00292
5	4	.00024	.00032	.00032	.00044	.00044	.00052	.00064	.00072	.00076	.00076	.00044
	8	.00052	.00056	.00064	.00074	.00092	.00106	.00116	.00140	.00130	.00118	.00084
	12	.00064	.00068	.00077	.00092	.00112	.00135	.00159	.00176	.00167	.00147	.00108
	16	.00058	.00061	.00067	.00080	.00096	.00116	.00136	.00146	.00127	.00108	.00074

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TABLE 26.– DISCHARGE SURVEY DATA. MIXING TUBE 2

[L/D = 8; r_{max} = 0.837 in.]

Radius (in.)		0	0.1	0.2	0.3	0.4	0.5	0.6	0.65	0.7	0.75	0.80
Nozzle	Pressure (lb/sq in.)	p'/p'_c										
1	4	0.00490	0.00647	0.01114	0.01873	0.02935	0.04281	0.05801	0.06545	0.07160	0.07220	0.06199
	8	.00308	.00434	.00829	.01461	.02344	.03560	.04957	.05660	.06274	.06464	.05700
	12	.00346	.00452	.00763	.01296	.02113	.03250	.04623	.05339	.06011	.06267	.05616
	16	.00352	.00441	.00749	.01265	.02051	.03150	.04499	.05184	.05828	.06111	.05491
2	4	.00153	.00229	.00434	.00776	.01250	.01865	.02541	.02866	.03128	.03120	.02633
	8	.00168	.00230	.00404	.00720	.01168	.01754	.02416	.02738	.02992	.03020	.02604
	12	.00141	.00197	.00367	.00664	.01088	.01645	.02279	.02560	.02864	.02924	.02555
	16	.00110	.00156	.00301	.00580	.01010	.01576	.02232	.02754	.02837	.02915	.02566
3	4	.00136	.00188	.00280	.00444	.00640	.00892	.01156	.01272	.01328	.01252	.01024
	8	.00120	.00158	.00253	.00405	.00621	.00877	.01178	.01312	.01406	.01374	.01152
	12	.00104	.00132	.00221	.00369	.00580	.00841	.01143	.01284	.01396	.01384	.01177
	16	.00076	.00099	.00182	.00317	.00514	.00768	.01062	.01204	.01324	.01336	.01148
4	4	.00064	.00092	.00148	.00200	.00284	.00368	.00476	.00488	.00512	.00468	.00384
	8	.00084	.00114	.00156	.00222	.00308	.00416	.00526	.00574	.00594	.00514	.00456
	12	.00093	.00107	.00157	.00231	.00332	.00453	.00584	.00643	.00676	.00640	.00525
	16	.00050	.00067	.00107	.00180	.00277	.00401	.00536	.00595	.00639	.00622	.00523
5	4	.00024	.00024	.00036	.00040	.00056	.00068	.00088	.00100	.00112	.00112	.00088
	8	.00040	.00050	.00060	.00074	.00098	.00126	.00158	.00174	.00182	.00180	.00144
	12	.00053	.00063	.00079	.00103	.00133	.00163	.00203	.00215	.00221	.00211	.00176
	16	.00040	.00042	.00056	.00080	.00111	.00148	.00189	.00207	.00219	.00213	.00179

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TABLE 27.- DISCHARGE SURVEY DATA. MIXING TUBE 2

[L/D = 6; r_{max} = 0.759 in.]

Radius (in.)		0	0.1	0.2	0.3	0.4	0.5	0.6	0.65	0.7	0.75
Nozzle	Pressure (lb/sq in.)	p'/p'_c									
1	4	0.00080	0.00192	0.00665	0.01626	0.03339	0.05726	0.08312	0.09329	0.09481	0.06759
	8	.00144	.00280	.00788	.01816	.03412	.05520	.07828	.08764	.09032	.06632
	12	.00149	.00302	.00742	.01684	.03130	.05030	.07199	.08128	.08512	.06404
	16	.00072	.00194	.00640	.01550	.02984	.04864	.06986	.07936	.08364	.06318
2	4	.00080	.00144	.00373	.00874	.01675	.02729	.03828	.04248	.04261	.03002
	8	.00040	.00108	.00340	.00822	.01608	.02626	.03728	.04168	.04248	.03062
	12	.00027	.00080	.00284	.00733	.01484	.02470	.03468	.03971	.04085	.02989
	16	.00020	.00070	.00269	.00722	.01484	.02496	.03577	.04222	.04130	.03012
3	4	.00072	.00112	.00240	.00460	.00773	.01165	.01546	.01674	.01602	.01113
	8	.00024	.00058	.00162	.00374	.00710	.01039	.01601	.01781	.01769	.01245
	12	.00011	.00036	.00123	.00315	.00636	.01061	.01525	.01725	.01758	.01259
	16	.00018	.00038	.00125	.00315	.00630	.01058	.01526	.01723	.01757	.01264
4	4	.00032	.00048	.00088	.00192	.00336	.00464	.00625	.00665	.00601	.00392
	8	.00024	.00042	.00096	.00196	.00341	.00502	.00682	.00722	.00682	.00461
	12	.00043	.00060	.00115	.00220	.00375	.00557	.00740	.00792	.00755	.00521
	16	.00020	.00038	.00078	.00164	.00304	.00480	.00670	.00740	.00730	.00510
5	4	.00016	.00020	.00028	.00048	.00060	.00084	.00120	.00124	.00124	.00068
	8	.00032	.00044	.00058	.00084	.00120	.00164	.00202	.00210	.00200	.00138
	12	.00040	.00055	.00075	.00116	.00165	.00221	.00271	.00298	.00284	.00191
	16	.00030	.00042	.00065	.00106	.00156	.00220	.00297	.00325	.00321	.00223

TABLE 28.- DISCHARGE SURVEY DATA. MIXING TUBE 2

[L/D = 4; r_{max} = 0.6805 in.]

Radius (in.)		0	0.1	0.2	0.3	0.4	0.45	0.5	0.55	0.6	0.65
Nozzle	Pressure (lb/sq in.)	p'/p'_c									
1	4	0.00016	0.00048	0.00424	0.01770	0.03763	0.05606	0.08360	0.10434	0.12388	0.12276
	8	-.00008	.00020	.00324	.01580	.04344	.06220	.08228	.10268	.12320	.12384
	12	-.00011	.00013	.00301	.01581	.04000	.05752	.07627	.09595	.11629	.11912
	16	.00000	.00024	.00280	.01354	.03794	.05482	.07334	.09266	.11650	.11913
2	4	.00008	.00012	.00120	.00572	.01620	.02400	.03292	.04236	.05124	.05136
	8	-.00028	-.00024	.00084	.00550	.01872	.02476	.03574	.04316	.05260	.05332
	12	-.00016	-.00006	.00101	.00563	.01659	.02443	.03317	.04245	.05164	.05306
	16	.00000	.00008	.00101	.00523	.01566	.02337	.03197	.04139	.05084	.05276
3	4	.00000	.00016	.00100	.00353	.00914	.01218	.01599	.01940	.02236	.02088
	8	.00000	.00010	.00074	.00312	.00846	.01210	.01608	.01982	.02324	.02222
	12	.00000	.00001	.00041	.00245	.00756	.01128	.01535	.01944	.02323	.02277
	16	.00000	.00005	.00045	.00258	.00767	.01145	.01565	.01977	.02371	.02322
4	4	.00000	.00020	.00036	.00140	.00328	.00460	.00616	.00748	.00868	.00800
	8	.00000	.00008	.00056	.00182	.00414	.00566	.00720	.00866	.00988	.00922
	12	.00005	.00012	.00056	.00177	.00416	.00577	.00744	.00912	.01060	.01012
	16	-.00006	.00001	.00030	.00142	.00376	.00540	.00716	.00894	.01058	.01029
5	4	.00008	.00008	.00016	.00028	.00052	.00072	.00096	.00128	.00172	.00184
	8	.00008	.00020	.00050	.00092	.00146	.00174	.00202	.00236	.00266	.00248
	12	.00013	.00028	.00063	.00112	.00171	.00201	.00236	.00271	.00308	.00289
	16	.00005	.00015	.00049	.00117	.00215	.00269	.00328	.00389	.00445	.00424

TABLE 29.- DISCHARGE SURVEY DATA. MIXING TUBE 3

[L/D = 10; r_{max} = 1.179 in.]

Radius (in.)		0	0.2	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.15
Nozzle	Pressure (lb/sq in.)	p'/p'_c										
1	4	0.00048	0.00112	0.00328	0.00572	0.00972	0.01544	0.02368	0.03328	0.04292	0.04336	0.03564
	8	.00060	.00110	.00286	.00486	.00814	.01298	.01960	.02772	.03610	.03770	.03172
	12	.00051	.00085	.00217	.00376	.00635	.01027	.01593	.02321	.03112	.03393	.02900
	16	-.00220	-.00196	-.00061	.00099	.00379	.00791	.01370	.02075	.02817	.03156	.02752
2	4	.00016	.00048	.00136	.00248	.00412	.00648	.01016	.01372	.01740	.01724	.01408
	8	.00000	.00018	.00092	.00188	.00348	.00580	.00902	.01298	.01714	.01770	.01466
	12	-.00008	.00007	.00076	.00164	.00308	.00519	.00812	.01179	.01547	.01649	.01381
	16	.00000	.00009	.00063	.00131	.00264	.00461	.00743	.01104	.01509	.01643	.01390
3	4	.00024	.00048	.00168	.00176	.00240	.00356	.00500	.00652	.00756	.00660	.00516
	8	.00020	.00030	.00068	.00110	.00184	.00281	.00413	.00571	.00724	.00706	.00567
	12	.00000	.00012	.00048	.00089	.00152	.00248	.00380	.00542	.00694	.00704	.00578
	16	.00000	.00010	.00043	.00085	.00153	.00254	.00391	.00553	.00718	.00732	.00606
4	4	.00000	.00008	.00028	.00048	.00082	.00116	.00168	.00228	.00280	.00240	.00188
	8	.00032	.00044	.00074	.00108	.00142	.00186	.00244	.00298	.00332	.00280	.00226
	12	.00013	.00023	.00052	.00084	.00120	.00171	.00235	.00307	.00358	.00320	.00255
	16	.00012	.00018	.00047	.00072	.00112	.00161	.00224	.00299	.00361	.00333	.00270
5	4	.00012	.00016	.00016	.00024	.00024	.00032	.00032	.00032	.00032	.00032	.00028
	8	.00014	.00016	.00026	.00034	.00044	.00058	.00072	.00080	.00084	.00072	.00056
	12	.00047	.00052	.00068	.00077	.00091	.00105	.00116	.00123	.00120	.00104	.00089
	16	.00014	.00020	.00035	.00048	.00064	.00082	.00103	.00122	.00131	.00117	.00098

TABLE 30.– DISCHARGE SURVEY DATA. MIXING TUBE 3

[$L/D = 8$; $r_{max} = 1.042$ in.]

Radius (in.)		0	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	1.0
Nozzle	Pressure (lb/sq in.)	p'/p'_c										
1	4	–0.00064	–0.00008	0.00088	0.00312	0.00780	0.01544	0.02676	0.04084	0.05528	0.05784	0.05260
	8	–.00028	.00002	.00058	.00222	.00580	.01254	.02276	.03642	.05078	.05440	.05080
	12	–.00018	.00003	.00039	.00163	.00477	.01100	.02074	.03386	.04799	.05222	.04934
	16	–.00010	–.00001	.00028	.00122	.00398	.00955	.01875	.03141	.04517	.05023	.04824
2	4	–.00016	–.00012	.00040	.00132	.00337	.00678	.01180	.01813	.02419	.02544	.02283
	8	–.00024	–.00006	.00032	.00124	.00326	.00665	.01146	.01759	.02383	.02520	.02301
	12	–.00003	.00013	.00053	.00132	.00319	.00632	.01097	.01692	.02297	.02459	.02273
	16	–.00002	.00011	.00035	.00105	.00264	.00569	.01019	.01612	.02229	.02401	.02239
3	4	.00000	.00012	.00040	.00120	.00237	.00402	.00622	.00920	.01088	.01076	.00931
	8	.00000	.00010	.00032	.00090	.00196	.00370	.00610	.00900	.01168	.01198	.01058
	12	.00000	.00007	.00021	.00063	.00151	.00304	.00517	.00789	.01073	.01131	.01031
	16	.00004	.00010	.00025	.00067	.00151	.00304	.00519	.00797	.01080	.01147	.01051
4	4	.00000	.00012	.00036	.00064	.00116	.00184	.00272	.00384	.00436	.00416	.00340
	8	.00004	.00018	.00034	.00062	.00110	.00182	.00276	.00382	.00466	.00452	.00382
	12	.00000	.00003	.00019	.00045	.00095	.00172	.00279	.00396	.00504	.00506	.00432
	16	.00008	.00014	.00028	.00057	.00103	.00176	.00274	.00401	.00515	.00530	.00464
5	4	.00024	.00024	.00020	.00020	.00024	.00032	.00044	.00060	.00080	.00084	.00076
	8	.00008	.00014	.00022	.00030	.00040	.00054	.00076	.00094	.00110	.00102	.00084
	12	.00019	.00029	.00040	.00051	.00072	.00089	.00117	.00140	.00153	.00149	.00127
	16	.00016	.00025	.00033	.00051	.00075	.00102	.00142	.00187	.00444	.00458	.00408

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TABLE 31.– DISCHARGE SURVEY DATA. MIXING TUBE 3

[$L/D = 6$; $r_{max} = 0.904$ in.]

Radius (in.)		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.85	0.9
Nozzle	Pressure (lb/sq in.)	p'/p'_c										
1	4	−0.00016	−0.00016	−0.00008	0.00032	0.00432	0.01392	0.03196	0.05640	0.08240	0.08480	0.06128
	8	−.00024	−.00024	.00008	.00056	.00340	.01224	.02876	.03188	.07740	.08152	.05992
	12	−.00011	−.00005	.00029	.00163	.00568	.01405	.02781	.04669	.06859	.07344	.05587
	16	−.00012	−.00012	.00014	.00118	.00452	.01184	.02440	.04212	.06258	.06862	.05346
2	4	.00000	.00000	.00012	.00076	.00276	.00776	.01574	.02635	.03748	.03796	.02711
	8	.00000	.00000	.00014	.00064	.00272	.00742	.01534	.02586	.03712	.03778	.02790
	12	−.00005	−.00005	.00005	.00049	.00235	.00681	.01412	.02395	.03493	.03576	.02705
	16	−.00010	−.00010	−.00003	.00040	.00212	.00636	.01352	.02326	.03418	.03595	.02688
3	4	.00000	.00000	.00004	.00048	.00161	.00381	.00718	.01135	.01541	.01545	.01035
	8	.00008	.00008	.00016	.00058	.00172	.00410	.00762	.01240	.01684	.01672	.01164
	12	.00021	.00021	.00023	.00048	.00127	.00332	.00675	.01132	.01616	.01648	.01191
	16	−.00010	−.00010	−.00006	.00015	.00092	.00283	.00611	.01055	.01547	.01584	.01150
4	4	.00000	.00000	.00000	.00020	.00056	.00136	.00272	.00432	.00580	.00536	.00352
	8	.00008	.00008	.00016	.00036	.00084	.00180	.00312	.00496	.00637	.00581	.00406
	12	.00005	.00007	.00011	.00027	.00081	.00175	.00327	.00516	.00681	.00641	.00459
	16	−.00006	−.00005	.00000	.00011	.00056	.00147	.00299	.00499	.00691	.00672	.00477
5	4	.00000	.00000	.00000	.00000	.00012	.00024	.00048	.00068	.00096	.00096	.00060
	8	.00004	.00010	.00016	.00026	.00050	.00072	.00106	.00146	.00176	.00164	.00110
	12	.00008	.00016	.00028	.00049	.00083	.00124	.00171	.00222	.00255	.00238	.00163
	16	.00002	.00005	.00013	.00035	.00066	.00112	.00170	.00237	.00306	.00299	.00214

TABLE 32.- DISCHARGE SURVEY DATA. MIXING TUBE 3

[$L/D = 4$; $r_{max} = 0.766$ in.]

Radius (in.)		0	0.1	0.2	0.3	0.4	0.5	0.6	0.65	0.7	0.75
Nozzle	Pressure (lb/sq in.)	p'/p'_c									
1	4	0.00000	0.00000	0.00008	0.00208	0.01280	0.03776	0.07660	0.09872	0.11792	0.11112
	8	.00000	.00000	.00012	.00180	.01140	.02540	.07352	.09552	.11640	.11096
	12	.00011	.00013	.00016	.00192	.01093	.03453	.06832	.08928	.10907	.10667
	16	-.00008	-.00008	.00000	.00144	.00978	.03128	.06510	.08522	.10466	.10350
2	4	.00008	.00008	.00008	.00088	.00456	.01452	.03184	.04132	.05020	.04720
	8	.00004	.00004	.00004	.00062	.00408	.01399	.03109	.04090	.05039	.04849
	12	.00000	.00000	.00004	.00060	.00392	.01340	.02992	.03948	.04899	.04797
	16	.00000	.00000	.00003	.00054	.00392	.01351	.02982	.03921	.04853	.04788
3	4	.00000	.00000	.00008	.00040	.00248	.00728	.01484	.01852	.02168	.01904
	8	-.00012	-.00012	-.00006	.00030	.00232	.00737	.01546	.01951	.02281	.02023
	12	-.00005	-.00005	-.00004	.00017	.00169	.00512	.01452	.01870	.02250	.02054
	16	.00000	.00001	.00001	.00017	.00162	.00629	.01437	.01861	.02250	.02060
4	4	.00024	.00024	.00028	.00036	.00124	.00312	.00608	.00740	.00848	.00724
	8	.00004	.00004	.00004	.00036	.00140	.00366	.00685	.00831	.00949	.00823
	12	.00003	.00003	.00005	.00025	.00123	.00343	.00651	.00850	.00991	.00887
	16	.00004	.00004	.00007	.00022	.00108	.00331	.00693	.00876	.01036	.00939
5	4	.00004	.00004	.00004	.00008	.00028	.00048	.00100	.00128	.00168	.00160
	8	.00002	.00006	.00020	.00050	.00092	.00132	.00184	.00204	.00222	.00188
	12	.00003	.00009	.00025	.00068	.00122	.00184	.00250	.00279	.00302	.00256
	16	.00002	.00004	.00015	.00053	.00126	.00225	.00338	.00393	.00432	.00375

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TABLE 33.- DISCHARGE SURVEY DATA. MIXING TUBE 4

[L/D = 10; r_{max} = 1.359 in.]

Radius (in.)		0	0.2	0.4	0.6	0.8	0.9	1.0	1.1	1.2	1.3	1.35
Nozzle	Pressure (lb/sq in.)	p'/p'_c										
1	4	0.00032	0.00064	0.00104	0.00281	0.00842	0.01343	0.02020	0.02818	0.03519	0.03254	0.02417
	8	-.00020	-.00012	.00020	.00120	.00510	.00916	.01468	.02158	.02808	.02772	.02060
	12	-.00048	-.00037	.00017	.00161	.00519	.00859	.01313	.01870	.02400	.02407	.01830
	16	-.00436	-.00446	-.00430	-.00307	.00135	.00557	.01074	.01681	.02294	.02395	.01708
2	4	.00000	.00016	.00028	.00128	.00352	.00564	.00864	.01212	.01512	.01384	.00996
	8	-.00020	-.00016	-.00006	.00066	.00260	.00452	.00714	.01034	.01328	.01272	.00934
	12	-.00008	-.00005	-.00007	.00073	.00274	.00470	.00737	.01071	.01469	.01437	.01021
	16	-.00020	-.00019	-.00008	.00046	.00231	.00409	.00662	.00882	.01290	.01287	.00962
3	4	.00008	.00024	.00052	.00096	.00220	.00324	.00460	.00580	.00652	.00536	.00372
	8	-.00012	.00000	.00016	.00060	.00168	.00256	.00376	.00510	.00612	.00540	.00372
	12	.00005	.00011	.00023	.00064	.00173	.00259	.00387	.00529	.00652	.00592	.00432
	16	-.00002	.00003	.00012	.00048	.00141	.00231	.00348	.00494	.00624	.00591	.00427
4	4	.00024	.00032	.00040	.00060	.00096	.00144	.00192	.00228	.00240	.00184	.00120
	8	.00025	.00033	.00043	.00077	.00133	.00176	.00231	.00270	.00287	.00227	.00158
	12	.00005	.00011	.00023	.00051	.00096	.00139	.00192	.00247	.00279	.00233	.00164
	16	.00010	.00015	.00022	.00034	.00063	.00085	.00109	.00131	.00138	.00108	.00076
5	4	.00000	.00000	.00000	.00000	.00008	.00016	.00024	.00040	.00048	.00044	.00028
	8	.00000	.00004	.00008	.00018	.00036	.00044	.00054	.00054	.00054	.00044	.00028
	12	.00013	.00016	.00023	.00040	.00061	.00072	.00087	.00092	.00088	.00069	.00049
	16	.00010	.00012	.00020	.00036	.00061	.00077	.00094	.00109	.00111	.00091	.00068

TABLE 34.- DISCHARGE SURVEY DATA. MIXING TUBE 4

[L/D = 8; r_{max} = 1.182 in.]

Radius (in.)		0	0.2	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.15
Nozzle	Pressure (lb/sq in.)	p'/p'_c										
1	4	-0.00016	-0.00016	0.00036	0.00128	0.00396	0.00920	0.01820	0.03068	0.04536	0.05296	0.04616
	8	-.00016	-.00016	.00014	.00094	.00282	.00704	.01434	.02532	.03838	.04678	.04186
	12	-.00032	-.00027	-.00007	.00045	.00203	.00554	.01203	.02159	.03349	.04224	.03849
	16	-.00156	-.00156	-.00136	-.00085	.00073	.00432	.00982	.02015	.03137	.03996	.03706
2	4	.00000	.00000	.00044	.00100	.00248	.00492	.00880	.01424	.02044	.02336	.02016
	8	-.00020	-.00012	.00002	.00036	.00146	.00360	.00738	.01272	.01888	.02268	.02002
	12	-.00013	-.00008	.00009	.00043	.00135	.00327	.00673	.01176	.01768	.02167	.01944
	16	-.00004	-.00004	.00012	.00045	.00132	.00313	.00651	.01138	.01718	.02125	.01919
3	4	.00008	.00020	.00052	.00096	.00188	.00312	.00488	.00692	.00928	.00956	.00796
	8	.00000	.00004	.00024	.00056	.00128	.00242	.00423	.00651	.00915	.01026	.00873
	12	.00000	.00000	.00011	.00033	.00087	.00193	.00359	.00593	.00875	.01032	.00903
	16	.00000	.00002	.00012	.00039	.00097	.00208	.00376	.00605	.00871	.01029	.00904
4	4	.00000	.00000	.00020	.00040	.00056	.00104	.00160	.00236	.00296	.00288	.00228
	8	.00008	.00010	.00024	.00048	.00092	.00142	.00216	.00310	.00390	.00384	.00314
	12	-.00005	-.00007	.00005	.00020	.00055	.00107	.00185	.00279	.00383	.00401	.00329
	16	.00000	.00002	.00013	.00028	.00059	.00112	.00190	.00294	.00409	.00452	.00383
5	4	.00000	.00012	.00020	.00020	.00020	.00024	.00048	.00060	.00080	.00096	.00076
	8	.00000	.00006	.00014	.00026	.00034	.00046	.00064	.00082	.00096	.00086	.00074
	12	.00005	.00012	.00025	.00041	.00059	.00077	.00105	.00131	.00149	.00140	.00117
	16	.00006	.00011	.00022	.00036	.00053	.00079	.00112	.00148	.00182	.00188	.00158

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TABLE 35.- DISCHARGE SURVEY DATA. MIXING TUBE 4

[$L/D = 6$; $r_{max} = 1.005$ in.]

Radius (in.)		0	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	1.0
Nozzle	Pressure (lb/sq in.)	p'/p'_c										
1	4	-0.00048	-0.00024	0.00000	0.00144	0.00550	0.01460	0.02959	0.05081	0.07354	0.07625	0.05527
	8	-.00024	-.00024	.00000	.00104	.00452	.01235	.02561	.04484	.06685	.07105	.05319
	12	.00005	.00008	.00035	.00144	.00470	.01166	.02362	.04120	.06167	.06764	.04958
	16	.00000	-.00002	.00010	.00082	.00352	.00950	.02040	.03782	.05796	.06298	.04850
2	4	.00008	.00008	.00008	.00036	.00200	.00581	.01249	.02254	.03339	.03423	.02466
	8	-.00012	-.00012	-.00010	.00026	.00174	.00568	.01254	.02246	.03332	.03464	.02556
	12	-.00003	-.00003	.00005	.00041	.00187	.00543	.01173	.02099	.03146	.03303	.02470
	16	-.00024	-.00025	-.00025	.00010	.00137	.00476	.01084	.01989	.03033	.03224	.02435
3	4	-.00024	-.00020	-.00016	.00004	.00100	.00285	.00606	.01048	.01454	.01414	.00960
	8	-.00016	-.00016	-.00012	.00004	.00078	.00247	.00543	.00980	.01431	.01459	.01032
	12	.00000	.00003	.00003	.00016	.00073	.00235	.00536	.00980	.01459	.01591	.01094
	16	.00000	.00000	.00000	.00009	.00067	.00229	.00531	.00987	.01478	.01544	.01120
4	4	.00008	.00012	.00016	.00024	.00056	.00141	.00261	.00410	.00546	.00498	.00321
	8	.00008	.00008	.00008	.00028	.00076	.00162	.00292	.00468	.00612	.00584	.00394
	12	.00003	.00003	.00005	.00019	.00060	.00144	.00289	.00483	.00658	.00640	.00441
	16	-.00008	-.00007	-.00004	.00004	.00040	.00122	.00258	.00451	.00640	.00640	.00446
5	4	.00000	.00000	.00000	.00000	.00000	.00024	.00048	.00072	.00100	.00108	.00068
	8	.00004	.00010	.00020	.00034	.00044	.00074	.00104	.00136	.00150	.00144	.00094
	12	.00003	.00011	.00025	.00048	.00079	.00111	.00145	.00181	.00197	.00187	.00123
	16	.00000	.00001	.00014	.00035	.00069	.00114	.00171	.00234	.00288	.00283	.00196

TABLE 36.- DISCHARGE SURVEY DATA. MIXING TUBE 4

[$L/D = 4$; $r_{max} = 0.828$ in.]

Radius (in.)		0	0.1	0.2	0.3	0.4	0.5	0.6	0.65	0.7	0.75	0.8
Nozzle	Pressure (lb/sq in.)	p'/p'_c										
1	4	−0.00032	−0.00032	−0.00032	−0.00000	0.00344	0.01752	0.04784	0.06784	0.09136	0.11440	0.11624
	8	−.00008	−.00008	−.00008	.00008	.00320	.01594	.04399	.06285	.08521	.10824	.11249
	12	−.00027	−.00029	−.00029	−.00005	.00293	.01515	.04189	.05976	.08075	.11608	.10845
	16	.00020	.00020	.00020	.00034	.00306	.01478	.04078	.05814	.07850	.10022	.10634
2	4	.00000	.00000	.00000	.00000	.00096	.00586	.01813	.02684	.03707	.04722	.04863
	8	.00016	.00016	.00016	.00022	.00126	.00639	.01874	.02747	.03782	.04825	.05093
	12	−.00008	−.00008	−.00008	.00000	.00112	.00605	.01756	.02563	.03526	.04525	.04820
	16	−.00014	−.00017	−.00012	−.00007	.00081	.00509	.01586	.02311	.03337	.04370	.04728
3	4	.00016	.00016	.00016	.00016	.00104	.00389	.00998	.01371	.01772	.02096	.01968
	8	.00000	.00000	.00000	.00000	.00050	.00292	.00878	.01248	.01682	.02076	.02036
	12	.00003	.00003	.00003	.00003	.00036	.00255	.00836	.01223	.01683	.02113	.02133
	16	.00000	.00000	.00000	.00000	.00033	.00246	.00810	.01199	.01654	.02080	.02112
4	4	.00000	.00000	.00000	.00004	.00040	.00145	.00378	.00522	.00683	.00803	.00747
	8	.00000	.00000	.00000	.00002	.00044	.00180	.00458	.00619	.00795	.00937	.00873
	12	.00003	.00003	.00003	.00004	.00044	.00179	.00453	.00624	.00820	.00977	.00945
	16	.00000	.00000	.00000	.00002	.00029	.00142	.00420	.00596	.00803	.00991	.00983
5	4	.00000	.00000	.00000	.00004	.00016	.00032	.00048	.00080	.00120	.00152	.00164
	8	.00000	.00000	.00004	.00026	.00062	.00100	.00142	.00164	.00188	.00202	.00184
	12	.00007	.00007	.00013	.00035	.00072	.00109	.00152	.00175	.00203	.00223	.00204
	16	.00002	.00002	.00007	.00030	.00081	.00153	.00228	.00264	.00307	.00342	.00326

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TABLE 37.- DISCHARGE SURVEY DATA. NOZZLE 3

[$L/D = 2$; $p'_c = 12$ lb/sq in.]

r (in.) \ Mixing tube	1	2	3	4
	p'/p'_c			
0.00	0.00000	0.00000	0.00003	0.00000
.10	.00000	.00000	.00003	.00000
.20	.00000	.00000	.00003	.00000
.30	.00168	.00020	.00004	.00003
.40	.01323	.00607	.00224	.00075
.45	.02367	-------	.00783	.00395
.50	.03452	.02690	.01773	.01129
.55	.03279	.03916	.03023	.02236
.60	-------	.02753	.04131	.03533
.65	-------	-------	-------	.03169
r_{max}(in.)	.563	.602	.628	.656

TABLE 38.- PRIMARY AND SECONDARY NOZZLE PRESSURE RATIOS

[p'_c = 4 lb/sq in. (approx.)]

Mixing tube	1		2		3		4	
Nozzle \ Pressure ratios	p_t/p_a	p_a/p_c	p_t/p_a	p_a/p_c	p_t/p_a	p_a/p_c	p_t/p_a	p_a/p_c
L/D = 10								
1	0.9870	0.7874	0.9376	0.7867	0.8896	0.7871	0.8656	0.7868
2	.9933	.7871	.9725	.7862	.9543	.7862	.9429	.7861
3	.9968	.7865	.9875	.7852	.9798	.7868	.9740	.7868
4	.9986	.7868	.9951	.7868	.9919	.7868	.9900	.7870
5	.99973	.7874	.99919	.7869	.99878	.7869	.99864	.7862
L/D = 8								
1	.9870	.7868	.9515	.7859	.9182	.7868	.8960	.7868
2	.9930	.7866	.9786	.7858	.9650	.7862	.9577	.7867
3	.9967	.7864	.9899	.7866	.9843	.7858	.9805	.7865
4	.9986	.7868	.9959	.7872	.9938	.7865	.9921	.7865
5	.99977	.7870	.99934	.7871	.99899	.7873	.99885	.7863
L/D = 6								
1	.9856	.7870	.9645	.7868	.9458	.7869	.9317	.7873
2	.9926	.7867	.9838	.7867	.9767	.7868	.9694	.7870
3	.9966	.7872	.9920	.7870	.9885	.7867	.9857	.7865
4	.9984	.7873	.9968	.7871	.9955	.7873	.9944	.7867
5	.99973	.7873	.99946	.7867	.99922	.7873	.99912	.7870
L/D = 4								
1	.9867	.7869	.9762	.7869	.9681	.7871	.9602	.7870
2	.9932	.7870	.9891	.7869	.9854	.7869	.9827	.7865
3	.9965	.7870	.9946	.7865	.9930	.7869	.9915	.7865
4	.9986	.7865	.9978	.7868	.9971	.7869	.9965	.7862
5	.99978	.7867	.99959	.7870	.99946	.7869	.99939	.7869
L/D = 2								
1	.9913	.7869	.9886	.7869	.9870	.7863	.9843	.7866
2	.9953	.7899	.9942	.7864	.9932	.7871	.9924	.7868
3	.9976	.7873	.9970	.7872	.9964	.7865	.9961	.7868
4	.9989	.7871	.9987	.7871	.9984	.7871	.9983	.7869
5	.99987	.7873	.99984	.7872	.99980	.7873	.99973	.7867

TABLE 39.- PRIMARY AND SECONDARY NOZZLE PRESSURE RATIOS

[p'_c = 8 lb/sq in. (approx.)]

Mixing tube	1		2		3		4.	
Nozzle \ Pressure ratios	p_t/p_a	p_a/p_c	p_t/p_a	p_a/p_c	p_t/p_a	p_a/p_c	p_t/p_a	p_a/p_c
L/D = 10								
1	0.9754	0.6491	0.8805	0.6499	0.7874	0.6490	0.7206	0.6490
2	.9869	.6483	.9448	.6471	.9100	.6477	.8882	.6475
3	.9937	.6486	.9753	.6486	.9596	.6479	.9485	.6485
4	.9970	.6490	.9878	.6483	.9804	.6482	.9752	.6435
5	.9991	.6493	.9971	.6484	.9953	.6486	.9946	.6496
L/D = 8								
1	.9753	.6485	.9052	.6483	.8477	.6485	.7954	.6485
2	.9864	.6482	.9574	.6484	.9303	.6480	.9135	.6484
3	.9934	.6480	.9801	.6479	.9681	.6481	.9605	.6477
4	.9968	.6489	.9903	.6491	.9848	.6481	.9808	.6481
5	.9991	.6492	.9974	.6491	.9961	.6490	.9954	.6490
L/D = 6								
1	.9714	.6487	.9339	.6487	.8968	.6486	.8677	.6487
2	.9860	.6487	.9678	.6488	.9526	.6488	.9405	.6490
3	.9932	.6487	.9848	.6494	.9768	.6491	.9723	.6496
4	.9966	.6492	.9924	.6487	.9890	.6490	.9864	.6490
5	.9991	.6492	.9980	.6491	.9971	.6488	.9965	.6493
L/D = 4								
1	.9748	.6489	.9554	.6489	.9413	.6489	.9283	.6485
2	.9872	.6485	.9792	.6488	.9718	.6485	.9660	.6486
3	.9934	.6487	.9897	.6487	.9862	.6483	.9837	.6486
4	.9967	.6485	.9947	.6485	.9930	.6481	.9917	.6484
5	.9991	.6484	.9986	.6487	.9981	.6486	.9978	.6484
L/D = 2								
1	.9843	.6487	.9791	.6488	.9753	.6485	.9726	.6485
2	.9914	.6485	.9891	.6486	.9870	.6488	.9858	.6485
3	.9954	.6487	.9943	.6491	.9932	.6485	.9927	.6491
4	.9975	.6490	.9969	.6490	.9964	.6490	.9960	.6485
5	.9993	.6489	.9991	.6490	.9989	.6492	.9989	.6486

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TABLE 40.- PRIMARY AND SECONDARY NOZZLE PRESSURE RATIOS

[p'_c = 12 lb/sq in. (approx.)]

Mixing tube	1		2		3		4	
Pressure ratios / Nozzle	p_t/p_a	p_a/p_c	p_t/p_a	p_a/p_c	p_t/p_a	p_a/p_c	p_t/p_a	p_a/p_c
L/D = 10								
1	0.9649	0.5522	0.8259	0.5522	0.6746	0.5520	0.5672	0.5522
2	.9811	.5512	.9184	.5510	.8673	.5506	.8373	.5508
3	.9908	.5507	.9595	.5519	.9420	.5513	.9263	.5515
4	.9952	.5521	.9812	.5516	.9697	.5513	.9629	.5518
5	.9984	.5524	.9940	.5518	.9909	.5517	.9892	.5514
L/D = 8								
1	.9640	.5516	.8681	.5519	.7678	.5515	.6930	.5515
2	.9803	.5512	.9387	.5515	.9008	.5515	.8750	.5515
3	.9906	.5512	.9710	.5512	.9548	.5512	.9439	.5512
4	.9950	.5521	.9849	.5522	.9751	.5510	.9706	.5512
5	.9983	.5522	.9951	.5524	.9925	.5520	.9907	.5521
L/D = 6								
1	.9632	.5518	.9047	.5516	.8509	.5519	.8092	.5514
2	.9799	.5518	.9540	.5519	.9318	.5519	.9151	.5520
3	.9901	.5521	.9784	.5521	.9679	.5522	.9609	.5522
4	.9948	.5521	.9884	.5523	.9833	.5524	.9792	.5523
5	.9983	.5523	.9963	.5522	.9943	.5520	.9931	.5522
L/D = 4								
1	.9665	.5519	.9418	.5519	.9178	.5519	.8993	.5518
2	.9819	.5518	.9702	.5518	.9594	.5519	.9514	.5516
3	.9907	.5518	.9856	.5518	.9706	.5516	.9769	.5514
4	.9950	.5516	.9920	.5516	.9894	.5514	.9874	.5517
5	.9983	.5515	.9974	.5518	.9964	.5514	.9959	.5517
L/D = 2								
1	.9789	.5515	.9718	.5513	.9659	.5516	.9621	.5516
2	.9879	.5517	.9845	.5521	.9812	.5519	.9799	.5519
3	.9936	.5523	.9920	.5516	.9907	.5522	.9897	.5522
4	.9962	.5520	.9953	.5519	.9946	.5519	.9941	.5518
5	.9986	.5522	.9984	.5519	.9981	.5522	.9979	.5519

TABLE 41.- PRIMARY AND SECONDARY NOZZLE PRESSURE RATIOS

[p'_c = 16 lb/sq in. (approx.)]

Mixing tube	1		2		3		4	
Pressure ratios / Nozzle	p_t/p_a	p_a/p_c	p_t/p_a	p_a/p_c	p_t/p_a	p_a/p_c	p_t/p_a	p_a/p_c
L/D = 10								
1	0.9557	0.4805	0.7742	0.4804	0.5735	0.4803	0.5802	0.4803
2	.9757	.4790	.8948	.4790	.8281	.4789	.7767	.4791
3	.9879	.4799	.9523	.4799	.9238	.4797	.9030	.4798
4	.9938	.4803	.9761	.4799	.9602	.4794	.9532	.4802
5	.9976	.4807	.9912	.4801	.9861	.4800	.9837	.4800
L/D = 8								
1	.9548	.4799	.8266	.4799	.6855	.4799	.5798	.4799
2	.9746	.4795	.9200	.4797	.8677	.4796	.8398	.4796
3	.9875	.4795	.9615	.4799	.9401	.4794	.9254	.4794
4	.9936	.4805	.9805	.4805	.9696	.4794	.9630	.4794
5	.9976	.4806	.9931	.4806	.9889	.4804	.9867	.4801
L/D = 6								
1	.9532	.4802	.8808	.4800	.8076	.4799	.7482	.4798
2	.9744	.4802	.9421	.4802	.9173	.4800	.8891	.4804
3	.9872	.4805	.9716	.4804	.9647	.4805	.9637	.4803
4	.9933	.4804	.9849	.4806	.9782	.4807	.9733	.4807
5	.9975	.4804	.9946	.4806	.9920	.4806	.9902	.4807
L/D = 4								
1	.9586	.4802	.9270	.4802	.8964	.4802	.8728	.4802
2	.9769	.4799	.9619	.4792	.9478	.4794	.9376	.4802
3	.9882	.4802	.9812	.4800	.9745	.4799	.9699	.4799
4	.9936	.4799	.9899	.4799	.9865	.4799	.9839	.4799
5	.9976	.4798	.9961	.4798	.9948	.4799	.9939	.4799
L/D = 2								
1	.9738	.4802	.9664	.4799	.9591	.4799	.9534	.4799
2	.9844	.4802	.9803	.4804	.9766	.4804	.9741	.4804
3	.9916	.4805	.9897	.4805	.9878	.4805	.9866	.4805
4	.9953	.4804	.9941	.4804	.9932	.4804	.9925	.4804
5	.9982	.4806	.9978	.4802	.9974	.4806	.9971	.4804

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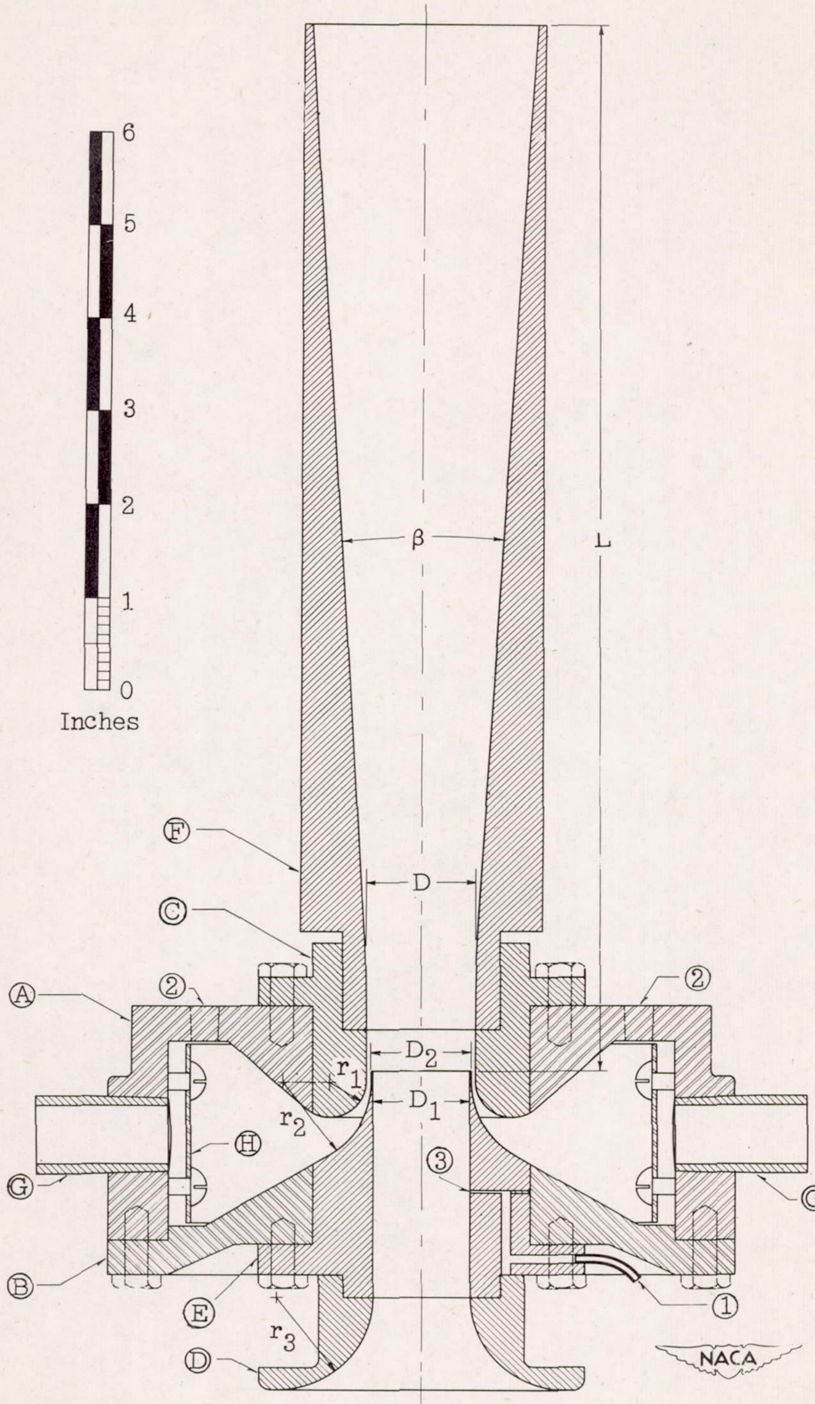

Figure 1.- Axial section of typical model.

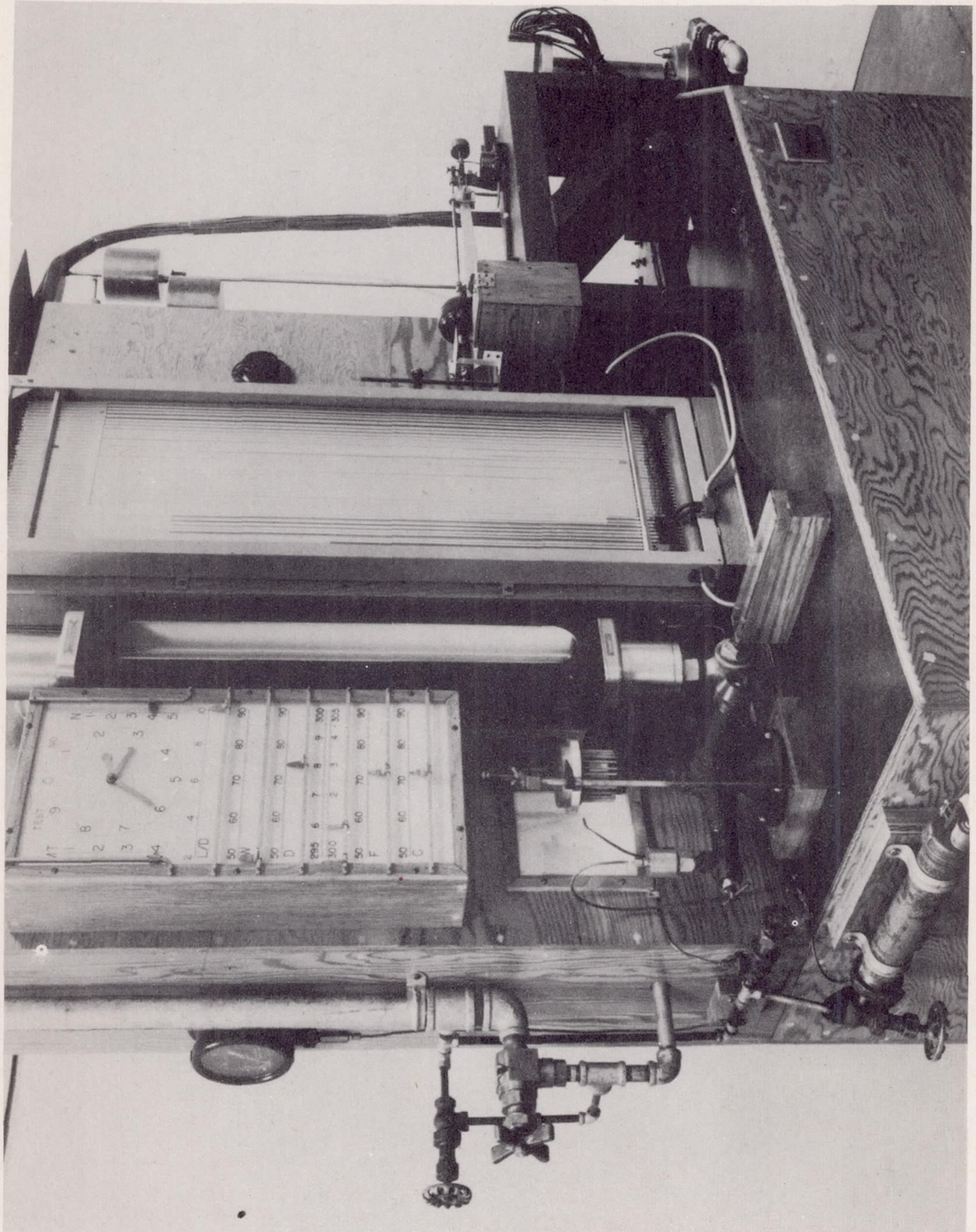

Figure 2.- General arrangement of apparatus.

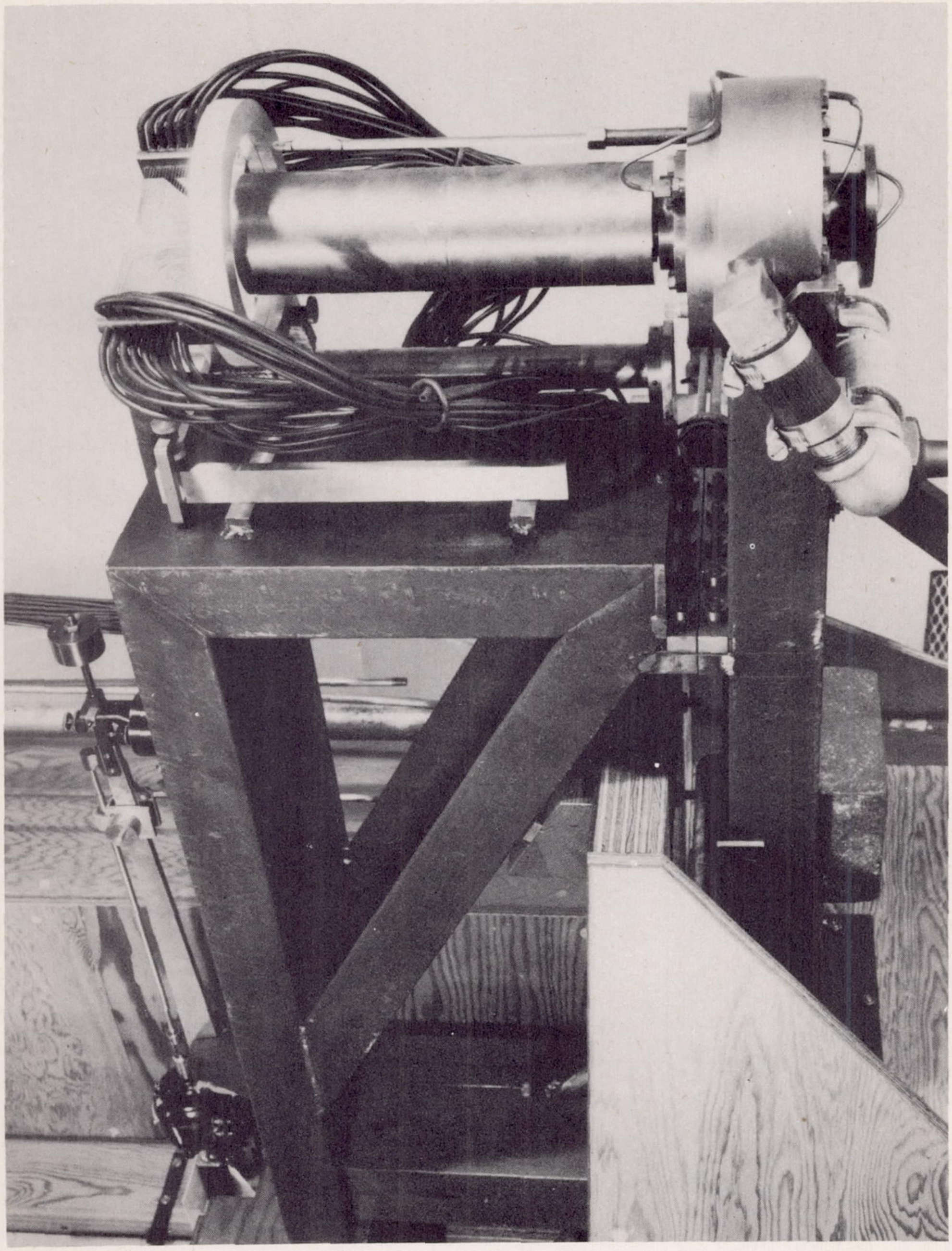

Figure 3.- Model and force-measuring equipment.

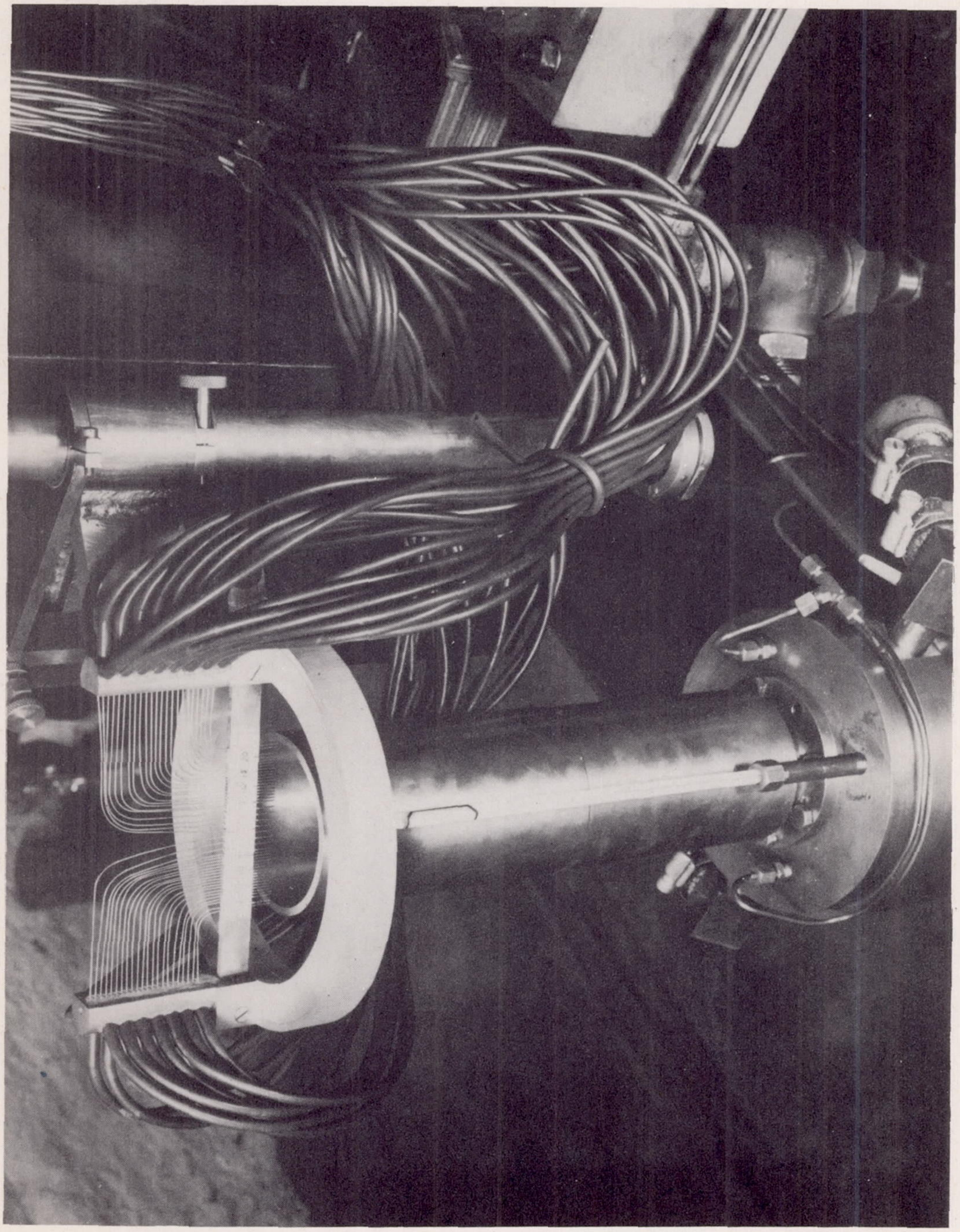

Figure 4.- Details of survey apparatus.

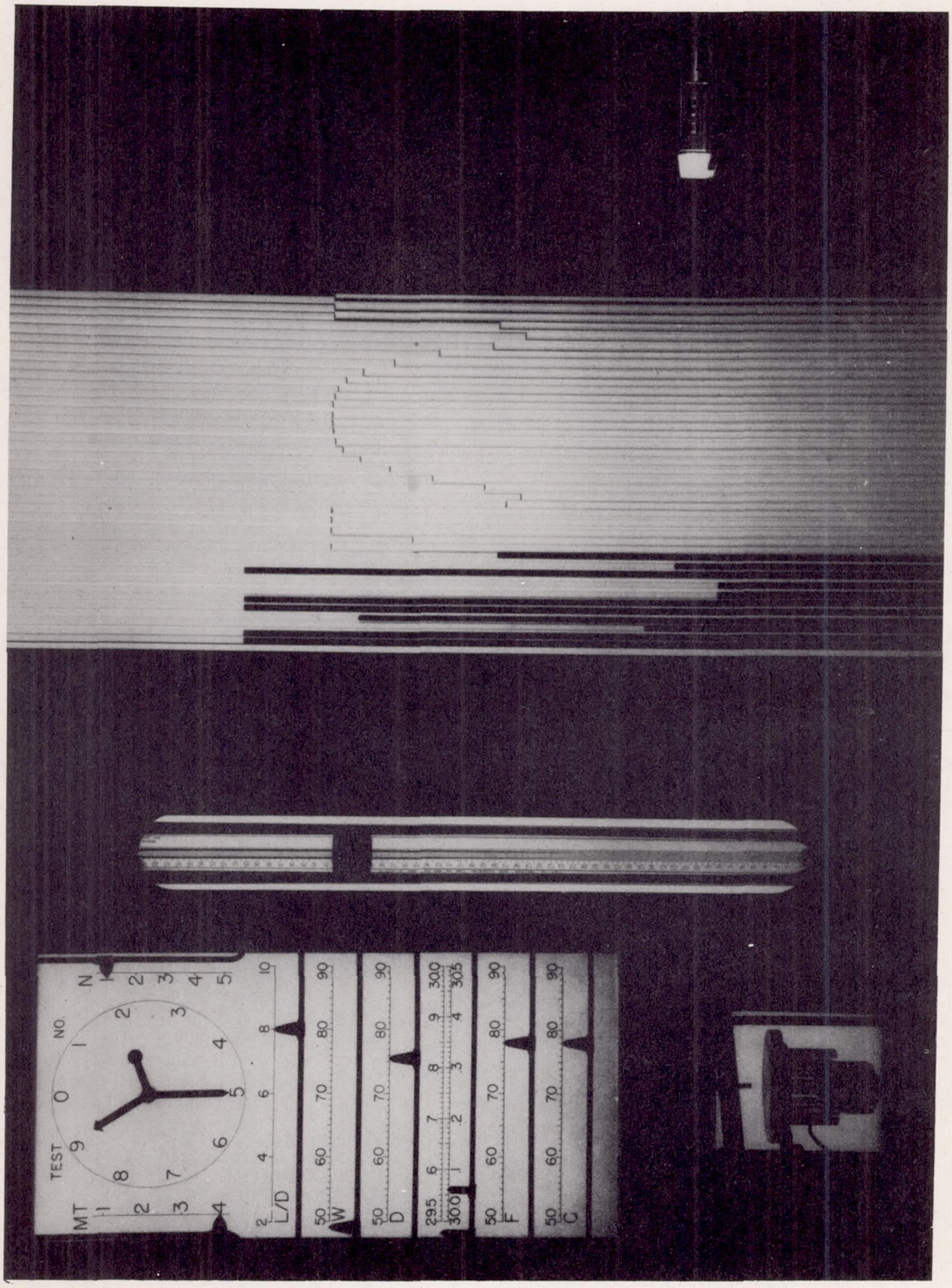

Figure 5.- Sample record.

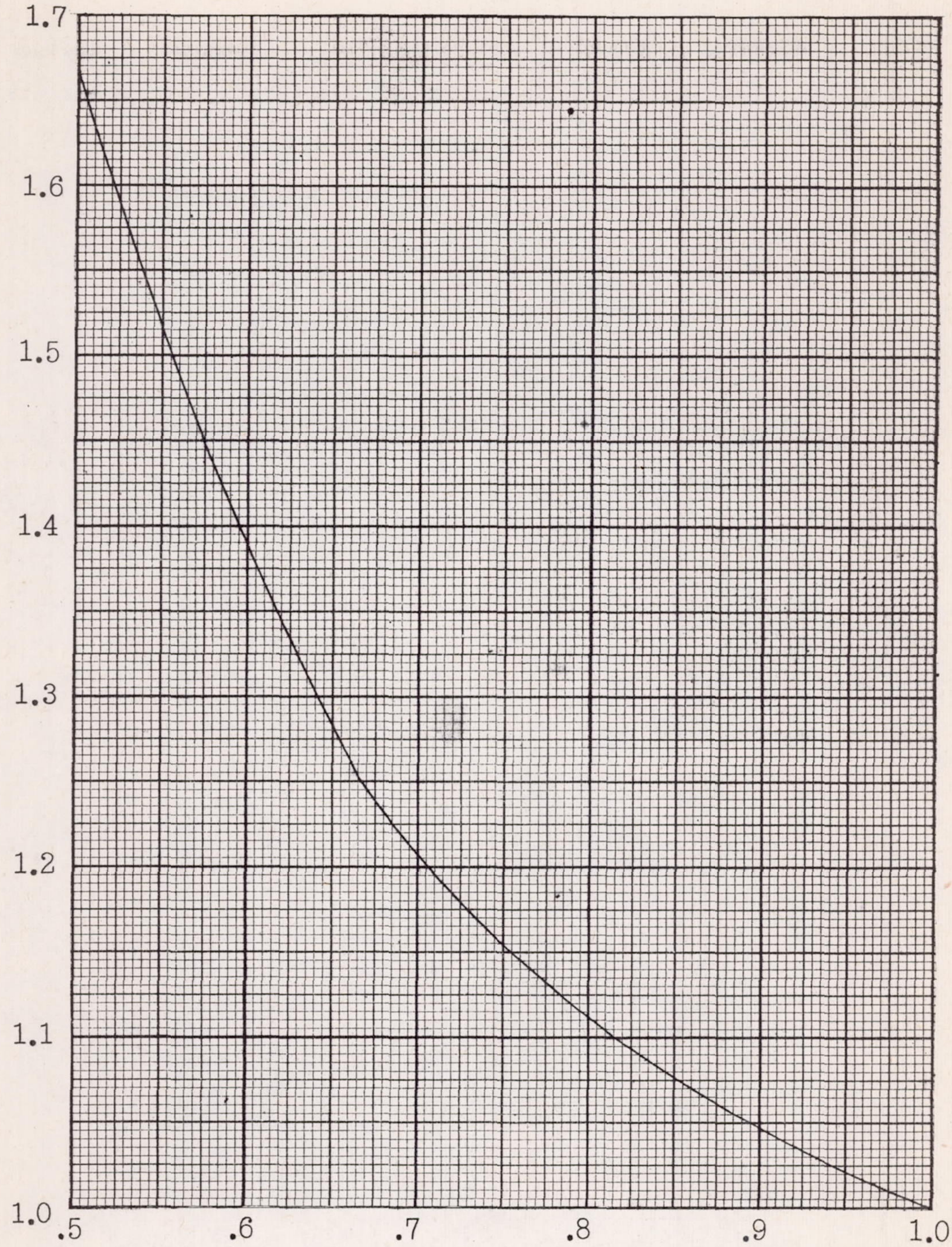

Figure 6.- Thrust correction factor.

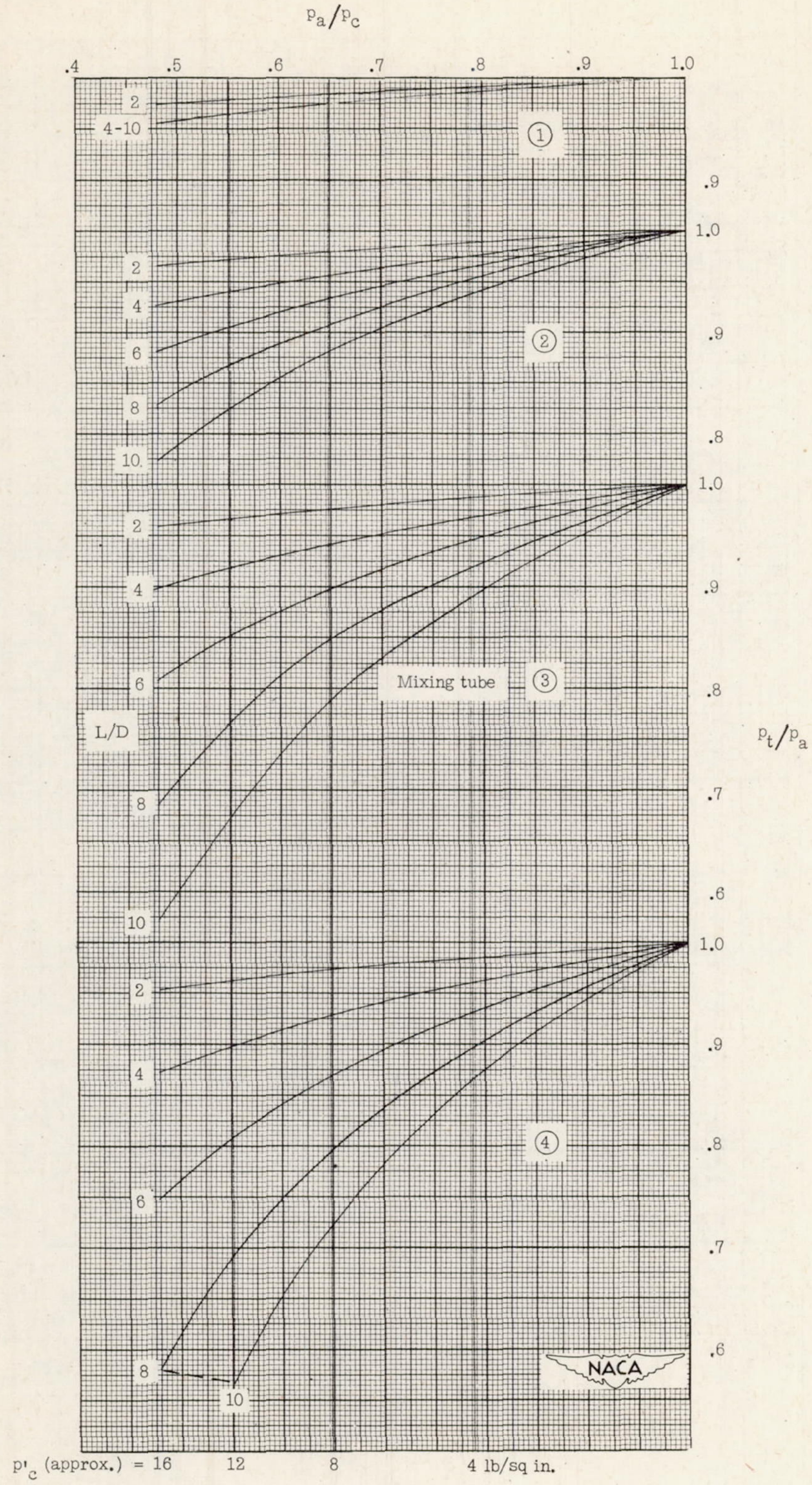

Figure 7.- Pressure-ratio relationships. Nozzle 1.

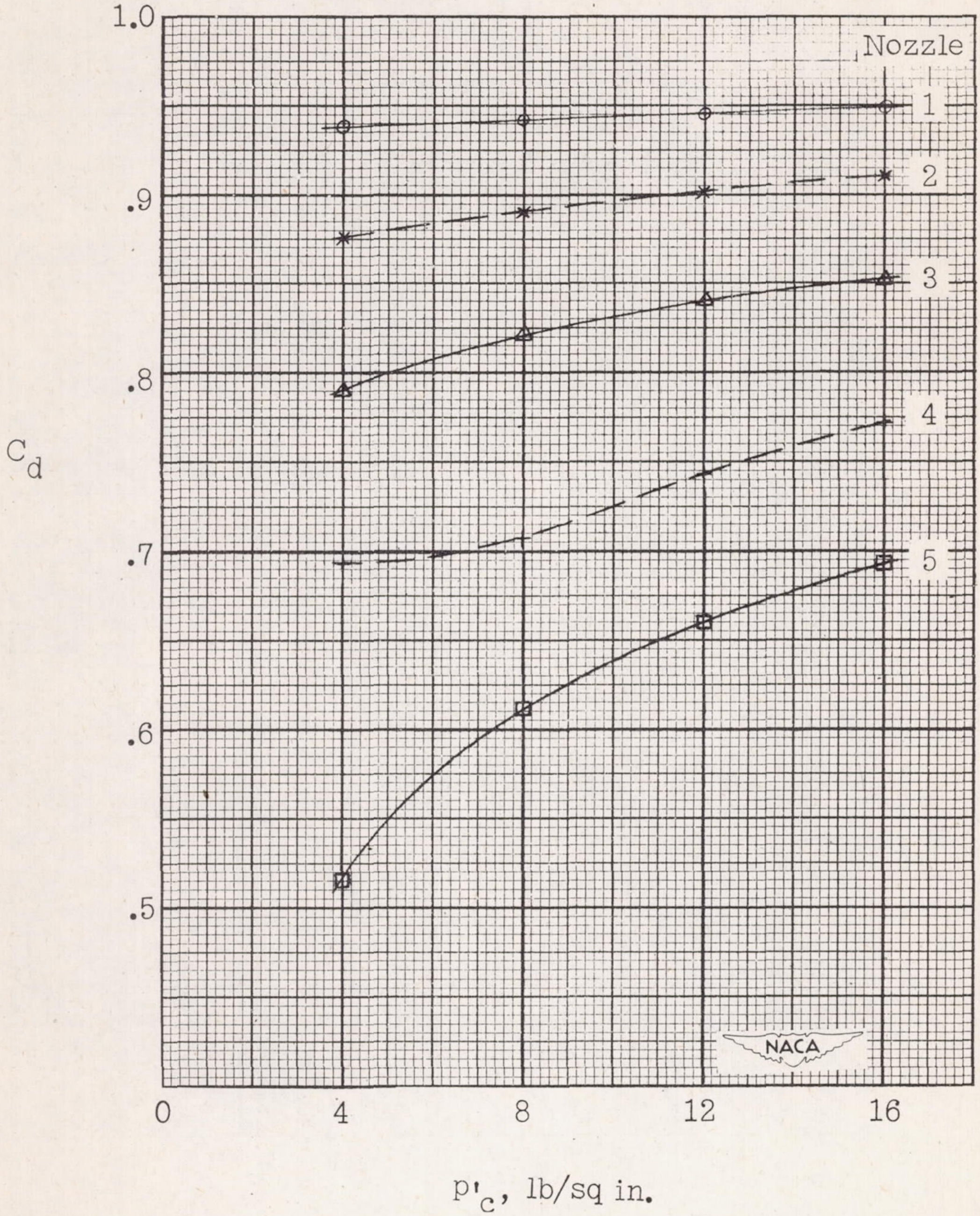

Figure 8.- Nozzle discharge coefficients.

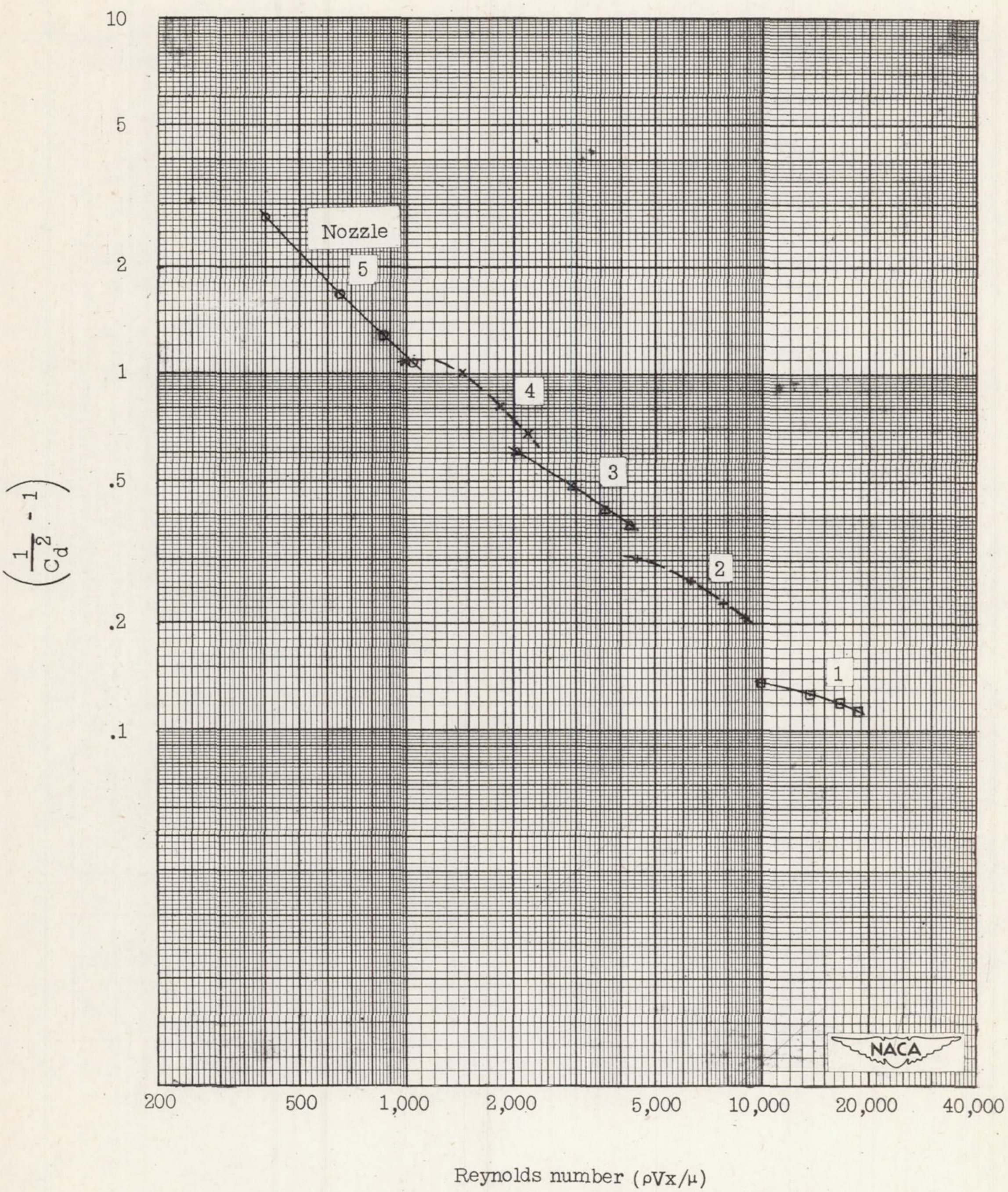

Figure 9.- Nozzle loss coefficients.

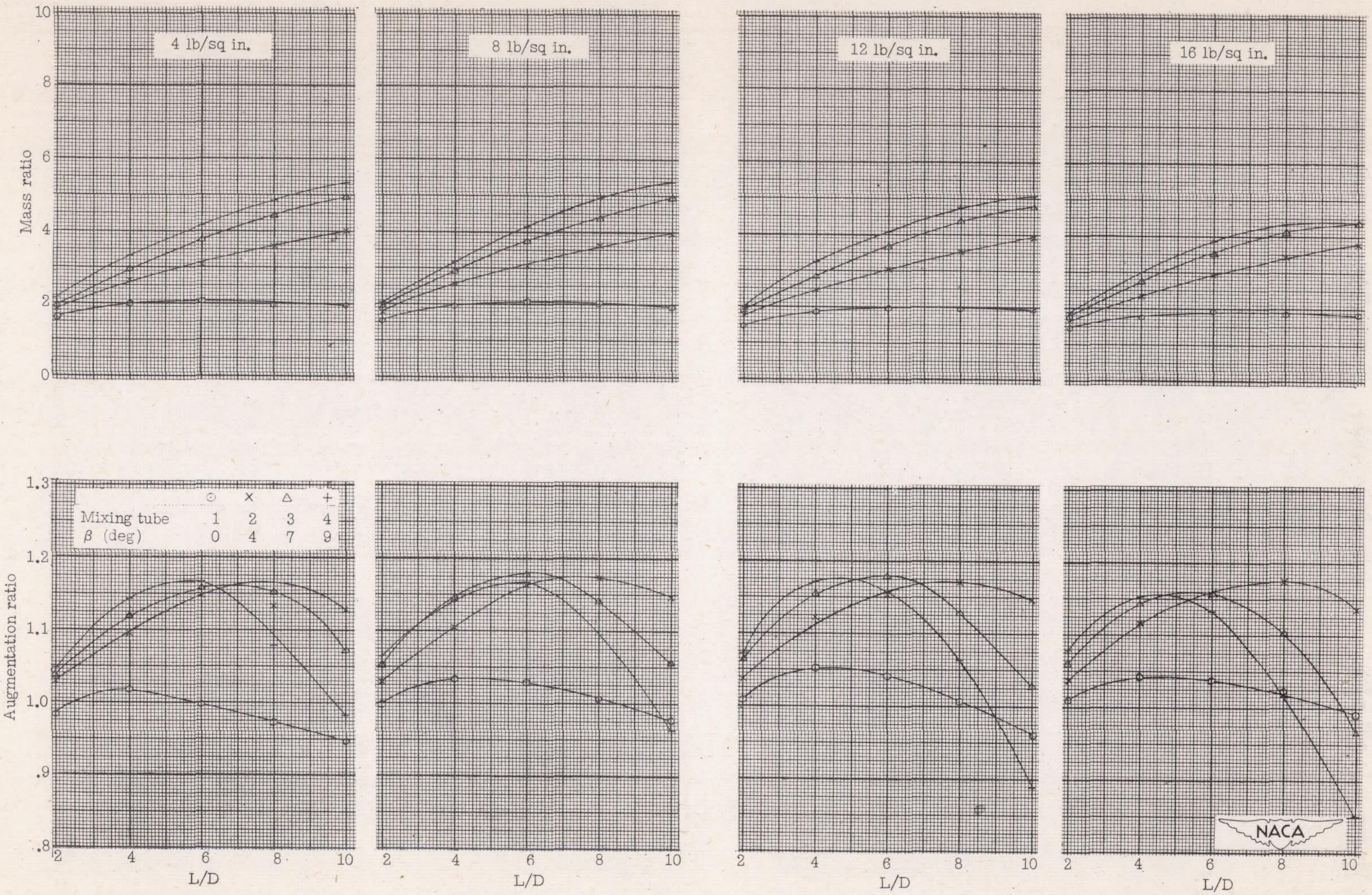

Figure 10.- Performance of nozzle 1. $A_m/A_s = 10$.

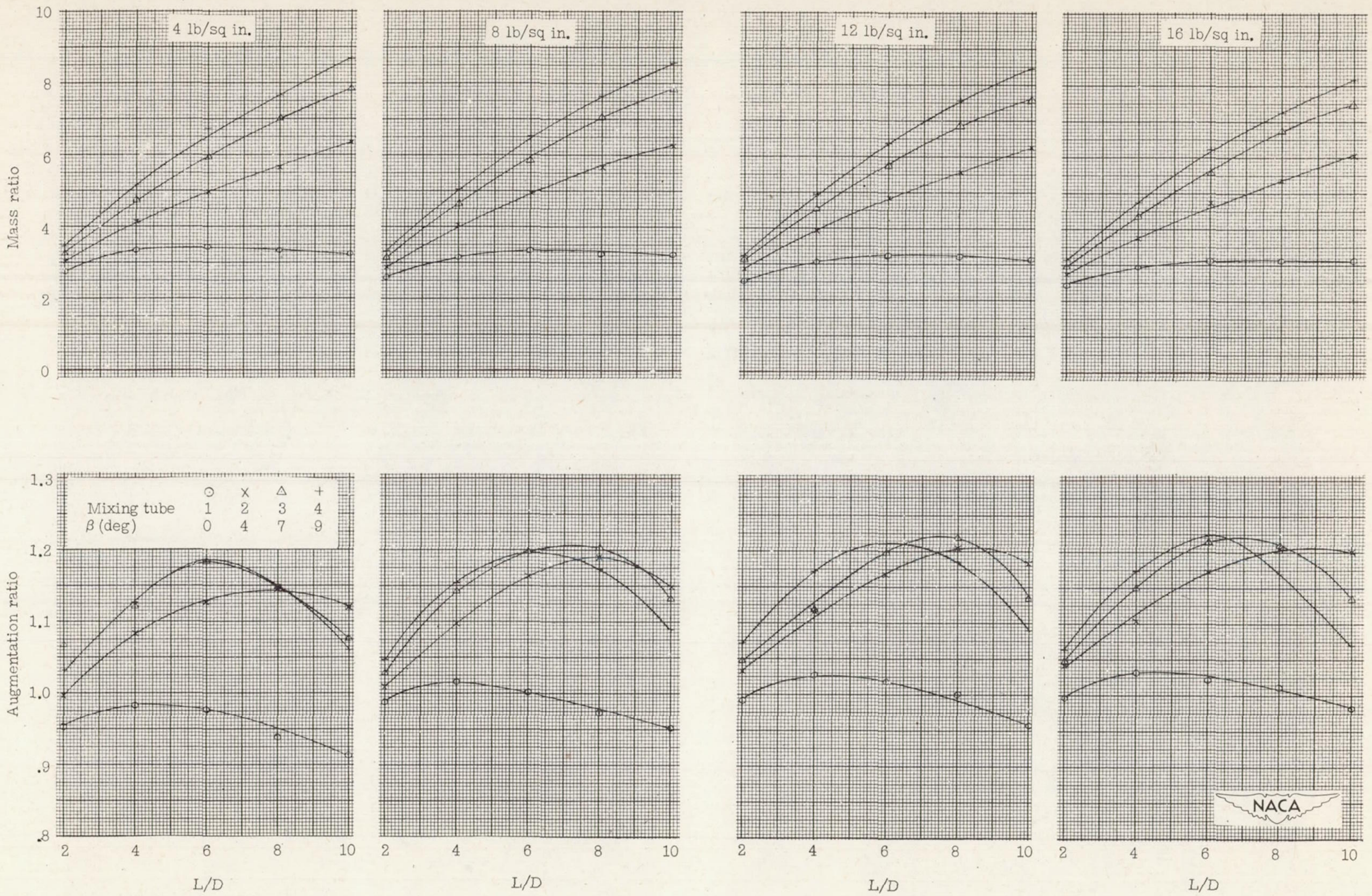

Figure 11.- Performance of nozzle 2. $A_m/A_s = 20$.

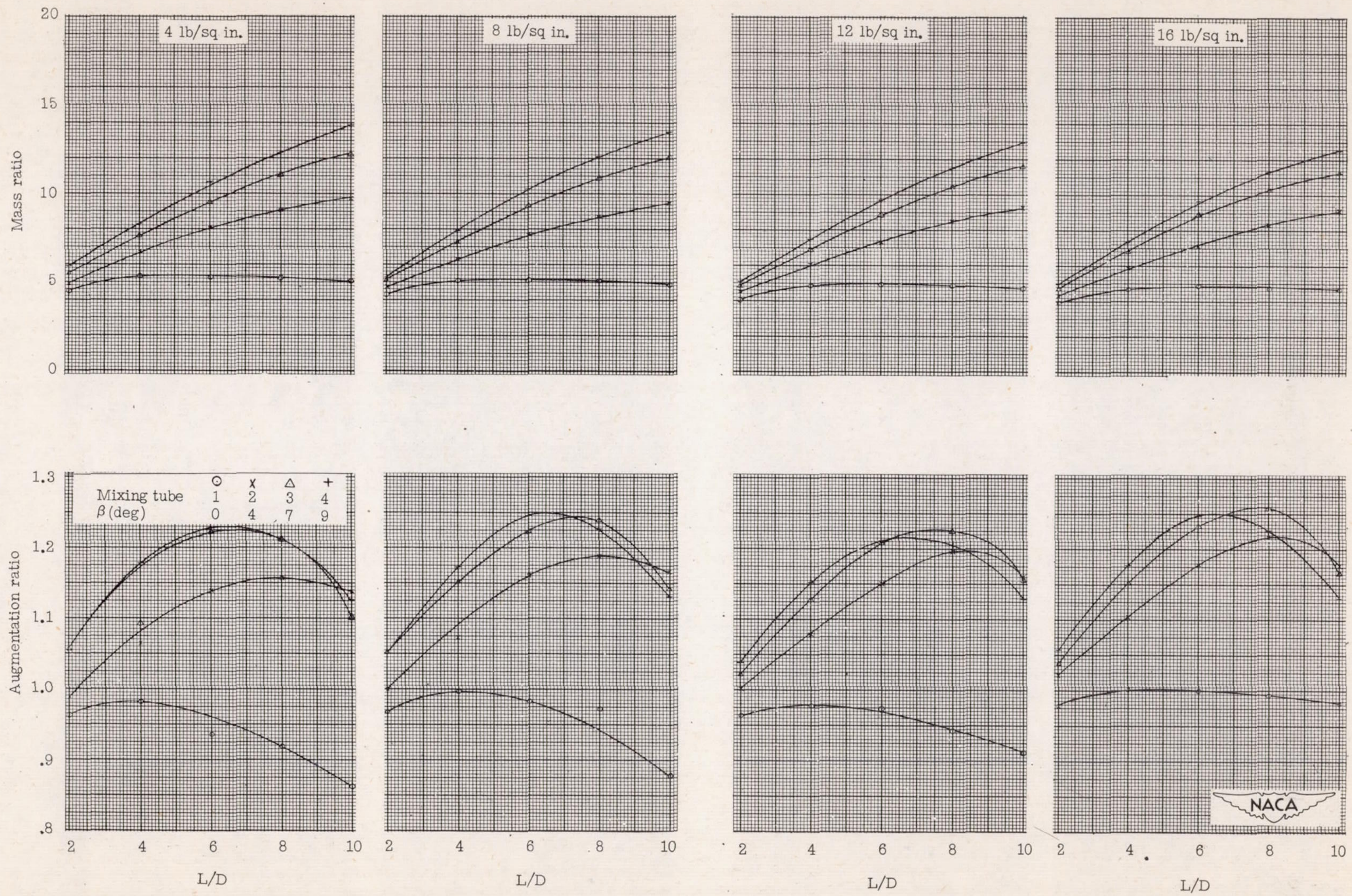

Figure 12.- Performance of nozzle 3. $A_m/A_s = 40$.

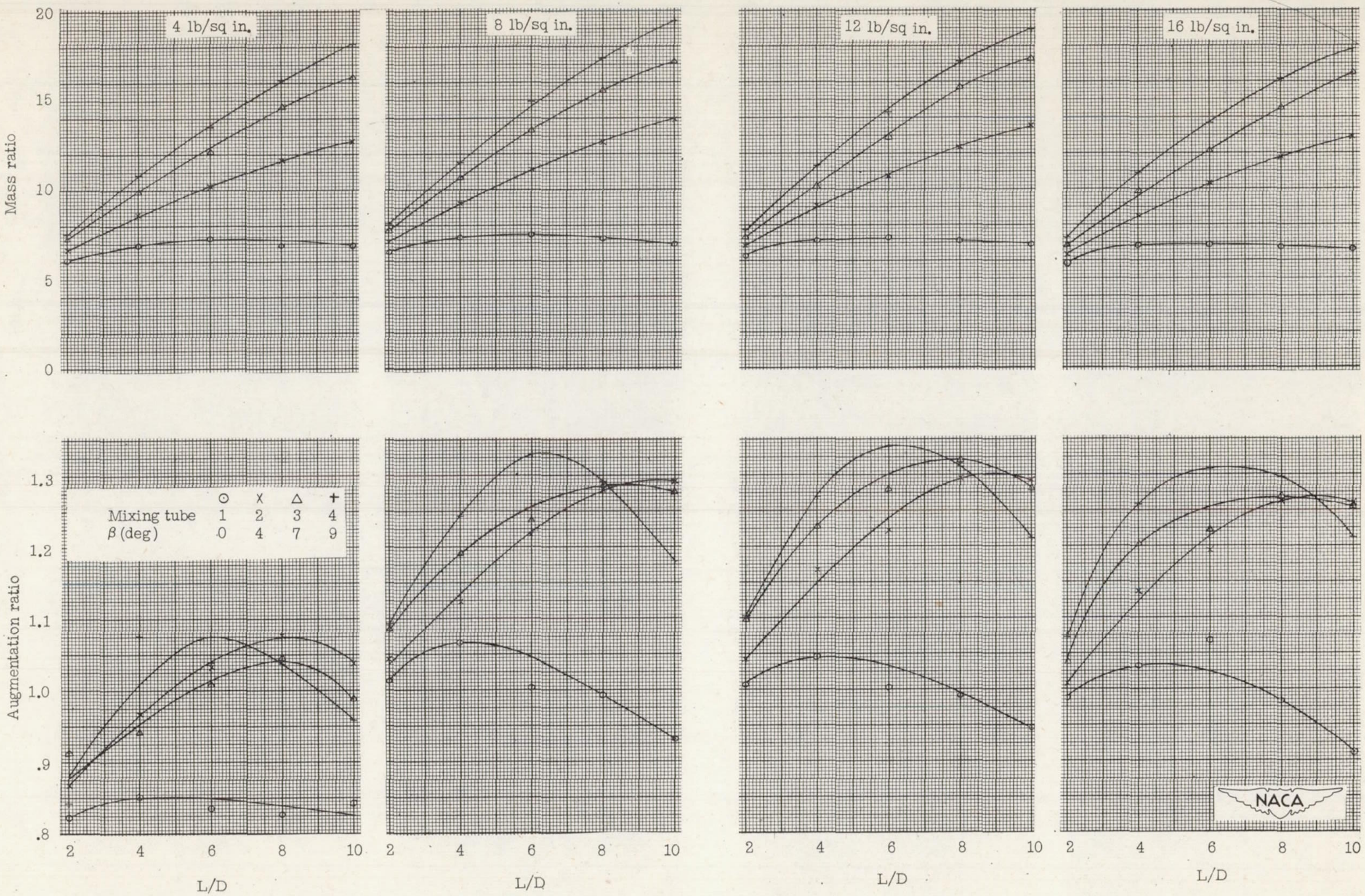

Figure 13.- Performance of nozzle 4. $A_m/A_s = 70$.

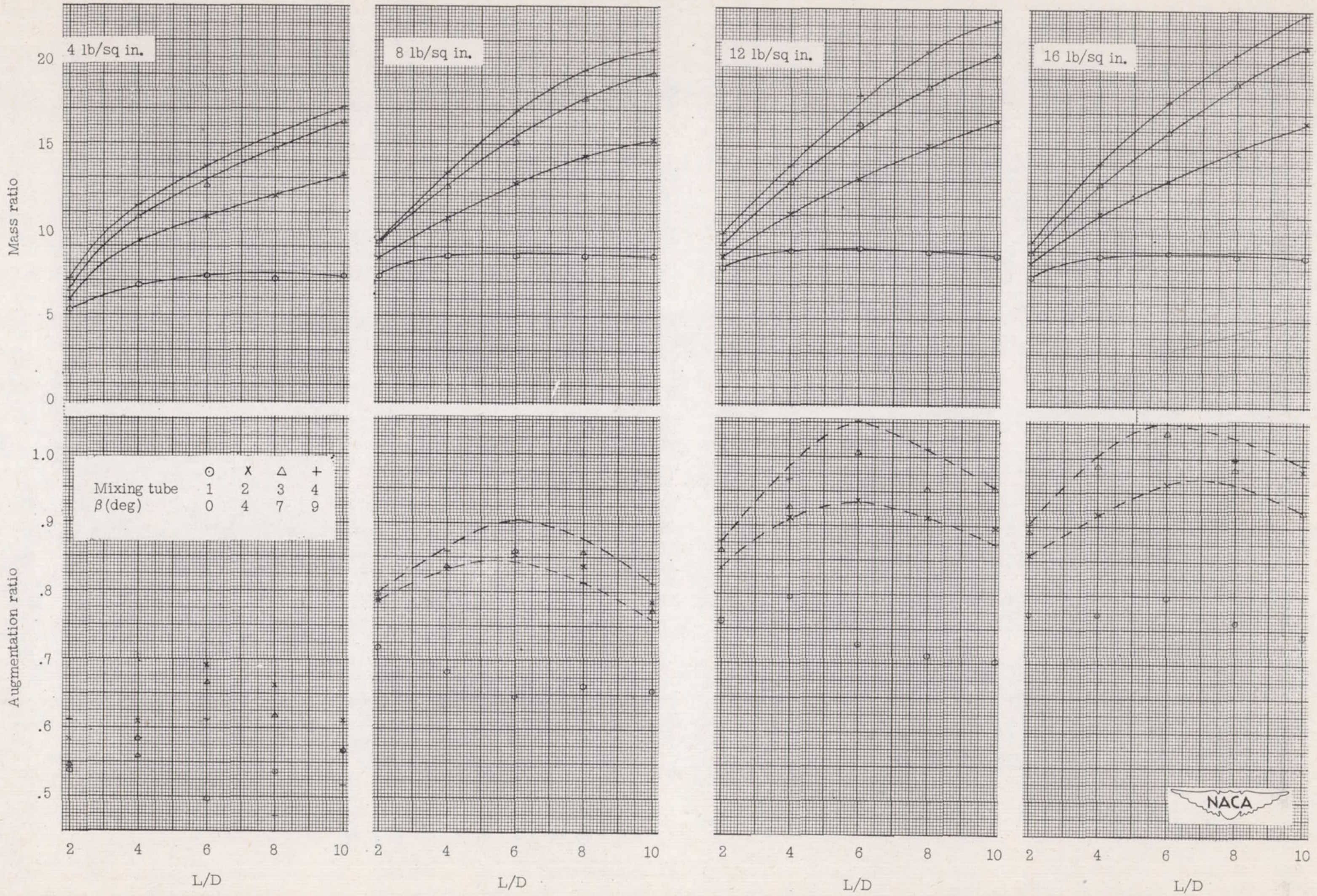

Figure 14.- Performance of nozzle 5. $A_m/A_s = 131$.

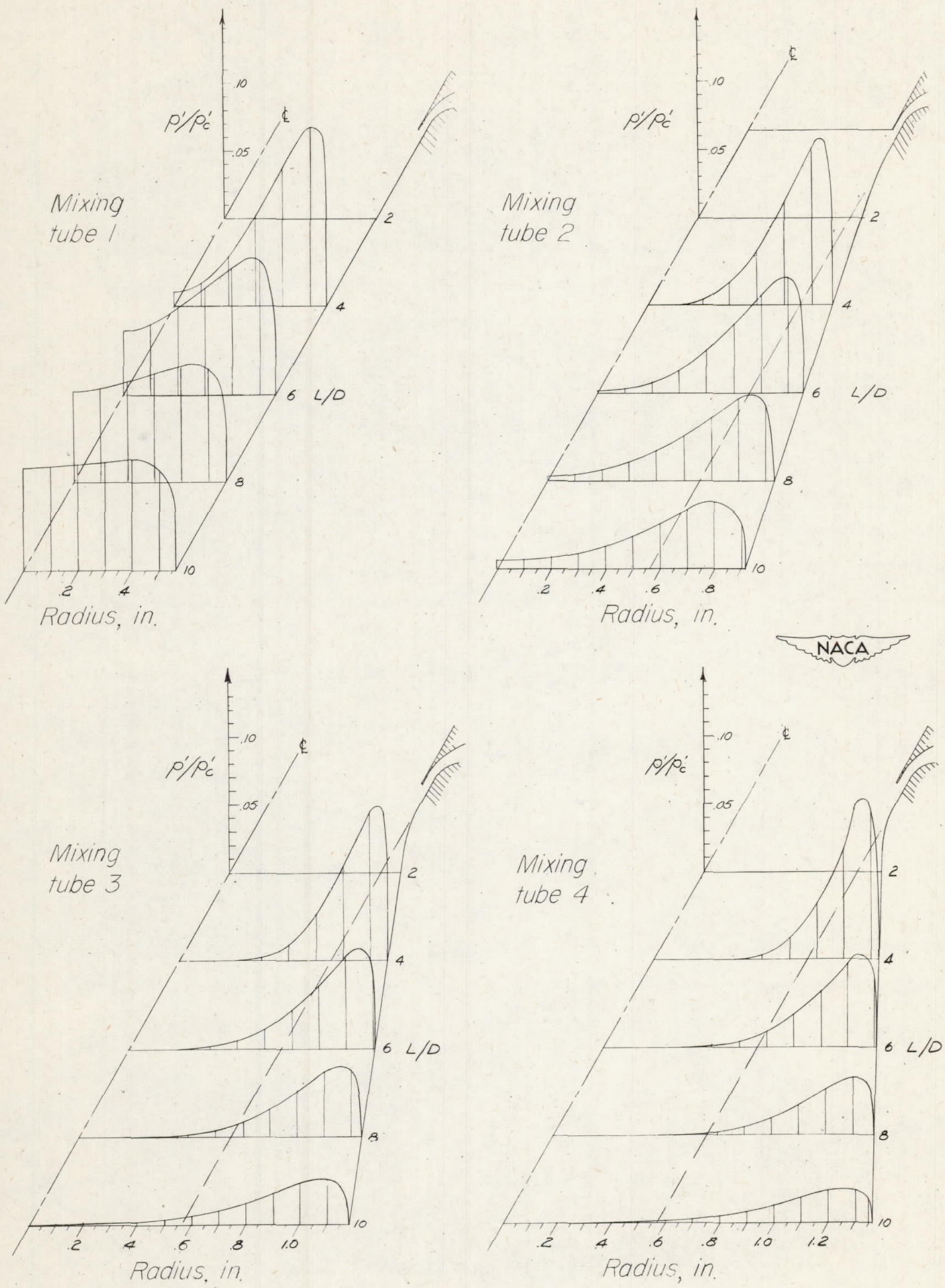

Figure 15.- Total-pressure surveys. Nozzle 1. p'_c = 12 pounds per square inch.

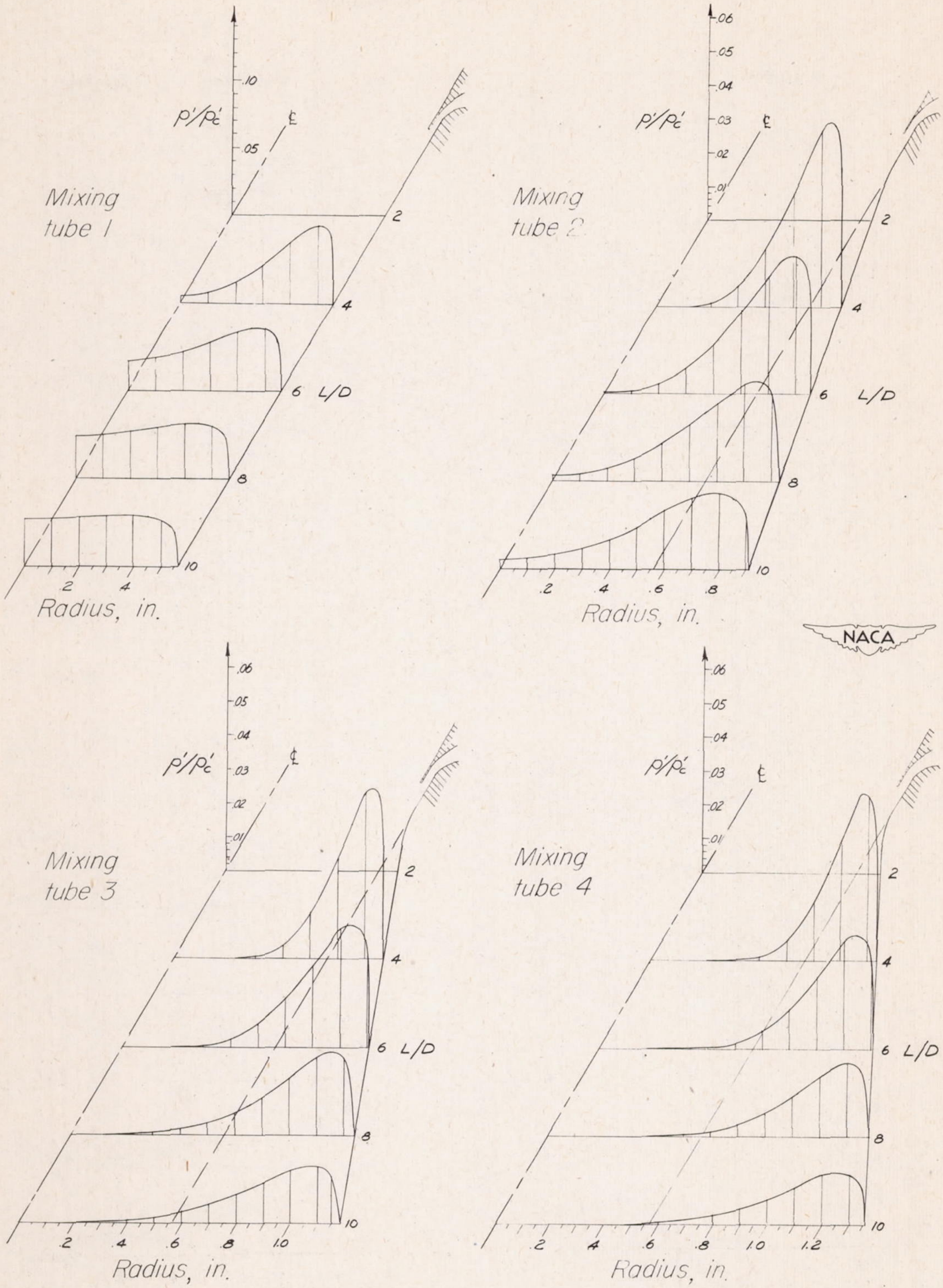

Figure 16.- Total-pressure surveys. Nozzle 2. p'_c = 12 pounds per square inch.

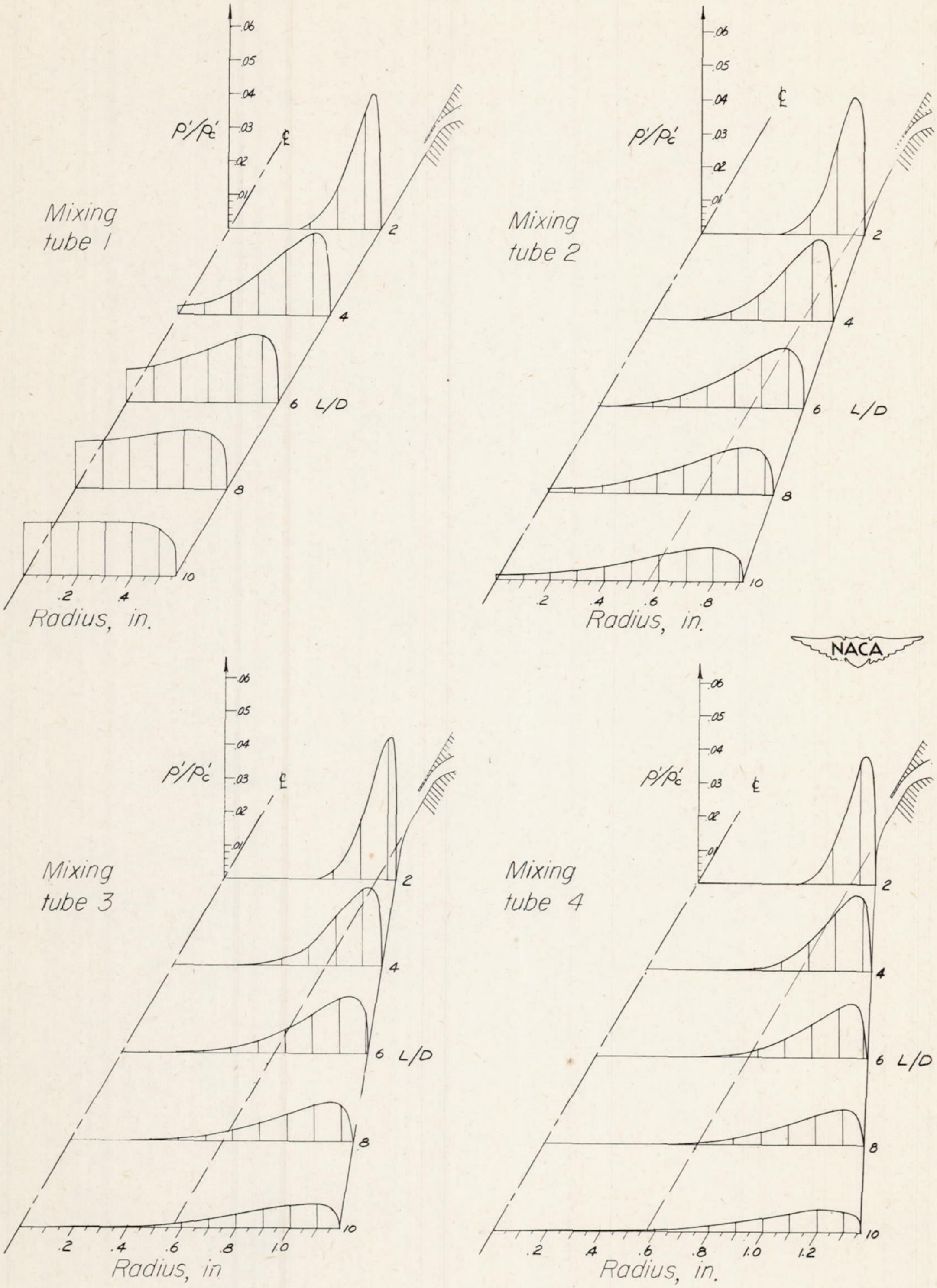

Figure 17.- Total-pressure surveys. Nozzle 3. p'_c = 12 pounds per square inch.

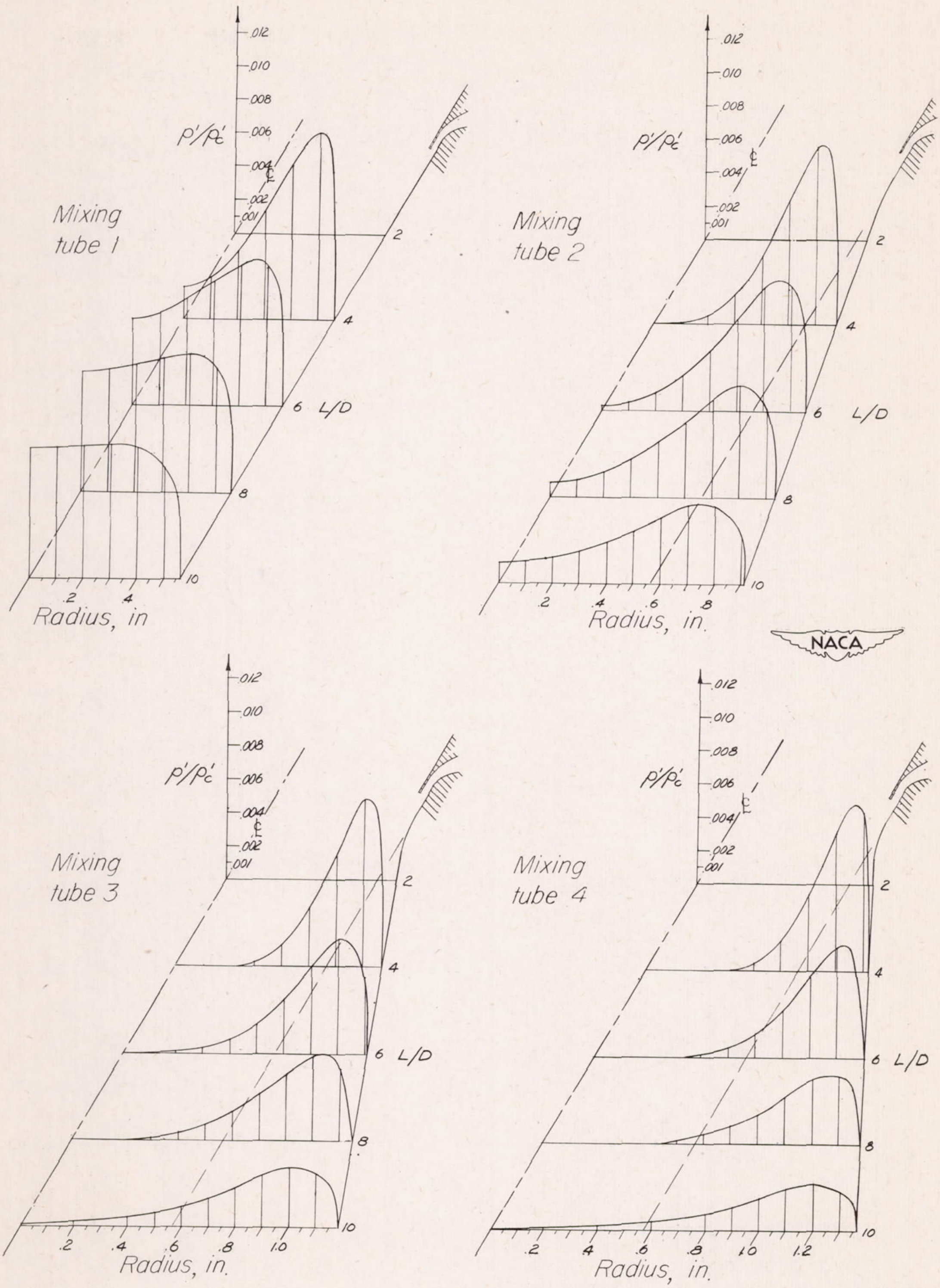

Figure 18.- Total-pressure surveys. Nozzle 4. p'_c = 12 pounds per square inch.

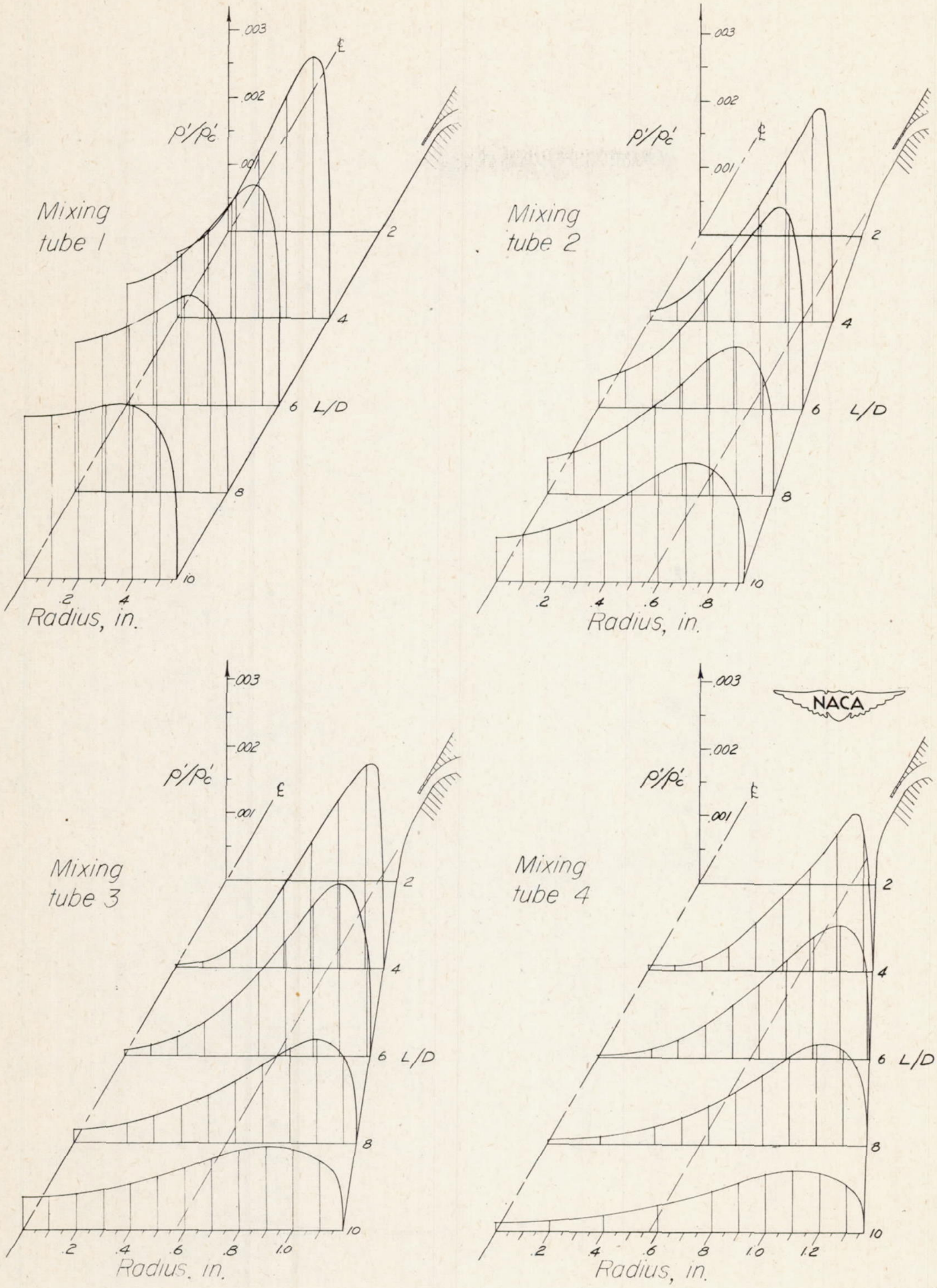

Figure 19.- Total-pressure surveys. Nozzle 5. p'_c = 12 pounds per square inch.

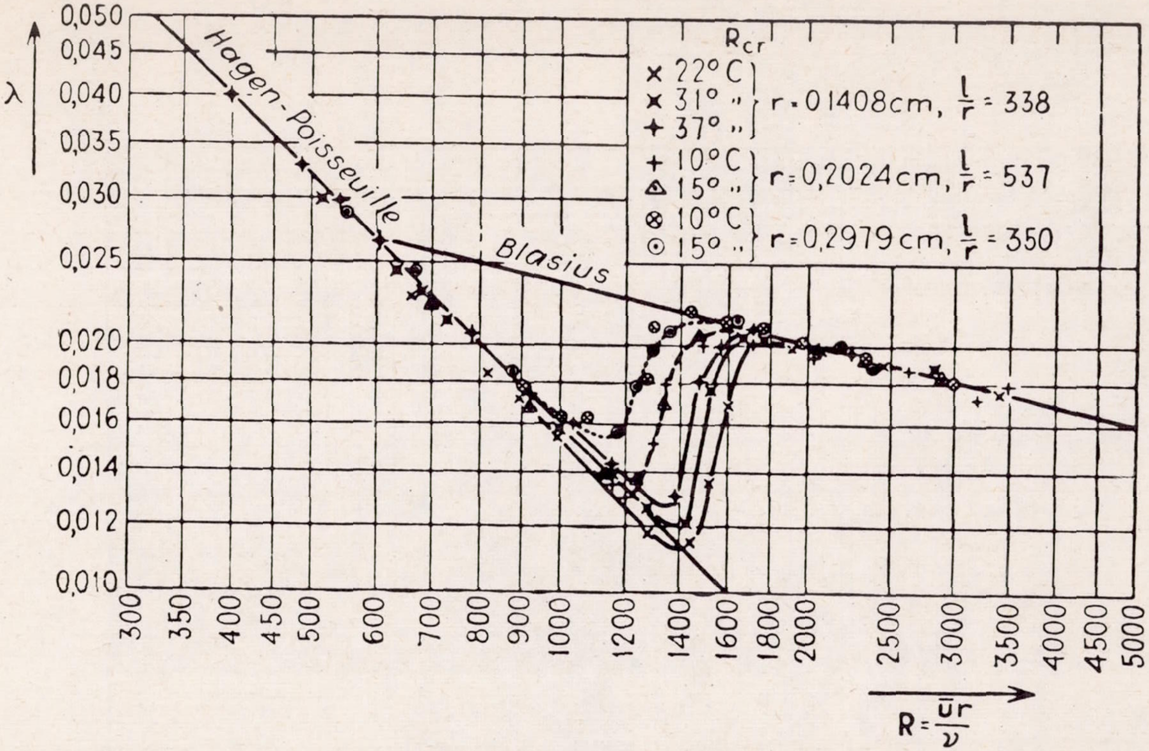

Figure 20.- Pressure-drop coefficients for smooth pipes. (From "Applied Hydro- and Aeromechanics" by Prandtl and Tietjens. 1934. McGraw-Hill Book Co.)

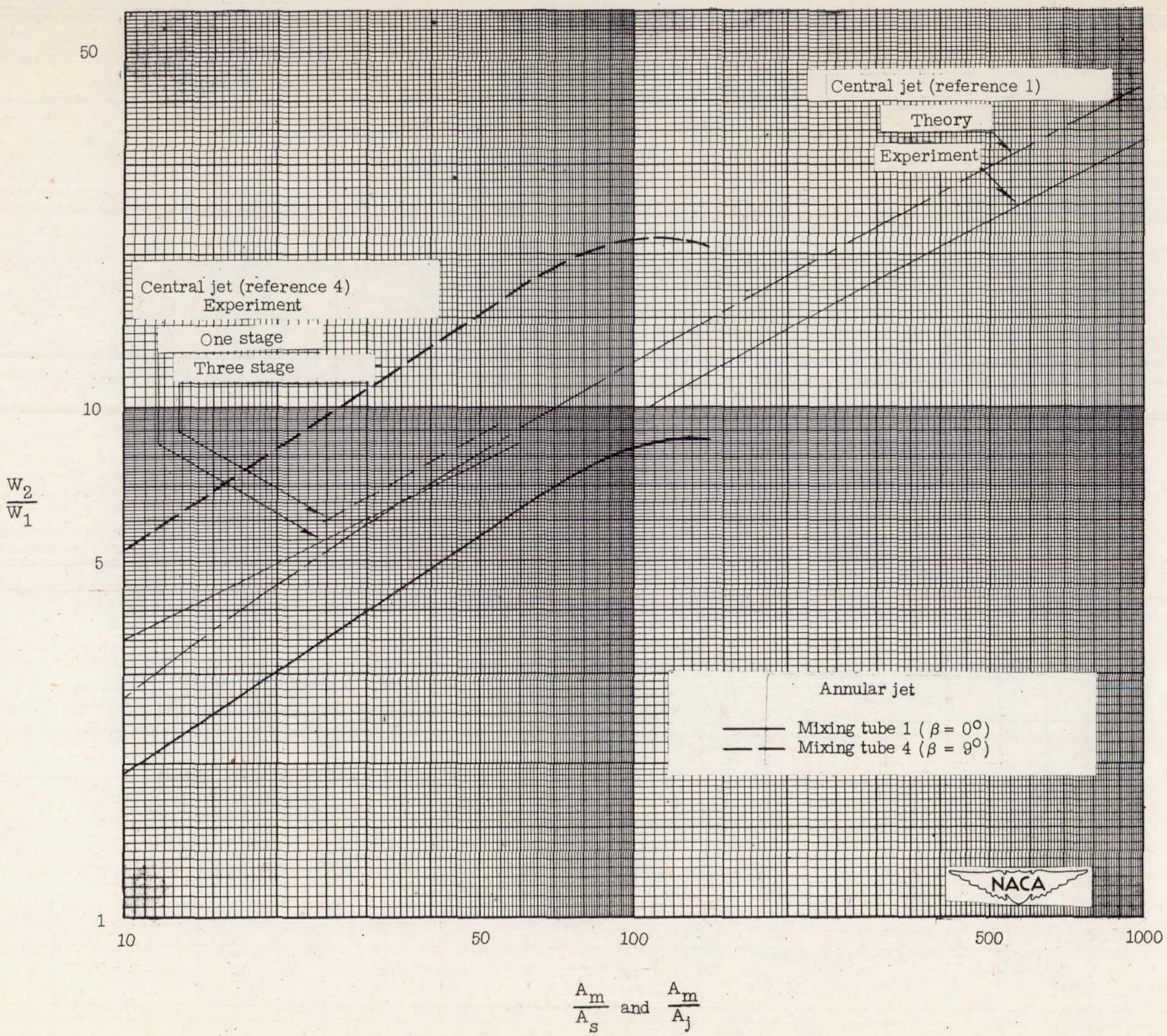

Figure 21.- Mass-flow ratio against area ratio. $\frac{L}{D} = 10$; $p'_{c} = 12$ pounds per square inch.

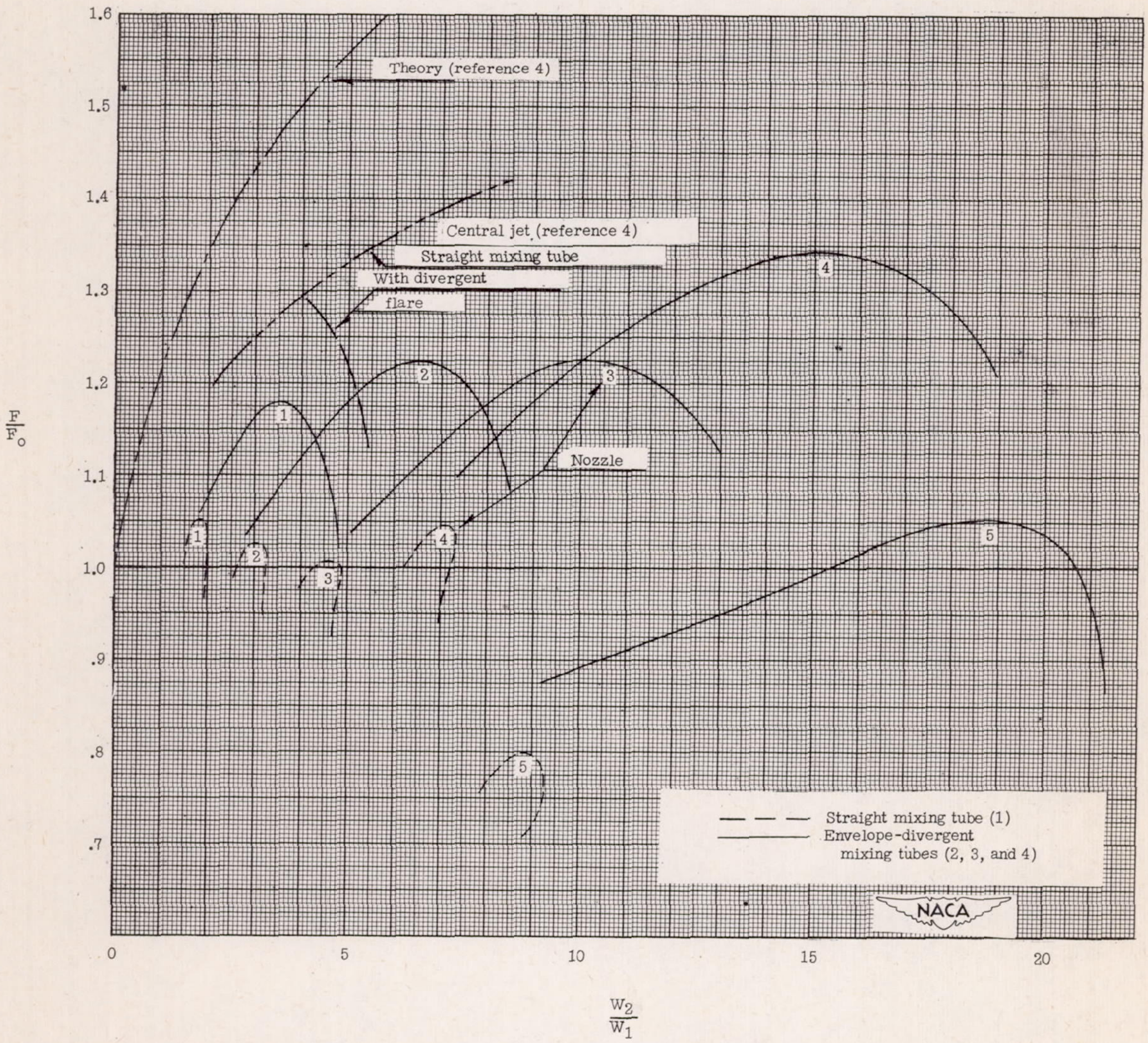

Figure 22.- Generalized performance chart. p'_c = 12 pounds per square inch.

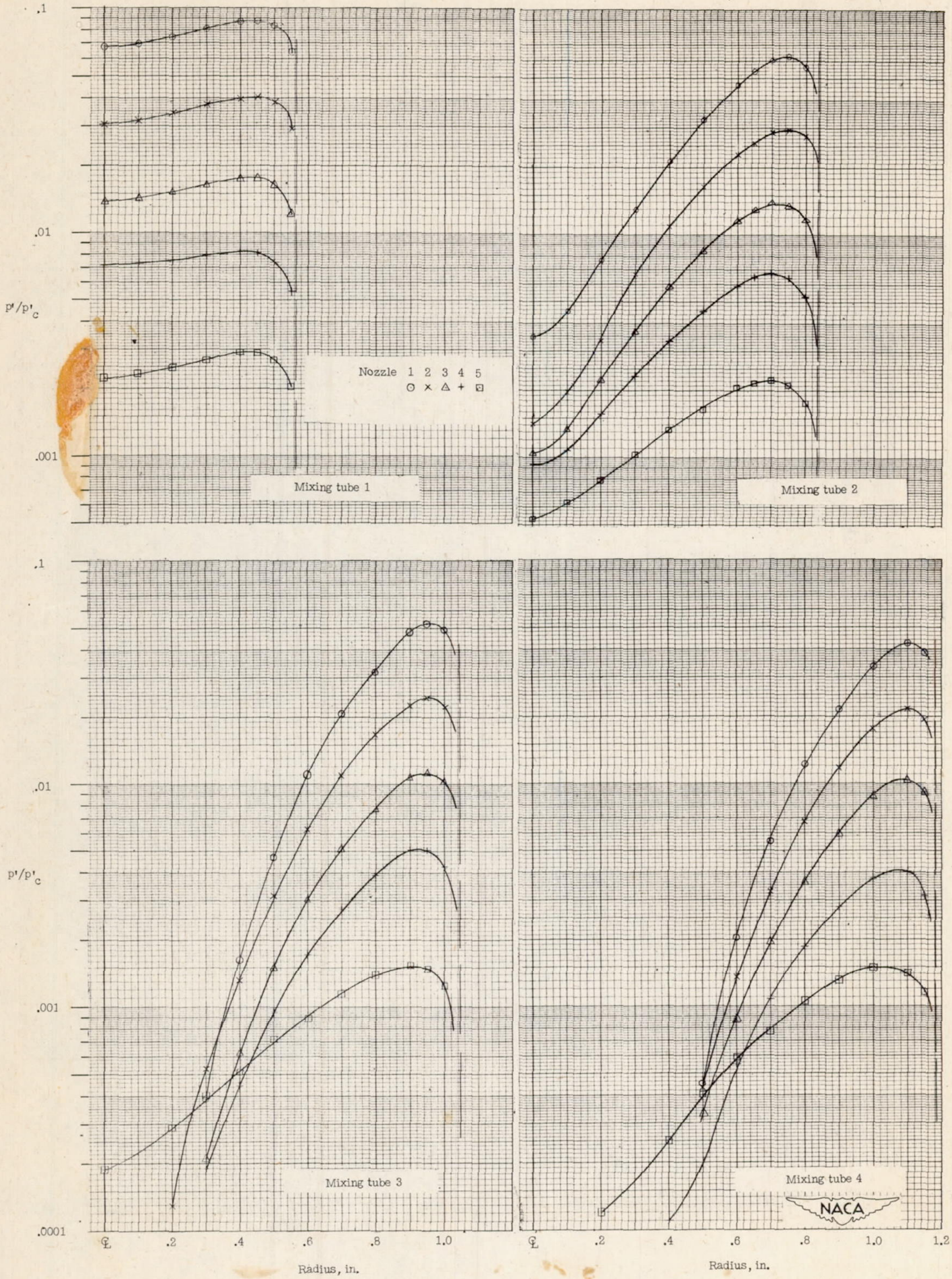

Figure 23.- Total-pressure variations. L/D = 8; p'_c = 12 pounds per square inch.