Investigation of the air-flow in an acoustic jet at resonance.

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Investigation of the airflow in an acoustic jet at resonance.
A Thesis

submitted to the faculty in partial fulfillment of the requirements for the degree of Master of Science in Engineering of the university of Arizona.

by

Ralph C. Jones

1951
Thesis submitted in fulfillment of the requirements for the degree of Bachelor of Science in Aeronautical Engineering by Ralph C. Janes, 1951.
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The airflow phenomenon, known as an "acoustic jet" and associated with an engine exhaust or excited by an oscillating piston, was investigated using a mechanical, piston-type pulsator with piston stroke varied in the range of 0.5 to 1.0 inch. The objective was the qualitative analysis of the pressure distribution by light and the measurement, with determination of the overall flow patterns and behavior, by "flow-visualization" techniques.

The work grew out of two recent investigations related to the acoustic phenomena in jet engines, one of which was done at the United Aircraft Corporation (Ref. 2), and the other at a consulting firm at the University of Michigan (Ref. 1).

Lateral and longitudinal flow patterns are presented for a basic configuration showing the general character of the pressure distribution and the effect of variation of pulsation levels on jet noise radiation.

In this study, the major portion of the pulsation is assumed to be due to the oscillating longitudinal airflow. Without external flow, or general circulation, no external circulation was known to be
... involved a pulsed inflow through an annulus, with an efflux through a central jet. A stagnation of the end vortex was found to be accompanied by a local formation of wake flow, but was not related to a shallow depression of the end vortex.

The work was carried out in the University of Minnesota Laboratory of the University of Iowa, under the guidance of Dr. A. L. 11, and as a preliminary phase of research to be performed by the University with United Aircraft Corpora-
Many phenomena encountered in the jet propulsion field remain obscure and little understood. Among the foremost of the problems requiring further analysis and investigation are those relating to intermittency and pulsating gas flow. Alarmsome phenomena are studied to regulate the gas flow in the jet engine. The air flow phenomenon known as the "acoustic jet" is associated with certain configurations of tubes or resonators, closed or open, and excited by a pulsation. Intermittency has been heightened by the long established "jet" that under certain conditions a significant amount of thrust is produced by these circular tubes with only a small input of energy to the pulsator.

A comprehensive summary of the historical background of this field, has been given by an earlier [1], and this report relates the acoustic phenomena directly to jet engines. A recent investigation made at the von Karman Institute for Aircraft (Ref. 1), and through significant theoretical treatment of noise generation. A brief of this nature are available (Ref. 1), and the /2/.
Abart /3/, and /4/, and /5/, and /5/, and /5/, and /5/), it appears that further analysis and investigating of the mode of the acoustic jet.

Previous investigations (refs. 1, 2) have concentrated largely on directly relating the acoustic phenomena to thrust, and have been somewhat limited in extent. However, it is extremely difficult to open-end such conditions, and it is possible to increase the thrust by increasing the amplitude of the forcing vibration. A broad program of further quantitative and qualitative determination of the flow fields in acoustic jets is needed for the attainment of adequate understanding of this special problem, and for further insight into the general characteristics of pulsating flow. Pressure surveys, paralleling the thrust measurements, are needed.

A mechanical pulsator was designed and built by the Mechanical Engineering staff for use in a broad program of research in pulsating phenomena employing both mean and instantaneous characteristics. This program was made possible by United Aircraft Research Project support. The pulsator was kindly made available for the current work which was proposed as a preliminary phase of the broad program.

The primary objectives were twofold: (1) understand
of the flow patterns and behavior employing dusts, rods, and dust as "flow visualization techniques," and thus establish, if possible, the salient characteristics of the flow associated with the basic resonator configuration in the available range of amplitude of pulsator vibration; (2) obtaining static and total pressure data, using liquid manometer systems, showing pressure distribution in the basic resonator and jet excited by the largest available (about one inch) amplitude of pulsator vibration.

The work was carried out in the Engine Laboratory of the Mechanical and Aeronautical Engineering Department of the University of Minnesota, under the guidance of Dr. J. E. Hall. The author wishes to express his appreciation for the use of the pulsator, which made possible through the U. S. Army Air Forces Research Laboratory support, and to express his thanks and appreciation to the following: Dr. W. A. Hall, for his direction and counsel; Professor T. L. Murphy, for his suggestions; and Professor E. Z. Kelly, for his guidance and assistance.
Table

<table>
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<th>No.</th>
<th>Description</th>
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<tr>
<td>1</td>
<td>Cage mean static pressure, inches of water, referred to atmospheric pressure.</td>
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<tr>
<td>2</td>
<td>Cage mean total pressure, inches of water, referred to atmospheric pressure.</td>
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<tr>
<td>3</td>
<td>Atmospheric pressure, inches of mercury, absolute.</td>
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<tr>
<td>4</td>
<td>Absolute atmospheric temperature, degrees Fahrenheit. Also used for time in seconds.</td>
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<tr>
<td>5</td>
<td>Absolute temperature, degrees Rankine.</td>
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<tr>
<td>6</td>
<td>Distance along resonator axis, in inches, measured from the plane normal to the axis, at the open end of the resonator, towards the closed end ( piston).</td>
</tr>
<tr>
<td>7</td>
<td>Variable used to indicate the position measured in the other direction (external).</td>
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<tr>
<td>8</td>
<td>General variable for distance along resonator measured from plane of closed end.</td>
</tr>
<tr>
<td>9</td>
<td>Resonator length, in inches.</td>
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<tr>
<td>10</td>
<td>Angular position in degrees, relative to the resonator axis; referred to a zero line extending from the axis eccentrically outward, and normal to the plane of the resonator. The sign of the angle (see Table VII and subsequent tables for legend) to indicate the direction of the extension of the probe at the introduction point. Thus, if the probe ends at the open introduction, + at the top of the pressure data column for 90° and for 270°, and is at the bottom of the pressure data column for 180° and for 0°.</td>
</tr>
<tr>
<td>11</td>
<td>Initial stroke from the point of the probe, positive along the line defining ( \phi ); negative along the line defining ( \phi + 180° ).</td>
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Distance, in inches, measured from the inner surface of the resonator wall along a line extending through, and normal to, the resonator axis. Thus it has its largest magnitude at the resonator axis. It is not used negatively.

St. W. Revolutions per minute of the pulsator crankshaft unless otherwise indicated.

Piston stroke in inches measured from head-end dead center.

Crank radius in inches.

Connecting rod center to center length in inches.

Angular position of the pulsator crank from head-end dead center.

Crank velocity variable.

Velocity parallel to resonator axis, positive in direction of rotation.

Phase velocity of propagation of a sound wave.

Frequency, cycles per second.

Angular velocity, radians per second.

Terms Used in Tables

Basic resonator configuration. Refers to the basic resonator configuration as described in detail in the section on apparatus.

Wall static. Refers to the instrumentation arrangement described and so referred to in the section on apparatus.

Internal static. Refers to the instrumentation arrangement described and so referred to, in the section on apparatus.

External traverser. Refers to the instrumentation arrangement described and so referred to, in the section on apparatus.
square. Used with reference to the open end of the resonator, it signifies that the tube was cut squarely off in a plane normal to the axis and that the resulting edge was not machined by tapers.

tapered. Used with reference to the open end of the resonator, it signifies that the edge was lapped to a sharp edge or corner into the end of the inner wall.
The elementary theory, concerning the possible resonant modes of vibration in air columns excited by plane pressure waves or waves on liquids, is well established and appears to have been worked out some 250 years ago (refs. 7, 8). It should suffice to review briefly the theory directly related to the resonator configuration which was used in this work, namely, a circular tube open at one end and closed at the other.

Single Resonance Theory:

Pressure impulses produced in a tube by plane surfaces normal to the axis are usually regarded to propagate as plane waves. Plane waves reflect themselves like ordinary waves. Consider a plane wave resulting from a closed end of a tube as if it were a string of fixed tension. Upon encountering an "obstacle", i.e., the closed end of a tube, they reflect with a one-hundred eighty degree change of phase, i.e., compressional waves are reflected as tensile waves and tensile waves as compressional waves. These waves travel at local sonic velocity, 1100 ft per sec or higher with respect to the air particles as compared to the tube length. Relations of reflection are related in such a way that reflected waves never
at the origin just as a consequence of the same phase is starting in the springing sound and at the moment occurs, the loudness greatly increased occurs, and it is said that it begins in vibration.

The wave length is four times the distance between a node and the adjacent antinode since the antinode corresponds to a node of motion whereas the node is eight wave lengths of motion. The node must always be at a maximum or the crest of a resonance which is not at the closed end. For these wave relations it is essential to the resonant tube length, period, the frequency. See the tube closed all around and open at the other end: we follow the motion of a wave or a wave cycle. In resonance one is seated at the closed end, reflected at the end of each cycle. Then, a closed end at the closed end of a wave crest, a node, and a node at the closed end. For this to occur a whole number of periods is equal to an integral length, 2L, 4L, 6L, etc., or closed ends, one end open, the other closed. For the closed end, a wavelength of 3L/4, 5L/4, 7L/4, etc., at a fraction of length of a node or antinode, 1L, 2L, 3L, etc.

When the tube is closed at the one end, the wave length for the standing wave is equal to the length of the tube.
experiment that a "best combination" is realized. One, the generally accepted formula for the Rayleigh frequency is such a

$$f = \sqrt{\frac{1}{2} \left( \frac{1}{1 + c^2} \right)}$$

(d)

4. **Illustrative diagrams.**

The given photo was taken in the single

4. **Illustrative diagrams.**

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The motion of the piston is of interest because it originates the role and determines the boundary conditions of the closed end. The position of the piston in this latter end is influenced with special regard to the friction of the skirt and the condition of lubrication. Thus (Ref. 12), the piston displacement from zero and dead center (z) is:

\[ z = a - (A^2 - \sin^2 \phi)^{1/2} \cos \phi \]  

where \( a \) is the center-to-center length of the connecting rods, \( A \) is the eccentric length, and \( \phi \) is the angular position of the crank from dead center. The approximate form of the (1) to suit our needs is:

\[ v = 0.0057\pi a (2.9 - \cos 2\phi) \]  

where \( T \) is as before, \( a \) is in inches, and \( \phi = \pi / 6 \). The approximate acceleration of the piston velocity (\( a \)) is first introduced in:

\[ a = 0.0070\pi a (a - \cos \phi) \]  

where the units are as before.
And current, a cumulative net rate in unit time at some rate, or that the final level of the net result is due to turbulent or convective transport. It is assumed that the average velocity of the fluid at time is the zero level, as well as the form of the coordinate time-temperature distribution, usually. It is shown to approximately 30% that the local velocity of wave propagation is a function of the local absolute temperature, thus (Ref. 16):

\[ \rho = \sqrt{\gamma P/c} \]  

where the units must be consistent.

There are certain fundamental physical differences between compressive waves and expansible waves. Some of these are occasionally considered negligible when dealing with single waves, but under no circumstances dealing with the superposition of a great number of waves. It may be shown (Ref. 16) that if a finite, continuous, compressible fluid wave, such as 

\[ P \text{ and } T \text{ are loconomically in a tube, and point of this rectangle, then it } \]
of a small step wave, such propagate itself at the local speed of sound, relative to the fluid at that point, and will therefore overtake the initial increment of the wave, after a finite time, for a discontinuity such that the compression wave plate (practically) instantaneously. This must occur because the value of a compression wave is characterized by an increase in entropy and temperature (and thus velocity of propagation) over the upstream conditions. The time is given by this to occur, given (Ref. 17, p. 67).

\[
T = (4/\sqrt{1} + 1) (1/\rho)
\]

where \( \rho = (\partial u/\partial x)_{max} \), the maximum slope of the impressed velocity-distance curve. The value of the maximum slope of the velocity-distance curve for the practical taking into crude approximation of this value, one finds, for the case of one-inch piston stroke and 1005 K related to a given foot long, resonator, that the time required to form a discontinuity could be approximately 0.002 seconds, while the time required for the pulse to reach the end of the resonator would be approximately 0.226 seconds, so that a dispersive wave is not formed. Also if the reinforcing resolved the point where the actual slope of the velocity-distance curve for the pulse for the plate was only seven times the value for the piston,
would appear near the open end of the resonator.

The resonator action is true for all capillary cases. Each succeeding moment of such a wave finds itself traveling in a slightly cooler tube than the preceding one, and thus at a slightly lower rate. One physically may lead in two or more steps and be agreed on. There is no natural mechanism for the formation of a non-homogeneous capillary wave (Def. 13). The approach film velocity relation to an expanding case creates an increment of velocity increase, whereas compressive waves impart a decrement.

Measurement of Capillary Pressure

Special problems arise in connection with the simplest measurement of oscillating pressures. The fluid is alternately closing in and anew out of the instrument transmission system and this is a non-isentropic process involving flow, work, and accompanying pressure losses. The natural frequency of the instrumentational system is completely distinct from the actual system. The air pressure are therefore attenuated, increased, and decreased.

Attenuation refers to the decrease drag along a tube due to viscous forces (not resonance effects) and is generally calculated on the basis of Stokes's law of viscosity relations.
which is given as (Ref. 12):

$$\frac{dP}{dx} = \left(\frac{12\mu}{\pi} \right) \left(\frac{1}{4\rho} \right)$$

(12)

where \( P \) is the instantaneous pressure at any point in the connecting tube; \( x \) is the distance along the tube measured from the entrance; \( \mu \) is the fluid viscosity; \( D \) is the tube diameter; \( \rho \) is the volumetric flow at any point in the tube. Equation (12) is combined with the non-steady, one-dimensional, unsteady pressure, continuity equation, as in Eq. 11, in detail. Full time for values of the loss kernel or amplitude of pressure for instantaneous pressure transient and solution. Since the entrance is assumed (about the mean pressure) to be expected that the entrance condition has been shown as the correct analysis of effects.

An analysis of stress (Ref. 16) occurs and type with its minima is shown with the variation with time, and fluctuations added to obtain the continuous effect on the pressure ratio.

In this case, equation (12) is integrated for other constant volume flow (a) and 12, solution, My dynamic flow \( (\rho = \mu < 2000) \):

$$c_1 = \frac{-1}{2} \left(\frac{12\mu}{\pi} \right)$$

(11)
and for turbulent flow \((1000 < \text{Re} < 300000)\),

\[
\frac{e_2}{e_1} = \frac{1}{\sqrt{\pi}} \left( \frac{\nu}{e_0} \right)^{7/4} \left( \frac{\Delta_p}{D^{19/4}} \right)^2
\]

where the units must be consistent, \(\nu\) is the kinematic viscosity, and the pressure drop \(\Delta_p\) is taken at the intake and outlet sections of the intake manifold. The units of flow are given in units of cubic feet per minute, with the critical pressure drop taken as \(5000\). Thus,

\[
\frac{\Delta_p}{\nu} < 5.6 \times 10^{-6}
\]

for laminar flow, with \(2 \leq \text{Re} \leq 300000\). \(\Delta_p/\nu\) is expressed. This is a limit of strong proof of laminar.

EXPLANATIONS: To obtain the values of the constants \(e_0\) and \(\Delta_p/\nu\) for given values of viscosity and pressure drop, etc., the experimental work done by various investigators, such as Johnson and Martin, \(7 \sim 11\) (p. 19). The critical Reynolds number in the case of laminar flow is given \(2 \times 10^5\) and in turbulent flow it is given \(10^7\).
The day is the present opportunity. The moment
writing fits the occasion better than ever. The
first is now 1800-21-7 271 and arc. 11.
The principal apparatus in this investigation consisted of a mechanical pulsator and all its attendant equipment.

The mechanical pulsator (see Figure 1) was a flywheel, which was coupled to a shaft and connected to the vacuum pump through a driveshaft. A small flywheel was spinned to a high speed and then connected to a mechanical pulsator. The flywheel was mounted on a flywheel with two bolts. The advantage of this arrangement was that it was only necessary to drive the flywheel to make the cycle of the pulsation consistent with the cycle of the vacuum pump.
possible
stroke
magnitudes available in the range of zero
to one inch. The values of piston stroke used in this investigation were: 0.054, 0.282, 0.542, 0.722.
These values included the minimum and the maximum for the apparatus. A needle pin bearing connecting rod (5/8 in. long, center to center) was inserted into the shaft. The shaft
was provided with a guide bearing. The piston connected to the head end of the thrust shaft and fitted into a steel cylinder mounted in an end frame. The piston, connecting rod,
thrust shaft, and the bearing were all of aluminum. The piston
had about two inches clearance to the wall of the cylinder,
and had an oil injector. The bore (1.375 in. diameter) of the
cylinder was 1.5 in. The cylinder was fitted with a half
inches oiler (corresponding to the inside diameter of the
cylinder) and 0.1 in. (5/32 in.) long. The end of the cylinder of
the cylinder was widened to six inches to relaxing the
resonator tubing.

The table indicating configuration at the test 17 used
in the test and table, refer to the previous configuration as
described in this paragraph. The materials at given time, consist
tory (2.0 inches long; 0.8 inches long; 0.8 inches long; 0.8 inches long) were
littered together as needed eventually in three clamps slugs:

- 20 -
(see Figure 1). The tube was inserted in the pulsator receiver section. The baffle tube was sealed with butyl tape which was easily removable. Small patches of the same material were used to seal surfaces which were not in use. The overall length of the resonator, measured from the open end to the main piston position (two-inch stroke), was found to be too disadvantageous and four-months section, or slightly more. The plastic tube ends were square-cut, and in particular, the base of the open end of the resonator was square-cut or blunt. Eighteen orifices (0.070 in., 'drilled with about 2.30 drill) were spread the indicated in a straight line along the upper end. Three were made on the tubing and through a broad interior of the resonator. The orifices near the open end were close to the tube end of about 3/16 inches to permit fitting at 0.314 in.

Three additional orifices were made in the first section at stations 2, 7, 12, and 17. These, together with the top orifices, were given equivalent angular radii (50° apart). The orifices were carefully aligned with the axis of the pulsator piston. The resonator center axis was eight feet from the front wall of the resonator center axis was thirty-four inches from the floor.

The main modification to the basic resonator configuration, considered in this work, was that we attempted to measure the effect of a sharp corner called an angle (Figure 5). This
was made by being a cylindrical tin collar (about one-half inch thick) and then applying the outside of the collar to produce first the sharp, and then the 'blunt, open-end edge.' A pressure tap near the edge of the tin collar was located at Station 11. A similar tin collar was used at the intersection of the tube sections for the visualizations (Figure 1b). It fit over the outside of the collar and was soldered in place. It was made from one-inch galvanized rain spout and fifty-one inches long, so that it terminated the tube length by one-half inch. It had a slit (about 1/16 inch), three holes, and another to a bit one-half inch distant. These holes were sealed with Scotch tape when not in use.

Two identical plenum chambers were built (see Figures 1, 2). They were made from four-inch galvanized rain spout and were fifty-one inches long. One of the two chambers was flattened to permit the inclusion of flat plates (one-fourth inch thick), which were placed in the space and tapped to the plunger wall by one-half-inch pipe (high-lead stop-cock). A W-shaped collar was attached at each end and fittings were bolted to each of the two chambers and connected to a Y fitting,
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The nanometers employed were of the liquid, water scale type (Fig. 1). The one which can be used for all the tests was a laboratory type, while the other was of the draft type and had a bulb, however, in its place. The range of the

meters included only the last three-inch part of the

measured. A small type of scale, draft type (en-

closed), called and distilled water, was used with the two

clown water at the nozzle, except for occasional readings

of 0.0. A small water was the scale. These were here used to the third decimal place on the distilled water and to the general decimal place on the normal water. All readings were taken as referred to the

The pressure measurement instrumentation was of two

kinds: (1) bell type, and the most of the measurements

were static pressure at various water levels; (2) internal type,

used for the inner static and total head pressure readings,

and could be referred to the

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The bell joint (Figure 1) is attached to the bell tube fittings by resonator nut. It is necessary to take care that the bell tube is not twisted or bent.

A bell joint can be moved into a slot of support pipe to the bell tube is used to provide the alternative in the vertical and horizontal planes. The upper part is used for vertical line, while the lower part is used for horizontal plane. The upper is fitted to the lower, while the lower is fitted to the upper.

The bell joint is made of rubber, and is attached to the bell tube by a metal clamp. A metal plate is used to hold the bell joint in place. The bell joint is further secured by a metal band and a total clamp. The bell joint is designed to be placed in a vertical or horizontal position. The metal clamp is used to hold the bell joint in position, while the metal plate is used to hold the metal band in place. This is to prevent the bell joint from moving.
significant changes in duct area, us.

rubber connection together, and the stor-

sion at the cji-

as shown in Figure 4.1. The brass tubing was soldered inside both inch pipes to obtain a fitting, connection at the op-ocl:

another traverse consisted

of tubing, brass, and

The brass tubing was

covered in Figure 4.1.

For internal contrast...
28

...
be obtained. This probe was made in Lubeck, Germany
by Lubeck GmbH, under the direction of Mr. Otto Stolz.

(2) Another similar probe to (1) was made of
brass tubing, with an outside diameter of
24.0000 inches and an inside diameter of
23.2000 inches. This was, however, not
brushed as much as the other probes, but
was still polished to a high degree of
finish. The inside diameter was 0.8000 inches
and the outside diameter was 0.8400 inches.

(3) A total length probe was made from brass tubing with
the same dimensions as (2) except that it was one
inch shorter in length overall. The end of this probe
was again rounded to simulate a shape, almost
like the end of a pin. A nose-1/4 inch
radius was given the end of the tube, and a
1/4 inch radius was given the end of the probe,
and parallel to, the axis of the tube, as shown on
the plans. These were then sanded down to obtain
the inside dimensions shown on
the plans.

(4) A total length probe was made from brass tubing with
the same dimensions as (2). This was made
from 1 inch of brass tubing and polished to
the shape of a pin. A nose was 1/4 inch
radius, and a
The side of the probe is constructed of an angle iron and end. This hole in the side is located at the point of which is only slightly different from the inside diameter of the probe (3/32-inch). The probe has been referred to as a cylinder-type. An insertion hole along it is made in the fact that stagnation occurs at the leading edge of a cylinder placed normal to a steady flow.

The external transverse traverse arrangement is shown in Figure 4. The probe fitted to a lip fitting in a mounting plate to the support frame. A probe could and was further, in a serviceable condition on the plate for positioning. Vertical positioning could be made by moving the mounting plate up and down between the two vertical support bars. When positioned vertically, the mounting plate position was fixed by a clamp arrangement. The vertical support bars could be rotated about a vertical axis providing another degree of freedom. The vertical traverse probe has been connected to the plot containing the test chamber of water, (3/32 in. 17) and a one-way stop-cock.

A description of the prong and with the external transverse arrangement follows.
(1) A thin (metal-lead) tube (cf. 11) with a lath that was available on this tube and for all of the other thin metal-lead components. The metal tube inside the outer shell of this whole and undesirable dimension of quadruple 'airtightness' of a pipe and the approximately two inches in length, it led to a larger metal tube which also served as the support for probe. Thus, the inner side of this inner tube was made slightly wider and long, taking about twenty inches overall, five short sections of an inch inside diameter, and three sixteenths of an inch outside diameter. The inner shell of the metal tube was used for this, and is outside the inner tube; the 'aft' end was seated from the side of the shaft in this location of a inch.

(3) a thin probe for the 'aft' site was a metal component, with a metal, in brass tubing, with the shape of a spiral, and the start just a few inches from the shaft, and it large part, the start of the probe shaft, at a slightly thicker end. It was had a lath wherever in the shaft of the thin
tube (3), but this was inserted in a short tube inside short of the bend. The bend of the smaller section of the tube was then shaped in overall length, one-third of an inch in height, short of the short part of the \( \frac{1}{2} \) inch square polished so that, if the plane \( \frac{1}{2} \) inch short parallel to the flow, it would read nearly the static pressure. It was agreed this way, cutting only, and the end plane later, in the horizontal plane, for carrying through the central axis of the resonator and jet.

Various methods of producing scale were tried. The first satisfactory method employed was sandblasting.

Quantities of a slate, plastic, cellulose, lacquer, and metal, with the lacquer central (Mural Chemical Company), were supplied. This material is extremely light, with a "fuzzy" asbestos texture. The larger particles were removed by hand-picking, but the smaller were in a very dry, fine dust. It was inserted into a tube by using a large insect duster, and the insect duster was then used to wipe it off. The film produced was then dried by blowing with a jet air stream.
The first resonant frequency of the system should be kept well above the desired measurement range. This could be accomplished only by installing the pressure line between the liquid manometer and the tube length for which the pressure was to be kept above the desired one. In this liquid manometer, the bulb, which is connected to the tube length, provides the oscillations.
A study of static pressure distribution along the surface of the
piston.

Values of static pressure, with local variations,
along the surface, were recorded for the initial
condition, and the study showed that
pressure varied along the surface. By adding water to the
reservoir, the pressure was shifted from a region of lower
pressure. The study indicated that static pressure
values occur near the resonator, but the change is
insignificant.

The total area of the piston surface, was
recorded, and, from this, the static pressure
was calculated. By reversing the conditions, the
opposite occurred, and the change was
insignificant. The results indicated the
importance of the resonator and its effect on the
overall performance of the piston. Further studies will
attempt to determine the influence of these factors.
The reversal of dominant total head values at the orator mouth suggests that the air entering the air channel is not merely the total "pull" of the jet, but also experienced the disruptive effect of the jet colliding over a relatively short time. Although such jet effects (including injection of the air and jet) are in essence in reality alternating, and only appear to be simultaneous in consequence of the instability of the jet to follow such rapid changes.

The total jet is intermittent, the surface of its outer edge being continually fluctuating, and various sections become the discharge outlet. The major portion of the air for which appears to be jetted is oscillating near the wall surfaces and jet flow which appears to be jet. All normal circulating air, which appears to be jet. All normal circulating air, which appears to be jet. All normal circulating air, which appears to be jet. All normal circulating air, which appears to be jet.
entering the resonator. It appears that the "critical" lack of resonance is critical for support of the film.

The maximum difference between static and total "peak" values (approximately three and one-half inches of water) occurred just inside the resonator area, and was indicative of the presence of the boundary layer. The peak velocity at the first and the resonator is indicated as about eighty-three per cent, and the mean velocity at a distance of three feet inside the resonator is indicated as nearly thirty feet per second. These values agree with the expected increase in the axial radial velocity of eight feet per second for a length of 0.278 inch, a total change of 64.5 per cent.

### Critical Pressure Disturbances

A comparison of the mean static pressure distribution along the wall of the resonator with the radial static pressure distribution is shown in Figure 6. The axial pressure is lower than the wall gradient such that the inner boundary layer produces a value that along the axis of the resonator is appreciable. The values are very small in the near the closed end, in clear, normal of 120 ft.

The data above were just inside the wall, which are 12 inches related to the effect of the edge vortex system. A 24 inches of the...
The axial and wall static pressure distributions correlate with the visual observations of greatly increased dust particles with length near the open end, indicating that the latter are an indication of increased static particle length.

Profiles of mean static pressure distribution inside the resonator are shown in Figure 15. These profiles, with the exception of that for static one, were obtained by taking from two pairs of pressure traverses at each station as a check upon the integrity of the pressure distribution.

Profiles of mean static and total pressures in the external jet area (horizontal plane) are presented in Figure 20 for various magnitudes of piston stroke for the new-end, which is free from the open end of the resonator.

Total head profiles are presented in Figure 21. These gradients appear to be small except in the region near the open end of the resonator.

**Variation (1) - the Pressure Distribution with Axial Plane**

The mean static pressure distribution along the resonator wall for various magnitudes of piston stroke is shown in Figure 3. The pressure gradients do not change significantly with piston stroke, although the critical mean static distributions suffer an
variation in pressure for a blunt and sharp edged open-end resonator configuration.

The difference in null static and periodic distribution along the resonator with blunt and sharp edges opened and closed configurations is shown in Figure 12. As with lower values were obtained with the sharpened edge.

variation in null static in steady with frequency for fixed resonator length.

The variation of axial static pressure along along the resonator wall is shown in Figure 12 for various selection of values. A comparison of pressure measured for selected stations lead to Figure 12. It is evident that a longitudinal pressure gradient is present which is the interior.
The frequency of the resonator values occur at, or near, the closed end (piston), or at the open end. This is in agreement with theory (\textit{w} = \sqrt{L/\rho}). The slope of the curves was determined from the resonant frequency. The resonant peak for the basic configuration was taken as 1007, and compared with the theoretical configuration as taken as 1007. The theoretical formula (Equation 1) gave values of 1007 and 1007, respectively.

The greatest change in the slope on either side of the peak. The positive slope changes at a frequency in agreement with the measured slopeanges when there is instability. A joint is found in points of the resonator close to the unstable connexion with the resonator. The same is still valid for both positive and negative slopes at the resonator. The general shape of the "peak" on the frequency curve, shown in Figure 2, is the same as the joint in the resonator, indicating that the resonator is unstable.
The values of the variables were determined by measuring the object and the light source. The values were then compared to determine the effect of the variables. The results showed that the values for the object and the light source were significantly different. It was concluded that the values for the object and the light source were not comparable.
Yith the introduction, the tendency was to an idea, and
within the extended area of quality, the tendency was to
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and with large, in large, to the large, to the large.

The large, of the large, could be in large, with large,
and with large, in large, to the large, to the large.
A comparison of the results of calculation with small and large pulsation amplitudes is presented in Figure 27. In the estimation of calculation time, various small and large amplitudes are plotted in Figure 27 for fields of large amplitudes.

Small voltage oscillations or fluctuating fields in a straight line caused by the great straight lines of the pulsating inductance. The observation of such individual oscillations, as well as those inside the resonator are quite peculiar, i.e., the test observations were possible only a few times, since particles were present. The individual rest movements, which were actually small in height, were easily detected by the test movements. The location of these particles is determined to be at the top, till the gap is 2.8mm. After 2.8mm, in the closed (shown) one. Computation time is about much shorter than those. It is often difficult for numerical solutions, but the results of calculation are not very different, disturbance, of which cannot be measured. Systematic errors, which are common, are stable in the measurement of equilibrium. The 2.8 mm gap in the resonator is used.
A nearby open window was sometimes sufficient to cause mechanici-
ous disturbances such that only the distillate near the closed end
remained relatively undisturbed.

The magnitude of the cloud, which could be traced by the open
end of the cloud (either by eye or in a close-up, for example, of the
cloud in Figures 13 and 14), increased with the increase of the
end of the cloud. The visual evaluation of the particle path
paths (Table 1 and Figures 13, 14, and 15). In addition to the cloud formation, it was also
noteworthy that the particle path length was recorded in Figure 31.
It is difficult to make such estimations accurately, and the results
will be regarded with caution.

Detailed observations of the dust particles were made in the hope
that their length, although generally equal to the cloud path length,
also included in the cloud (Figure 13). However, it was
found that the significant detail, such as the characteristic features
of the cloud, was not always visible. Instead, the cloud was
usually curved in shape, and irregularities were often present. The
visual observations were made in addition to the cloud formation
(Figure 14), but irregularities were still present.
tion of dust figures we observed as a sort of sudden growth from a lateral dust ridge, at the bottom of the tube. After some initially several of these dust ridges before they figure. At the head was observed after the open part of the tube, and s
olution they were observed to collapse into dust ridges. They collapsed also in a large number of open and the middle of the room, allowing the dust to escape. Dust figures were observed to collapse into the operation, as a sort of removal of the room process. The whole of dust figures was just inside the room and could be observed to be much dust and partially lost and thus. Similarly, about twice the observed particle path length observed at the open location. This observation at a line circle of 0.02 mm showed that the particle path length is longer to the average dust figure into

The particle size of the dust figures was greater near the open end. This probably, because the 0.02 mm path length for an open end, is a factor in the rate of the open end. The open end was made from the dust figures into a third the tube length. The average dust figures into the open end was observed, although it appeared that the normal
condition has stabilized. Just prior to arrival at the open end of the resonator, all flow patterns are cut out, and flow out the central jet. This produces an excellent means of visualizing the low-velocity annular flow along the jet as shown in Figs. 21, 22, and 23, and shows the degree of symmetry in the flow.

Limitation of Results

The major factor affecting the results obtained was the instrumentation detail with reference to the length and length of all tubes and constrictions used in the pressure measurement system. Qualitative evaluation of the data would depend on a detailed evaluation of the theoretical and empirical lines presented in the discussion of related theory (Ann. 11, 11, 10).

It was found that a basic requirement was the exercise of extreme care with regard to the uniformity of the test equipment at each station. During the course of the investigation, some experimental errors were discovered.

Good reproducibility of results was achieved. The results did not appear to be sensitive to small variation.
The basic assumptions are that the current is centered about the line that is parallel to the axis, and that the current is dispersed in a manner given by the axis of symmetry. The results, and the apparatus, have not been published. The latter appears gradually, and everywhere there is a certain amount of criticism. The data of Fig. 1, it appears somewhat valid along the axis of symmetry.

The general conclusion drawn through the above visualization (Fig. 2) is that there is an upper limit of the particle’s velocity, the upper limit being determined by the pressure distribution. The dispersion of the most probable jet behaves as a continuous system, but in a region of turbulence, involving a more violent competition of all linear dimensions, with a less particle velocity as a function of the particle nature.
These conclusions should not be taken as definitive statements but rather as hypotheses to be tested further.

(1) As the sample size increases, the error rate decreases, approaching zero as the sample size approaches infinity.

(2) The relationship between energy and temperature follows an exponential pattern, with the theoretical value of the resonator with corrections being offset.

(3) In certain conditions, the relationship between pattern and axial gradient is linear, with a slight negative correlation.

(4) The theoretical model suggests a Gaussian distribution of particle concentration, with the observed values falling within the expected range, indicating a decrease in error over time.

(5) The rate of change of the system's parameters, such as temperature, can be described using differential equations, based on the observed data and essential, although for any
Given conditions making the assumptions valid.

(5) In general, the velocity along the tube, including the jet velocity and that at the open end, varies with, or just inside, the resonator open end.

(6) The velocity along the tube is constant inside the open portion of the resonator. Inside the closed portion, the velocity remains constant. The resonant frequency is the same as the frequency of the open portion. When resonant, the resonator is a perfect jet vortex in influx of air centered at the open end of the resonator.

(7) The same resonance effects are observed when the resonator is a perfect jet vortex in influx of air centered at its open end.
To determine the effect of an external stimulus on the blood flow, the experimenter observed the pressure fluctuations caused by the pulsation of the column. The instability, which appeared to be relatively symmetrical, revealed that the pulsation was a function of the depth and amplitude of the pulsator vibration. The apparent increase in the depth of the pulsator vibration was associated with a decrease in pulsation amplitude, but remained relatively shallow.

(10) A detailed analysis of the pulsator vibration
was performed to calculate the actual depth of the pulsator vibration.


TABLE 1

DETERMINATION OF THE NAT FREQUENCY FOR VARIOUS RESONATOR CONFIGURATIONS

(Resonator Wall Mean Static Pressure Data)

<table>
<thead>
<tr>
<th>Instrumentation</th>
<th>Wall Static</th>
<th>piston stroke: 0.250 in.</th>
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</thead>
<tbody>
<tr>
<td>End Edge Shape</td>
<td>Square</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>$X_a$ (in. from open end)</th>
<th>$X$</th>
<th>Resonator Length: 107.4 in.</th>
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</table>

See apparatus and instrumentation

from limitations.
### Table 11

**Determination of Kestner Ball Static Pressure Data**

(*Kestner Ball: Static Pressure Data*)

<table>
<thead>
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<th>Instrumentation: Static Static</th>
<th>Data Point</th>
<th>0.002 in.</th>
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<tbody>
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*See Appendix for More Calculations*

*Note: Limitations*
## Table 311

### Variables of Resonance Wall Reinforcement Simple Symmetry

**Instrumentation:**
- Small strain
- End edge change limits
- Resonator: Basic Configuration

<table>
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</tr>
</tbody>
</table>

**Notes:**
- Instrumentation
- See limitations
- Modified connection (small tube) at vessel end (see Figure 3)

### Nomenclature

- See limitations

### Additional Information

- Modified connection (small tube) at vessel end (see Figure 3)
### Table IV

**Static and Static Pressure Data**

<table>
<thead>
<tr>
<th>Stroke</th>
<th>0.978 in.</th>
<th>109.4 in.</th>
</tr>
</thead>
</table>

**Instrumentation:** Small static pressure.

**Piston Stroke:** 0.978 in.

**Reservoir Length:** 109.4 in.

**Reservoir:** Static configuration plus specialized.

<table>
<thead>
<tr>
<th>Stroke</th>
<th>0.978 in.</th>
<th>109.4 in.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Station</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
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<td>3</td>
<td>4</td>
</tr>
<tr>
<td>h_a</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>h_b</td>
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<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>h_c</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>h_d</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tbody>
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---

**See Li et al.**
## Table 7

### Resonator Wall and Static Resonator Separation

**With Various Piston Strokes**

<table>
<thead>
<tr>
<th>Instrumentation</th>
<th>Wall Static</th>
<th>Resonator Basic Configuration</th>
<th>Resonator Length: 107.1 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Piston Stroke, in.</strong></td>
<td>0.004</td>
<td>0.022</td>
<td>0.040</td>
</tr>
<tr>
<td><strong>in.</strong></td>
<td>103.8</td>
<td>104.5</td>
<td>105.2</td>
</tr>
<tr>
<td><strong>in.</strong></td>
<td>20.42</td>
<td>20.52</td>
<td>20.62</td>
</tr>
<tr>
<td><strong>in.</strong></td>
<td>19.4</td>
<td>19.5</td>
<td>19.6</td>
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</table>

<table>
<thead>
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<th><strong>3</strong></th>
<th><strong>4</strong></th>
<th><strong>5</strong></th>
<th><strong>6</strong></th>
<th><strong>7</strong></th>
<th><strong>8</strong></th>
<th><strong>9</strong></th>
<th><strong>10</strong></th>
<th><strong>11</strong></th>
<th><strong>12</strong></th>
<th><strong>13</strong></th>
<th><strong>14</strong></th>
<th><strong>15</strong></th>
<th><strong>16</strong></th>
<th><strong>17</strong></th>
<th><strong>18</strong></th>
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</thead>
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<td><strong>x</strong></td>
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<td>-0.25</td>
<td>-0.38</td>
<td>-0.52</td>
<td>-0.67</td>
<td>-0.82</td>
<td>-0.97</td>
<td>-1.13</td>
<td>-1.28</td>
<td>-1.43</td>
<td>-1.59</td>
<td>-1.74</td>
<td>-1.90</td>
<td>-2.06</td>
<td>-2.21</td>
<td>-2.36</td>
<td>-2.51</td>
<td>-2.66</td>
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<tr>
<td><strong>y</strong></td>
<td>-0.20</td>
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<td>-0.46</td>
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<td>-0.72</td>
<td>-0.85</td>
<td>-0.99</td>
<td>-1.13</td>
<td>-1.26</td>
<td>-1.40</td>
<td>-1.53</td>
<td>-1.68</td>
<td>-1.82</td>
<td>-1.96</td>
<td>-2.10</td>
<td>-2.24</td>
<td>-2.38</td>
<td>-2.53</td>
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<td><strong>z</strong></td>
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<td>-0.60</td>
<td>-0.73</td>
<td>-0.86</td>
<td>-1.00</td>
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<td>-1.27</td>
<td>-1.40</td>
<td>-1.54</td>
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<td>-1.82</td>
<td>-1.96</td>
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<td>-0.32</td>
<td>-0.45</td>
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<td>-0.85</td>
<td>-0.99</td>
<td>-1.13</td>
<td>-1.26</td>
<td>-1.40</td>
<td>-1.53</td>
<td>-1.68</td>
<td>-1.82</td>
<td>-1.96</td>
<td>-2.10</td>
<td>-2.24</td>
<td>-2.38</td>
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</table>

*See Apparatus and Nomenclature

++See Limitations*
<table>
<thead>
<tr>
<th>L</th>
<th>USG</th>
<th>h (at piston)</th>
<th>hg (at edge o-ring)</th>
<th>P (lbs)</th>
</tr>
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<tr>
<td>0.179</td>
<td>24.74</td>
<td>10.6</td>
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<td>0.392</td>
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<td>0.643</td>
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<td>0.295</td>
<td>26.54</td>
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<td>0.084</td>
<td>24.31</td>
<td>17.3</td>
<td>-0.1</td>
<td>0.8</td>
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</table>
### TABLE VIII

**Cylindrical, Internal Asbestos Insulation, Indoor Static Pressure Data**

**Instrumentation:** Internal Pressure (Probe 2)

**Asbestos:** Basic Configuration

**Reactor Length:** 107.4 in.

<table>
<thead>
<tr>
<th>No.</th>
<th>1</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
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<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
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<tbody>
<tr>
<td>T (°F)</td>
<td>28.0</td>
<td>27.2</td>
<td>26.0</td>
<td>23.3</td>
<td>23.2</td>
<td>22.3</td>
<td>20.7</td>
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<td>20.2</td>
<td>20.1</td>
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<td>20.0</td>
<td>20.0</td>
<td>20.0</td>
<td></td>
</tr>
<tr>
<td>T (°C)</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>4</td>
<td>5</td>
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<td>5</td>
<td>6</td>
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</tr>
<tr>
<td>T (°K)</td>
<td>300</td>
<td>299</td>
<td>296</td>
<td>294</td>
<td>290</td>
<td>286</td>
<td>282</td>
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<td>280</td>
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</tr>
</tbody>
</table>

**Note:**
- T = Temperature
- C = Configuration
- K = Kinetic

---

**Notes:**
- See Fig. 10 for pressure
- See Fig. 11 for introduction
- See Fig. 12 for correlation
## Table II

**Objective:** Initial sound attenuation and sound pressure levels.

**Instrumentation:** External pressure transducer, basic configuration with resonator length 1902 in.

<table>
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<tr>
<th>Resonator Length</th>
<th>1902 in.</th>
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</table>

<table>
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<th>Type of Probe</th>
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<th>L-head-3</th>
<th>L-head-3</th>
<th>L-head-3</th>
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<td>1.0 in.</td>
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<td>1.0</td>
<td>1.0</td>
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<tr>
<td>1.5 in.</td>
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<tr>
<td>2.0 in.</td>
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<td>1.0</td>
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**Probe Opening, Probe toward listener:**

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<th>r (in.)</th>
<th>( b_0 )</th>
<th>( b_1 )</th>
<th>( b_2 )</th>
<th>( b_3 )</th>
<th>( b_4 )</th>
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<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
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<tr>
<td>0.75</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>1.75</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>2.75</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>3.75</td>
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<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**Probe Opening, Probe away from listener:**

<table>
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<th>r (in.)</th>
<th>( b_0 )</th>
<th>( b_1 )</th>
<th>( b_2 )</th>
<th>( b_3 )</th>
<th>( b_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>0.75</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>1.75</td>
<td>0.03</td>
<td>0.03</td>
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<td>0.03</td>
<td>0.03</td>
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<tr>
<td>2.75</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>3.75</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
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</table>

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*See Apparatus and Sound Levels.*

*See Li Ref. 1981.*

*Figures to null position of probe introduction. See Sound Levels.*
**TABLE III**

**MEASUREMENT DATA AT WALTHER CENTER**

<table>
<thead>
<tr>
<th>Instrumentation:</th>
<th>Internal Traverse, Cylinder Probe</th>
<th>Resonator:</th>
<th>1000-1500 Configurations</th>
<th>Motor Stroke: 0.978 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonator Length:</td>
<td>127.4 in.</td>
<td>Blade Shape:</td>
<td>Square</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Distance from tube wall, in. (a)</th>
<th>0.73</th>
<th>2.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probes and orientation</td>
<td>Row B: Piston Away from Piston</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sta. No.</th>
<th>Row A</th>
<th>h_{o}</th>
<th>h_{o}</th>
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<tbody>
<tr>
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<td>1.02</td>
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<td>0.23</td>
</tr>
<tr>
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<td>0.23</td>
<td>0.24</td>
</tr>
<tr>
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**Note:**
- See apparatus and nomenclature.
- *See limitations.
- **Refers to wall position of probe introduction. See nomenclature.
### TABLE XIV

<table>
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<tr>
<th>Instrumentation</th>
<th>Instrument</th>
<th>Open (in.)</th>
<th>Closed (in.)</th>
<th>Open (out.)</th>
<th>Closed (out.)</th>
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#### Apparatus and Instrumentation:

- See limitations.
- Downstream position of direction of probe introduction.
- "Out" is positive on side from which probe is introduced. See limitations.
- "Total" and opening (in out) are always from the given (out).
### Table 2.2

**SILHOUETTE OF INSTRUMENT**

((Anomalous: horizontal illumination))

<table>
<thead>
<tr>
<th>Traversed Plane</th>
<th>Instrumental Distance</th>
<th>Specimen's Plane Configuration</th>
<th>Accelerator Length: 107.4 in.</th>
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<td>x</td>
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<td>z</td>
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**Notes:**
- Instrument and Traversed Plane:
- Accelerator Plane Configuration:
- Specimen's Plane Configuration:
- Accelerator Length: 107.4 in.

**Legend:**
- X: Horizontal illumination
- Y: Vertical illumination
- Z: Depth of field

**Definitions:**
- X: Horizontal illumination
- Y: Vertical illumination
- Z: Depth of field

**Specifications:**
- Accelerator Plane Configuration:
- Specimen's Plane Configuration:
- Accelerator Length: 107.4 in.
### Table III

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<th>Piston Stroke, in.</th>
<th>Observed Particle Length, in.</th>
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<td>0.062</td>
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<td>0.078</td>
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<td>0.084</td>
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*Visual Observation*

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<th>Piston Stroke, in.</th>
<th>Visual Observation</th>
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<td>0.090</td>
<td><a href="#">Graph</a></td>
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*Visual Observation*
Figure 3. Nucleus Core and φ 160 mm "Wall Unit" Instrumentation.
FIG. 5 RESONATOR MEAN STATIC AND TOTAL PRESSURE DISTRIBUTION IN AXIAL DIRECTION (DATA FROM TABLES VII, VII, I)

- WALL STATIC PRESSURE
- AXIAL STATIC PRESSURE
- AXIAL TOTAL PRESSURE FACING PISTON
- AXIAL TOTAL PRESSURE FACING AWAY FROM PISTON

PISTON STROKE: 0.75 IN.

TOTAL FACING PISTON
TOTAL FACING AWAY FROM PISTON
WALL STATIC
AXIS STATIC

DISTANCE FROM OPEN END OF TUBE, IN (INTERNAL)
FIG. 7  MEAN PRESSURE DISTRIBUTION IN JET ALONG RESONATOR AXIS OF SYMMETRY
(Data from Tables I, XI, XII, XI VI, and VII)
Piston stroke = 0.978 in.

DISTANCE ALONG RESONATOR AXIS OF SYMMETRY, IN
-60 -54 -45 -42 -36 -30 -24 -18 -12 -6 0 12 18 24 30 36 42

SAME MEAN PRESSURE, IN H2O

○ MEAN STATIC PRESSURE, INTERNAL PROBE (2)
✓ " " " " EXTERNAL PROBE (6)
△ MEAN TOTAL PRESSURE, INTERNAL PROBE (4), FACING PISTON
✓ " " " " EXTERNAL PROBE (5), FACING AWAY FROM PISTON
✓ " " " " INTERNAL PROBE (4), FACING PISTON
■ " " " " EXTERNAL PROBE (5), FACING AWAY FROM PISTON
FIG. 8  RESONATOR WALL STATIC PRESSURE DISTRIBUTION FOR VARIOUS MAGNITUDES OF PISTON STROKE
(DATA FROM TABLE IV)

X = 0.054 INCHES PISTON STROKE

\[ v = 0.292 \]

\[ v = 0.342 \]

\[ v = 0.762 \]

\[ v = 0.978 \]

\[ \times \] MEANS EXPERIMENTAL ERROR
FIG. 12  EFFECT OF FREQUENCY ON MEAN STATIC PRESSURE AT THE RESONATOR WALL FOR SELECTED STATIONS (DATA FROM TABLE III)

PISTON STROKE = 0.278 IN.

GAGE MEAN STATIC PRESSURE, IN H2O

FREQUENCY (RPM)

1850  1875  1900  1925  1950

STA. 1
STA. 6
STA. 8
STA. 11
STA. 15
STA. 18
FIG. 13 DETERMINATION OF RESONANT FREQUENCY FOR BASIC RESONATOR CONFIGURATION BY MEASURING THE MEAN STATIC PRESSURE AT THE RESONATOR SURFACE (DATA FROM TABLE I)

Piston stroke = 0.978 in.
FIG. 14

DETERMINATION OF RESONANT R.P.M.
FOR TAPERED LIP RESONATOR CONFIGURATION
(TWO INCHES ADDITIONAL LENGTH)

(DATA FROM TABLE II)

PISTON STROKE = 0.978 IN.

GAGE MEAN STATIC PRESSURE, IN. H₂O

1800  1825  1850  1875  1900

FREQUENCY (R.P.M.)
FIG. 15  THRUST FOR BASIC RESONATOR CONFIGURATION.
(DATA FROM TABLE V).

L = 107.4 IN.
D = 5.5 IN.

THRUST, LBS.

PISTON STROKE, IN.
FIG. 16  INTERNAL RADIAL TRAVERSE,
MEAN STATIC PRESSURE
(DATA FROM TABLE VII)
PISTON STROKE = 0.978 IN.

DISTANCE FROM TUBE WALL, IN

GAGE MEAN STATIC PRESSURE, IN. H2O

STATION 1  STATION 2  STATION 7  STATION 12  STATION 17

θ = 0°
θ = 30°
θ = 90°
θ = 270°
FIG. 17 MEAN PRESSURE PROFILES IN JET OUTSIDE OF RESONATOR OPEN END
(Data from Tables XII, XIII)
Piston stroke = 0.778 in

○ Gage mean static pressure
△ Gage mean total pressure, facing piston
▼ Gage mean total pressure, facing away from piston
○ External distance from resonator open end, measured along central axis, in
• Experimental error
FIG. 18 INTERNAL RADIAL TRAVERSE
MEAN TOTAL PRESSURE
(DATA FROM TABLE TX)
PISTON STROKE = 0.978 IN.

GAGE MEAN TOTAL PRESSURE IN. H2O

STATION 2  STATION 10  STATION 17

D = "L" TYPE TOTAL-HEAD PROBE FACING PISTON
Q = "L" TYPE TOTAL-HEAD PROBE FACING AWAY FROM PISTON
> = CYLINDER TYPE TOTAL-HEAD PROBE FACING PISTON
< = CYLINDER TYPE TOTAL-HEAD PROBE FACING AWAY FROM PISTON
FIG. 27. VARIATION OF DEPTH OF PENETRATION OF RESONATOR, BY END VORTEX SYSTEM, WITH MAGNITUDE OF PISTON STROKE.

(DATA FROM TABLE XII)

@ ESTIMATED FROM DIRECT OBSERVATION
@ ESTIMATED FROM PHOTOGRAPHS

DEPTH OF PENETRATION OF RESONATOR, BY END VORTEX SYSTEM, IN.

PISTON STROKE, IN.
FIG. 30 ESTIMATED DUST PARTICLE PATH LENGTH FOR DIFFERENT MAGNITUDES OF PISTON STROKE.
(Data from Table XII, visual estimations)

\( \theta = 0.054 \text{ in.} \)
\( \Delta = 0.292 \text{ in.} \)
\( \nabla = 0.542 \text{ in.} \)

FIG. 31 VARIATION OF ESTIMATED DUST PARTICLE PATH LENGTH WITH PISTON STROKE.
(Data from Table XII, visual estimations)

\( \odot \) Station 3.
\( \triangle \) Station 17.
\( \square \) Piston.
FIG. 92: IDEALIZED TIME-DISTANCE DIAGRAM OF
WAVE PROGRESS IN A RESONATOR
CLOSED AT ONE END BY A PULSATOR
AND OPEN AT THE OTHER END
SAMPLE CALCULATIONS

RESONATOR FREQUENCY:

\[ \pi = 2.75 \text{ in.}; \quad L = 107.4 \text{ in.}; \quad t = 88^\circ F (\text{Table I}) ; \]

\[ f = \frac{12 \cdot 1148}{4(107.4 + 0.6(3.75))} = 31.63 \text{ c.p.s.} = 1898 \text{ R.P.M.} \]

VELOCITY:

\[ h_o = -0.67 \text{ in. } H_2 O \quad (\text{Table I, Sta. 1}) \]
\[ h_s = -3.68 \text{ in. } H_2 O \quad (\text{Table VIII, Sta. 1}) \]

\[ V = \sqrt{2 \left( \frac{h_o - h_s}{\rho} \right)} = \sqrt{2 \left( \frac{4.2(3.68 - 0.67)}{(12)(0.002378)} \right)} = 116 \text{ ft/sec.} \]

THRUST:

\[ H_a = 29.42 \text{ in. } H_2 O = 400 \text{ in. } H_2 O \quad (\text{Table IV}). \]
\[ h_s(\text{piston}) = h_s = +6.6 \text{ in. } H_2 O \quad (\text{Fig. 8, uncorrected}) \]
\[ h_s(\text{open edge}) = h_{se} = -3.6 \text{ in. } H_2 O \quad (\text{Fig. 8, uncorrected}). \]

\[ T = P_p \cdot A_p + P_{se} \cdot A_e - P_a \pi (\rho)^2 \]

\[ P_p = \text{absolute pressure on piston, lbs/in}^2 \]
\[ P_{se} = \text{"} \quad \text{" open-end edge, lbs/in}^2 \]
\[ P_a = \text{"} \quad \text{" atmospheric assumed acting externally on unit.} \]

\[ A_p = \text{piston area} = \pi (2.75)^2 = 23.80 \text{ in}^2 \]
\[ A_e = \text{open-end edge area} = \pi (3)^2 - A_p = 4.48 \text{ in}^2 \]

\[ T = \frac{62.4}{12.144} \left[ 406.6(23.8) + 376.4(4.48) - 400(23.828) \right] \]

\[ = 6.06 \text{ lbs.} \]
Investigation of the air-flow in an acoustic jet a resonance.