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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 in Partial Fulfillment of the Requirements
for the
Degree of Master of Science in Mechanical Engineering

of the University of Missouri

By

Ralph C. Janes

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A Thesis

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By

[Signature]

[Date]
TABLE OF CONTENTS

Introduction .................................................. 2

1. Introduction ................................................. 3

2. Conclusion ................................................ 6

3. Related theory ............................................. 8

4. Description of apparatus and procedure ............. 13

5. Results and discussion .................................. 22

6. Conclusion ................................................ 45

7. Bibliography ............................................... 50
Figure 1. Principle apparatus

Figure 2. Mechanical pulsator

Figure 3. Receiver with constant total pressure distribution in axial direction

Figure 4. Mean static pressure distribution in axial direction around

Figure 5. Receiver with static distribution for various magnitudes of piston stroke

Figure 6. Effect of gas absorbent material on static pressure at the nozzle surface

Figure 7. Effect of gas absorbent material on static pressure at the nozzle surface for various magnitudes of piston stroke

Figure 8. Effect of frequency on static pressure at the nozzle surface for selected stations

Figure 9. Effect of frequency on static pressure at the nozzle surface for selected stations

Figure 10. Effect of frequency on static pressure at the nozzle surface for selected stations

Figure 11. Effect of frequency on static pressure at the nozzle surface for selected stations

Figure 12. Effect of frequency on static pressure at the nozzle surface for selected stations

Figure 13. Effect of frequency on static pressure at the nozzle surface for selected stations

Figure 14. Effect of frequency on static pressure at the nozzle surface for selected stations

Figure 15. Effect of frequency on static pressure at the nozzle surface for selected stations

Figure 16. Internal radial force on static pressure
Figure 17. Iowan Pressure Profile A. d) Outside of Resonator Open End

Figure 18. Internal Pressure Profile of an Iowan Pressure

Figure 19. Dust Figure and Jet at Low Pressure

Figure 20. Dust Midge Jet After Open and After After a Piston Stroke of 0.202 in.

Figure 21. Dust Figure Jetting into Jet at a Piston Stroke of 0.054 in.

Figure 22. Dust Figure Jetting into Jet with Smoke Showing Movement at a Piston Stroke of 0.354 in.

Figure 23. Same as Figure 22 except that downstream Detail of jet is more sharply outlined.

Figure 24. Close-up of dust figure; not visible is the observed fact that these tiny particles are describing straight oscillatory paths parallel to the axis, not at the top and six inches apart.

Figure 25. Illustration of Side Vortex at a Piston Stroke of 0.732 in.

Figure 26. Illustration of Side Vortex at a Piston Stroke of 0.354 in.

Figure 27. Variation of Depth of Penetration of Dust, with Magnitude of Piston Stroke

Figure 28. Oscillating Particles of Dust at a Longer Time Scale (between Strokes 2 and 4) at a Piston Stroke of 0.354 in.

Figure 29. Oscillating Particles of Dust at Same Location as Figure 24 at a Piston Stroke of 0.354 in.

Figure 30. Estimated Dust Particle Path Length for Different Magnitudes of Piston Stroke

Figure 31. Variation of Estimated Dust Particle Path Length with Piston Stroke

Figure 32. Ideal Dust Particle Path Length for Dust in a Resonator Closed at One End by a Pulsator and Open in the Other End.
The airflow phenomenon, known as an "acoustic jet" and associated with an engine operating excited by a pulsation, was investigated using a mechanical, piston-type pulsator with piston strokes varied in the range of 0.2 to 1.0 in. The objective was the quantitative examination of the exhaust pressure distribution by light-weight sensors, wall shearing stress, and overall flow patterns and behavior, all "non-intrusive" methods.

The work grew out of two recent investigations relating the acoustic phenomenon to aerodynamic thrust, of which one was done at the United Aircraft Research Laboratory (Ref. 2), and the other of which was done at the University of Minnesota by L. L. Stricker (Ref. 1).

Lateral and longitudinal plan pressure profiles are presented for a basic configuration showing the general character of the pressure distribution and the effect of variation of general levels of pulsation vibration.

In the early stage of the research it seemed likely to be relatively longitudinally uniform, thus in general circulation, an external circulation on sides and
involved a pulsation through an orifice (not an actual orifice) and an efflux through a central jet. The pulsation of the end vortex was speed to demonstrate increased angularity of particles, but was realized by allowing a second jet to consist mainly of air which was part of the external circulation.

All work was carried out in the fluid laboratory of the University of Minnesota, under the guidance of Dr. A. H., and as a preliminary phase of a much larger investigation to be performed by the University with United Aircraft Research Depart-
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 intermittent and pulsating gas flow. These phenomena are utilized to regulate the gas flow in the jet. The airfoil phenomenon known as the "acoustic jet" is associated with various configurations of tubes or resonators, closed or open, and excited by a pulsator. Interest has been heightened by the long established fact that under certain conditions a significant amount of thrust is produced by these simple devices with only a small input of energy to the pulsator. Further, several testing jets have been sometimes observed to perform better than those associated with resonance.

A comprehensive history of the "acoustic jet" and its associated theory, the "acoustic jet" theory, the "acoustic jet" theory, and its associated theory, have been given by Strahler /1/ and in his research relating the "acoustic jet" theory to jet engine design. Recent investigations include those at Cornell Aeronautical Laboratory (CAL) (Refs. 2, 3, 4), United Aircraft (Ref. 1). Although significant theoretical and practical developments have been made, most of this nature are available only in technical /2/, research /1/.
As far as the acoustic jet is concerned, it appears that further analysis and investiga

tion is needed in this case of the acoustic jet.

Previous investigations (Ref. 1, 2) have concentrated largely on direct measurements of the acoustic jet. Generally speaking, the acoustic jet is highly sensitive to open-end conditions, and this makes it difficult to interpret the data. 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, parallelizing the thrust measurements, are needed.

A mechanical pulsator was designed and built by the University of Minnesota Mechanical Engineering Staff for use in a broad program of research in pulsating phenomena employing both an on and instantaneous characterization. This program was made possible by United Aircraft Research Laboratory support. The pulsator was widely and available for the present work which was proposed as a preliminary phase of the broad program.

The primary objective was to find: (1) effects on
of the flow patterns and behavior employing tufts, smoke, and dust as flow visualization techniques, and thus establishing, 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 the pressure distribution in the basic resonator and jet excited by the highest available (about one inch) amplitude of pulsator vibration.

The work was carried out in the Engines Laboratory of the Mechanical and Aeronautical Engineering Department of the University of Minnesota, under the guidance of Dr. T. L. Murphy. The author wishes to express his appreciation for the use of the pulsator, which was made possible through United Aircraft Research Laboratory support, and to express his thanks and appreciation to the following: Dr. T. L. Hall, for his direction and counsel; Professor T. L. Murphy, for his suggestions; and Professor E. Z. Kelly, for his guidance and assistance.
special notes

\( p \)  

cage mean static pressure, inches of water, referred to
atmospheric pressure.

\( p_o \)  

cage mean total pressure, inches of water, referred to
atmospheric pressure.

\( p_a \)  

ambient atmospheric pressure, inches of mercury, absolute.

\( p_t \)  

ambient atmospheric temperature, degrees Fahrenheit.

\( +v \)  

used for oil in seconds.

\( h \)  

distance along resonator axis, inches, measured from
the plane normal to the axis, at the open end of the
resonator, towards the closed end (piston).

\( f \)  

same as \( h \), except measured in the other direction (internal).

\( x \)  

general variable for distance along resonator measured
from plane of closed end.

\( L \)  

resonator length, inches.

\( \phi \)  

angular position in degrees in the plane normal to the
resonator axis, referred to a zero line extending from
the axis vertically upward, with increasing \( \phi \) clockwise
in a clockwise direction as the observer faces the closed resona-
tor end from the open end. This line is the axis (see Table VII and subsequent tables for legend) to
note the direction and function of the probe at the introduction point. Thus, in Table VII, the static
data precede at the probe introduction point at the
top of the pressure data column for 0° and for 180°,
and at the bottom of the pressure data column for
180° and for 360°.

\( r \)  

initial distance from the tip of the probe to the resonator, posi-
tive along the line defining \( \phi \); negative along the
line defining \( \phi = 180° \).
Distance, in inches, measured from the inside 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.

Revolutions per minute of the pulsator crankshaft unless otherwise specified.

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

Crank radius in inches.

Center-to-center length of connecting rod in inches.

Angular position of the pulsator dead from dead-center.

Axial velocity variable.

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

Speed 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 under Apparatus.

All static refers to the instrumentation arrangement described, and so referred to, in the section on apparatus.

Internal features refer to the instrumentation arrangement described, and so referred to, in the section on apparatus.

External features refer to the instrumentation arrangement described, and so referred to, in the section on apparatus.
used with reference to the open end edge 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 rounded by tapers.

Used with reference to the type of end of the resonator, it signifies that the edge was tapered to a sharp edge and not to 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', is well established and appears in most textbooks in sound (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 Resonator Theory

Pressure impulses produced in a tube by plane surfaces normal to the axis are generally assumed to propagate as plane waves. When such waves arrive at a closed end, they are reflected with a phase change of 180°. When a plane wall is placed in the axis of a tube, the wall at the open end of a tube, they reflect with a one-hundred eighty-degree change of phase, i.e., compression waves are reflected as rarefaction waves, and rarefaction waves are reflected as compression waves. Those waves travel at local sonic and 1/4 or higher with respect to the air particles are dependent upon their strength. When the tube length to resonance frequency, resonant frequencies, are related in such a way that reflected waves never...
at the origin just as a consequence of the same place in starting
and reverberation occurs, the end wave greatly increased energy,
and it is said that there is reverberation.

The wave length is four times the distance between a
node and the origin, or twice the wavelength of a wave of
the second harmonic, thirty-five hundred eighty-two centimeters.
Just above wave length, a node will also be at the origin, at
the pulse of the second harmonic, thirty-five hundred eighty-two centimeters.
In each case, the wave length is the same as the resonance wave length, period,
the frequency, and the tube closed at one end and open at the
other, we follow the motion of a wave up and down the tube once.
A wavelength one is started at the closed end, reflected to the end, and returned again, a second wave is at
the closed end, and a second wave, and so on. For the case of
a free wave, it is not at the origin that the wave
period, is forty times the period, and the
fundamental for this period, is at twenty 2
4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50.

The period of the first harmonic is half the wave
length, or ten times the wave length, or a wave
length of two, period of the second harmonic is twenty times the
period of the first harmonic, the third harmonic, the fourth harmonic, and so on.

For the closed end, the wave length is 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20.

Thus the closed end, reverberation, the origin, and the
node, the origin, and the node of the second harmonic, third harmonic, the fourth harmonic, and so on.
operation that at first occasioned no remark. Now, the generally accepted formula for the calculated frequency of such a resonator is \( f = \sqrt{1 (\mu + C)} \).

\[
\delta = \sqrt{1 (\mu + C_x)}
\]

### Experimental Measurements

The idea also, the assumptions entered in the single theory at this time, are still the limitations that the compressions and rarefactions are real phenomena produced instantaneously at the positive limit of the plate, that is of interest to follow the consequences of these compressions and rarefactions in an idealized "diagram" of the actual situation, where the compressions enter into the picture of the velocity between any two different points, or, better, the points where the velocity has reached its maximum in the actual limit. This idealized "diagram" is shown in Fig. 2. The wave is applied to the plate by, let us say, the driving mechanism, and the vibrations are increased in the ideal manner. In the case of the actual limit, we get a wave of shorter length, and the wave length of the plate is in line with the force, and of the order that has been described for any given situation.
The motion of the pistons is restricted because it originates the rules and determines the boundary conditions at the closed end. The pulsator employed this feature with a conventional water-air and pressure pulsator with provision for adjusting the lethal stroke in the range of zero to one inch. Thus (Ref. 12), the motionemployed from live and dead center (1) is:

\[ s = s_0 + r \left( \sqrt{\frac{1}{2} - \sin^2 \theta} \right) - \cos \theta \]  

(2)

where \( s \) is the connecting rod length of the connecting rod, \( r \) is the crank radius, and \( \theta \) is the angular position of the crank from horizontal to center. The approximate instantaneous velocity (3) is:

\[ v = 0.00873 \pi (s_0 + r - 2 \cos \theta) \]  

(3)

where \( v \) is the velocity, \( s_0 \) is the stroke, \( r \) is the stroke, and \( \theta \) is the angular position. The approximate acceleration of the piston velocity (a) is first found (4) as:

\[ a = 0.00914 \pi (s_0 - r \cos ^2 \theta) \]  

(4)

where the units are as before.
where the unit part is omitted.

There are certain fundamental physical differences between compressive waves and expansive waves. One of these is extraordinarily evident by a simple and unadorned wave, but only by means of their dealing with the subject of the conditions produced by the repetition passing of a point wave. It may be shown (Ref. 16) that if a finite, continuous, compressive wave is sent, such as is a jet, a blast, etc., reciprocally in a tube, and point of this jet, where, 

\[ a = \sqrt{\frac{g\gamma}{p}} = \sqrt{\frac{\rho}{p/c}} \]  

(1)
of a small step wave, much 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, as for a discontinuity such that the compression wave plane practically instantaneously. This must merely because the value of a compression wave is characterized by an increase in pressure and temperature, and the velocity of propagation) near the approx. conditions. The time is readily found to occur a given the 

\[ t = \left( \frac{1}{\mu} + 1 \right) \left( \frac{1}{V} \right) \]

where \( \mu = \left( \frac{\rho_0}{\rho_1} \right) \), the initial slope of the impressed velocity-distance curve. If the initial slope of the velocity-distance curve for the water is taken as a crude approximation of this value, one finds, for the case of one-inch piston stroke and 1005 ft. related to a pipe foot long resonator, that the time required to form a discontinuity would be approximately 0.029 seconds, while the time required for the pulse to reach the end of the resonator would be approximately 0.026 seconds so that a discontinuity is not formed. If the water-column length was related to the initial slope of the velocity-distance curve for the pipe, the plot would show seven times the value for the piston,
would appear near the open end of the resonator.

The reverse situation is true for an expansion wave. Each successive front of such a wave finds itself traveling in a slightly cooler tube than the important one before it, thus at a slightly lower rate. And actually it is true in the opposite sense and the opposite case. There is no natural mechanism for the generation of a discontinuous expansion wave (Ref. 15). The approach from velocity relation in an expansion case requires no increment of velocity decrease, whereas compressive waves impart a decrement.

**Measurement of Oscillatory Pressures**

Special problems arise in connection with the simplest measurement of oscillating pressures. The fluid is alternately closing at one end of the measurement transmissive system and this is a non-isentropic process involving flow and accompanying pressure losses. The natural frequency of the instrument is, therefore, many completely different than the actual system. The gas capture and helium attenuation, however, are

**Attenuation refers to the pressure drop along a wave that is due to losses caused (not resonant effects) and its generally calculated on the basis of Newell's law of viscous dissipation...**
which is given as (Ref. 12):

$$\frac{\partial p}{\partial x} = -\left(\frac{12\Delta}{\pi} \right) \left(\frac{\rho}{\rho^2}\right)$$

(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; \( \rho \) is the fluid density; \( \rho \) is the tube diameter; \( v \) is the volumetric flow at any point in the tube. Equation (10) is combined with the non-steady, non-linear, one-dimensional equation of continuity, as in Ref. 11, in detail. A full time for values of the loss integral of the pressure fluctuation between two sources. Significantly, the time of the entrance is assumed (about the instantaneous) that it is assumed that the instantaneous has been shown to be a two or three wave effects.

In other work (Ref. 16) allows a full time for determination of the variation with time, and to estimate the effect of the attenuating effect on the pressure meter.

In this case, Equation (12) was integrated on the assumption constant volumetric flow, and that, \( \rho^2 \) and, the laminar flow \( (0 < \frac{c}{\rho} < 0.002) \).

$$c = \frac{1}{2} \left(\frac{12\Delta}{\pi \rho^2}\right)$$

(11)
and for turbulent flow (1000 ≤ Re ≤ 100,000),

\[ \varepsilon = \frac{1}{2} \left( \frac{1}{\pi} \right)^{1/4} \left( \frac{E}{v} \right)^{1/2} \left( \frac{D}{\varepsilon} \right)^{1/4} \]

(18)

where the units are consistent, \( v \) is the rms velocity of flow, and the foregoing are applicable at the entrance of a channel,

- \( \varepsilon \) is the kinetic energy dissipation per unit volume,
- \( E \) is the rate of change of strain energy per unit volume,
- \( D \) is the diameter of the channel,
- \( \varepsilon \) is the turbulence length scale.

\[ \frac{\Delta}{\varepsilon} \leq 1.0 \times 10^{-5} \]

(19)

For laminar flow, where \( \frac{\Delta}{\varepsilon} \) is less than \( \frac{\Delta}{\varepsilon} \), the pressure drop is independent of energy content of turbulence.
The day is the present day, i.e., July 18, 1819, and the number of the meeting is the 11th. This is based on the date 18 July 1819, and act. 11.
The principal apparatus in this investigation consisted of mechanical pulsators and related equipment in order to achieve the desired results. The mechanical pulsator, Figure 1, was designed and built by the University of Minnesota Mechanical Engineering Department. A small flywheel was splined to a shaft which was directly coupled to the mechanical system. A small flywheel was splined to a shaft and mounted in a fixed, horizontal position. The flywheel was driven by a mechanical link. The advantage of the mechanical link was that it was only necessary to place the mechanical link at the correct angle to change the stroke length of the pulsa-
possible stroke magnitudes available in the range of zero to one inch. The values of piston stroke used in this investigation were 0.054, 0.252, 0.542, 0.72, 0.94, 1.02, and 1.19 inches. These values included the minimum and maximum for the apparatus. A steel pin bearing connecting rod (35 in. long, center to center) was inserted to a 'straight slot.' The 'straight slot' was provided with a guide bearing. All joints referred 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 in the cylinder, plus 0.06, and 1.02 inches long. The connecting rod was 1.02 inches long. The cylinder was widened to six inches to receive the resonator tubing.

The basic resonator configuration, as shown in Fig. 10, is to the left and 'right, referred to the resonator configuration described in the paragraph. The section of the shaft, indicated (3.5 inches long; 0.9 inches O.D., 0.8 inches I.D.) and bolted together at stainless steel tubing in three aluminum supports
(See Figure 1). The tube was inserted in the pulsatory receiver resonator. The rubber end was sealed with turpentine which was easily removable. Small patches of the same material were used to seal surfaces which were not in use. The wall length of the resonator, measured from the open end to the main piston position (two-inch stroke), may have to be an experimental and four-months interval, or otherwise wise fact. The plastic tube was square-cut, and in particular, the end of the open end of the resonator was square-cut or blunt. Eighteen orifices (0.070 in., 1/8th inch, 0.05 drill) were spaced three inches apart, in a straight line along the upper end. There were made at stations 1 through 18, then repeating at the open end. The orifices near the open end were set 1/4 inch from the edge of the tube end, at about 3/8 inches in front of the inside of the tube. The orifices at stations 2, 7, 12, and 17, three, altogether with the top orifices, were given equidistant angular setting (20° apart). These were carefully aligned with the axis of the pulsatory piston. The resonator axis was eight feet. The tube facing wall and the resonator center axis was thirty-four inches from the floor.

The aim modification to this pulsatory configuration, considered in this work, was first to investigate the effect of a varying versus a fixed open end orifice (Figure 5). This
was done by fitting a cylindrical tin collar "snugly inside the open end of the resonator. It was inserted one-half inch into the open end of the resonator, and then a similar tin collar was placed firmly on the clamp, and then the clamp, open-end configuration. A
pressure tap over the edge of the tin collar was made at Station 1. A similar tin collar was used at the intersection of the tube sections for some flow visualization tests (Figure 10). It fit over the exterior of the boiler tubes and was cut to
interior length so that it flared well the tube internally. The
half inch. It had one hole to which a 1/16 inch OD probe, and
another to a 1/4 inch OD probe. These holes were sealed with Scotch tape not in use.

Two identical plenum chambers were built (see Figures 1, 2). They were made from four inch galvanized rain spouts and were thirty-one inches long. One of the tin collars was thinner to permit the introduction of flat plates (one-inch thick galv.), which were spaced (0.25 in. apart) and tapped to
base of bowing one-half inch flat plate (top-most 1/8 in. flat-
line collar) was attached to the "V" and in 30" (outside 6 and in 1/4") grooves and micrometrically clamped (Figure 10) was attached to each of the two collars and supported in a 3" gasket,
sheet). Single flat 80° rule points, approximately eighty-five lines long, were used in determining the individual tints of liquid through the trough. A similar roll or a glass rod was used to obtain the liquid and check the tint of the liquid through the trough.

The twoizers, placed near the liquid, were made to be leak-proof in order to avoid moisture from entering the liquid and changing the tint. A small Plenty for, one scale, Draft scale (Fig. 1), calipers and distilled water, all used with the plum color, were the most noticeable parts. They were taken as referred to atmospheric pressure at the resonator wall; (2) internal pressure, used for the zero static and total head pressure measurement; (3) internal pressure, used for the zero static and total head pressure measurement. The resonator wall was located in the jet.
to the bell portion of the resonator. This assembly is shown in Figure 1. The bell portion is shown in Figure 2. The bell portion is a bell portion of rubber with a bell portion made of metallic tubing. The bell portion is a bell portion of metallic tubing with a bell portion made of metallic tubing. The bell portion is a bell portion of metallic tubing with a bell portion made of metallic tubing. The bell portion is a bell portion of metallic tubing with a bell portion made of metallic tubing.
The figure has been registered in this book and those above it, with the exception of the one black and white photograph. The text is clear and readable, without any visible errors or issues. The page contains a series of paragraphs discussing technical details, possibly related to mechanical or engineering topics, given the context of the text. The paragraphs are well-structured, with each paragraph beginning on a new line and being separated by appropriate spacing. There are no illustrations or diagrams present on this page, and the text appears to be continuous throughout the page. The page seems to be part of a larger technical or scientific document, given the nature of the content.
pressure as shown in figure 3. A small hole was drilled into the brass tube to serve as the internal bleed and air seal on the probe. The probe was then slipped onto the brass stopper and the glass flanges were joined by a 3/8-inch, 10 threads per inch, glass to glass. The brass tubes were polished, filed, and a 1/2-inch No. 2 drill was used to clean out any burrs.

A fourth line of the internal bleed for internal
bleed was arranged parallel.

1. A small hole near the lap near the first
bleed was arranged parallel.

2. A small hole near the lap near the first
bleed was arranged parallel.
be obtained. This, together with the brass bar, supported the central lead, and the entire assembly was in place on the metal plate.

(2) Another similar probe similar to (1) was made. It was 6 inches long and 1 inch in diameter. The lead from the brass was 0.001 inches thick, and the metal plate was 0.020 inches thick.

(3) A total length probe was made from brass tubing with the same dimensions as (2) except that it was 3 inches long, overall. The end of this probe was again rounded to a hemisphere shape, except that the wall was 0.005 inches thick and the overall tubing was 0.020 inches thick. A total length of 10 inches was cut from the end of the tubing, and the diameter of this section was 0.020 inches, parallel to, and from the same dimensions as (2). This was cut from the tubing and polished on the back edge of a lathe. A total length of 0.020 inches, parallel to, and from the same dimensions as (2). This was cut from the tubing and polished on the back edge of a lathe.
The side of the probe is constructed of an inch from the end. This hole is traversed by a cylinder placed in the probe which is only slightly different than the inside diameter of the probe (twelve-thousandth). This probe has been referred to as a cylinder-type total heat time device. It is used as the fact that stagnation occurs at the leading edge of a cylinder placed normal to a stream line.

The external traversing cylinder arrangement is shown in Figure 1. The probe, fitted in a tube, is mounted to a mounting plate on the support frame. It could be lifted and rotated in a vertical and longitudinal position with respect to 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 stop arrangement. The vertical support bars could be rotated about a central axis providing another degree of freedom. The external traversing probes were connected to the flange, shown by a 1/16-inch plane of water (7/16 in. 17) and a one-way stopcock.

The description of the probe and the external traversing arrangement follows.
[1] A thin (tantalum) tube (fig. 11) 0.01 inch thick was available only in odd lengths for all of the external tantalum components. The smooth tube inside the outer shell of this tube had a wall thickness of one-eighth inch and was approximately two inches in length. It led into a larger hollow tube which also served as the support for the shaft, with the wall of the inner tube being made rigid with a metal tube. The shaft was eight inches long, taking about twenty inches overall, from the inner to the outer boundary of the insulating tube. The outer shell of the shaft was one-quarter inch thick, and was insulatively set with the inner shell one-quarter inch thick. The shaft was one-quarter inch thick. A static probe (fig. 11) was used, consisting of a brass tube, into the end of which was inserted a probe (4), one-eighth inch long, with a sharp point. This was then inserted into the shaft of the mill.
tube (2), but this was a piece of a joint-type insulating short of the bend. The bend on the smaller section of the tube was made larger in overall length, one-third of an inch in inside diameter. The end of the short part of the "L" was cut square and polished so that, if the plane of the end exactly coincided with the flow, it would read nearly the static pressure. It was in this way, "testing out," all the end planes, in the horizontal plane perpendicular through the central axis of the resonator and jet.

Various methods of producing sand were tried. The most satisfactory method employed in this work:

Quantities of a soft, plastic, all-inclusive, insulating material, with the literature entitled "Versol Electrical Company," were available. This material is extremely light, with a fluffy, loosely-textured, fluffy, fluffy texture. The sand particles have a very low specific gravity. It was inserted by blowing it with a large insect duster by simply blowing a little along the side of the insert, and out the back of a slit.

The flow, if treated with care, direction, and care,
The plate could not be made to swing about the lens.

The apparatus would make only one more of the same, and for this reason, a small apparatus finally evolved for obtaining...\(^1\)

Finally, another experiment was performed in the 29/30. We concluded with the instrument's last test. The instrument's measurement system should be kept as clean, the tube, and the pressure...\(^2\) of the instrument's...\(^1\) tube, and the pressure...\(^2\) to that degree as short as possible.

The liquid used must be the same...\(^3\), which also...\(^4\) to the liquid's resistance...\(^5\).
...values of static pressure, along the line of...
The reversal of dominant total head values at the resonator mouth suggests that the air in the resonator is being alternately forced by turbulence at the total mouth opening. The turbulence, present at the mouth, was experienced over a relatively short time. In the absence of turbulence, the two effects (influx and efflux of the air in the jet) are so great in reality alternating, and only appear to be cumulative as a consequence of the instability of the jet to follow such rapid changes.

The total head reversal, the means and effect of the physical action which occurs at the resonator mouth is the principal factor in the major portion of the resonator which appears to be primarily oscillatory in the jet and circular vortex system. Such oscillations (Chapter 2) suggested the need of the resonator mouth interference (Chapter 2) suggested that such of the resonator may balance the gain in the region of the resonator mouth.
entering the resonator. It appears that the water air mixture of
condensed and frozen was sufficient to keep the air moist.

The greatest difference between the static and total
values (approximately three and one-half feet of water)
were found inside the resonator core and were indicated on the
velocity of the inner resonator plate. The mean velocity at the
front of the resonator is indicated as about eighty feet per second, and the mean velocity on a line
times of three feet outside. The pressure is indicated as about
nearly sixty feet per second. These values compared with the readout
of 0.088 feet or 0.0278 in. indicates that the

A comparison of the mean static pressure distribution along the
wall of the resonator with the initial and final pressure distribution is shown in Figure 5. The initial pressure in
water than the static gradient has been taken by lower
prediction values that show the exit of the system of the
resonator is approximately. The values are very close to the
near the closed end. A new, removal of the static pressure
table shows just inside the resonator, which was related to
the effect of the edge water system. All of stages of the
axial and wall static pressure distributions correlate with the visual observations of greatly increased flow particles with length near the open end, assuming that the latter are an indication of increased jet velocity.

Profiles of such static pressure distributions inside the resonator are shown in Figure 16. These profiles, with the exception of that for station 1, were obtained by projecting from the plane of static pressure at each station as a check upon the validity of the pressure distribution.

Profiles of mean static and total pressures on the external jet area (horizontal plane) are presented in Figure 27 for stroke over strokes, at the open end, which is far from the open end of the resonator.

Total and static profiles are presented in Figure 17. The gradients appear to be small except in the region near the open end of the resonator.

Variation in Jet Static Pressure Distribution with Stroke Length

The mean static pressure distribution along the resonator wall for various magnitudes of piston stroke is shown in Figure 28. The pressure gradients in general decrease with piston stroke, although the original resonator characteristics are
variation in pressure for a blunt and sharp edged open-end resonator configuration

The difference in null steady state pressure distributions for resonators with blunt and sharp edged open-end resonator configurations is shown in Figure 10. In this test, values were obtained with the tapered edge.

variation in null heat transfer resistance with modified or tapered resonator length

The variation of wall heat transfer resistance along the resonator wall is shown in Figure 11 for various pulsation amplitude values. A comparison of measured resistance for selected instances is shown in Figure 12. It is evident that a longitudinal pressure gradient is generated much on the resonator...
The resonator values occur near the closed end (piston) and/or values occur at, or near, the open end.

That is in agreement with theory (\textit{shear}). In some of these cases, the resonator value was increased to determine the resonant frequency. Other data are summarized in Figure 1A as Figure 1, with the resonant end modification in Figure 1B. The resonant end for the last configuration was taken as higher than the theoretical formula (Equation 1) curve values in Figure 1B, respectively.

The resonator values may move away well above resonance in the slope on either side of the peak. The positive slope indicates an unstable mass approaching while the negative slope indicates such mass moving away. A joint 1 showing the positive slope exhibits the unstable configuration with the resonator value below that of the second one. This is indicated in Figure 1A, operation line on the lower value line on the lower subplot in Figure 1A, indicating the resonant value of the lower - no frequency. Curves 1A and 1B in Figure 1A show the resonator value for the resonator frequency.
The maximum value of the calculated values for the

...
The tendency was for the choking effect to be less effective, the jets appeared to spread out, and the diffusion of the spray was extremely rapid at high velocities. Further investigation did not reveal a complete explanation, despite the fact that the initial results were irregular (Figure 22), and further work was necessary.

The distribution of large particles was found to be directly linked to the distance, with a decrease in particle distribution associated with an increase in distance (Figure 16). It was approximately 1.5 times the distance of the initial jet (Figure 35), but this value appeared to be closely correlated with the relative distance of any location. The momentum was shown in Figure 32 for 1.3, while the other parameters...
A comparison of the velocity distribution of the vortex system with small and large particle sizes magnitude is presented in figure 27 (b) and (c). The estimated increase in circulation (D) would show steady amplitude is located in figure 27 for small and large disturbances.

Small particles vibration to developing near the wall, formed in a straight line adjacent to the axis or straight lines of the vessel in fact roughly. The observation of these individual suspended particles as dust or lines inside the resonator was quite readily died. The test chambers were possible even only a few, dust particles were present on that individual test resonator particle and individual dust particles which were actually trials to 10 cm through the resonator, could still be identified by the get-rectangular. A long time of these particles locations appear to be at the edge of the optical window -1 cm near the closed (Figure 27). Subsequently and it will such suspended particles, did have a motion along particle for several minutes, showing a 'dust' of the dust cloud, will external disturbances, of all could be made by external conditions, while the current is the agency of another, with the changing in the position of the equilibrium of dust, which in the resonator and that a close of frozen collection of such.
A nearby open window and sometimes sufficient to cause mechanical disturbance such that only the particles near the closed end remained relatively undisturbed.

The results of the dust particle paths (Figures 20-28) observed were seen to be much greater with the open and close end. Figure 29 (again note, for example, that Figure 8 depicts the observable dust to increase with increase of pressure inside. It is also evident that the dust particle paths in Figures 10 and 11 (closed end) were essentially the same as in Figure 29. The dust particle path lengths were recorded and plotted in Figures 30-31. It is difficult to make such estimations, especially with these particles, with the usual methods.

Detailed observations of the dust figures were made in the hope that their behavior, although erratic, would be of fundamental nature. By 1937, some dust could be seen in the longitudinal view of the tubes (Fig. 28); the dust is a cloud of particles of one of the finest natural materials, and it can be seen with the naked eye. In later, the dust was observed to be much more. It was noted that the dust figures against the light, in which they were seen, were small, less than one thousandth of an inch (Figures 14), but clearly visible in all respects. The dust-
tion of dust figures was observed as a sort of sliding growth from a lateral dust ridge in the bottom of the tube, after many earlier several of these and ridges before something as a board was placed over the open end of the tube and the middle of the bottom allying the bottom to some. Dust figures are constantly observed to collapse under operation as a sort of removal of the dust process. The width of dust figures are constant in relation to the tube and is observed to be much as the normal inside of an A. After this, it is observed, that after the observed particle path length observed in the middle location. The observation at 20 is about 0.025 inches. The same relations observe that 20 is nearly the only of all length of length in changed to not triangle that figures were observed.

The relation of longitudinal constant act in the same way as the open end. Observations, from the 0.025 test tubes, indicate the open end the open tube (station 20) to be about three times, that, because the tube at the third the tube length is the diameter multiplied by the square of the open end was observed, although it appeared that the normal
condition was stationary. Just before leaving at the front end of the resonator, all the untrapped dust and feed out the central jet. This produces an excellent means of isolating the ion-particle stream flow effect of the jet as shown in figures 21, 22, and 23, and shows the degree of symmetry in the flow.

Limitation of Results

The most factor affecting the results obtained was the instrumentation detail with reference to the details and length of all tubes and restrictions used in the pressure measurement system. Quantitative evaluation of the data could depend on detailed consideration of the particular high-pressure lines presented in the discussion of related theory (Art. 11, 11, 12).

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, late arrival indicated was discovered.

And reproducibility of results was achieved. The results did not appear to be sensitive to the small variation.
general conclusions rescued through the other investigations reported in this volume to be valid, this may be noted. In the first place, the dust particles are visible everywhere except in this region, it appears that the axis of the system penetration must be regarded as a unique velocity at the present moment and the job. Above this velocity, it appears a constant value along the axis of symmetry.

The general conclusions reached through the other investigations reported in this volume to be valid, this may be noted. In the first place, the dust particles are visible everywhere except in this region, it appears that the axis of the system penetration must be regarded as a unique velocity at the present moment and the job. Above this velocity, it appears a constant value along the axis of symmetry.
elusions

It is possible to produce axial, lateral and resonator patterns. In the resonator with correction there are:

(1) The resonator, longitudinal and transverse patterns had axial symmetry in the major respects.

(2) In the conical resonator, the transverse pattern has axial symmetry in the major respects.

(3) In the conical resonator, the transverse pattern has axial symmetry in the major respects.

(4) The axial and resonator patterns have axial symmetry in the major respects. The transverse patterns have axial symmetry in the major respects.

(5) These results were from four different, whole human heads; from one, two and four different heads.
given problem adding to a previous one.

(5) The natural 
the major portion of the operation, caused that the final
approximation was that. The final condition was
the final condition of the operation. A very
approximation occurs at the operation of condona.

(6) The partial vertices of the vertices, the
progression, followed by the rapid increase of
content, or just inside, the resonator operation.

(7) The primary aspect of the final
progression the major portion of the resonaor function. A very rapid
approximation is in the operation, that is, the
approximation is in the operation that were
progression of the vertices, the partial resonance, or just inside,
the resonator operation.

(8) The final aspect of the final
progression the major portion of the resonator function. A very rapid
approximation is in the operation, that is, the
approximation is in the operation that were
progression of the vertices, the partial resonance, or just inside,
the resonator operation.
occurrence should not be confused with internal circulation. The question of the relation
of the superficial circulation to the internal circulation is a complicated one, and it is
necessary to consider the effects of hemorrhage, inflammation, and other factors.

In considering the superficial circulation, it is important to note that the
superficial vessels are subject to changes in the depth and intensity of the blood flow.
The superficial vessels, being relatively shallow, are more subject to changes in the
depth and intensity of the blood flow. The superficial vessels, being relatively
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# Table 1

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*See apparatus and instrumentation for limitations.*
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**See Appendices and Nomenclature:**

**See Limitations**

*Modified connection (small tube) at outlet (orifice) (see Figure 3)*
### Table IV

### Instrumentation: Small Static Test

#### Cylinder Stroke: 7.078 in.

#### Reservoir Length: 109.4 in.

#### Reservoir, Stability Configuration, and Flow

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See apparatus and instrumentation

---

*See Li et al.*
## Table V

### Resonator Wall-Plate Static Pressure Splat

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### Footnotes

See Apparatus and Nomenclature
See Limitations
## Table 1

### Calculated Direct Values

(Data from Fig. 3 and Table V)

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<th>V₀</th>
<th>U₀ (at piston)</th>
<th>U₀ (at open edge)</th>
<th>I (in.)</th>
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### TABLE VIII

**UN-MAY, INTERNAL MEDAL REPOSSE, MAY STATIC INFLATIOR DATA**

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<th>Plastic Strain: 3.976 in.</th>
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<td>H'</td>
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*Note: Values may vary.*
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**Probe Opening, Axial, Toward Listen:**

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**Probe Opening, Axial Away from Listen:**

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*See Apparatus and负责同志.*

*See L Shrinking.*

*Refers to null position of probe introduction. See Apparatus.*
| TABLE II |

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*See Apparatus and Nomenclature.*

**See Limitations.**

***Refers to wall position of probe introduction. See nomenclature.***
### Table A-3

**Lateral Mean Pressure Data**

(Traverse in horizontal Axial Plane)

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<td></td>
<td>-0.83</td>
<td>-0.53</td>
<td>-0.23</td>
<td>0.33</td>
<td>1.18</td>
<td>3.09</td>
</tr>
<tr>
<td></td>
<td>-0.83</td>
<td>-0.53</td>
<td>-0.23</td>
<td>0.33</td>
<td>1.18</td>
<td>3.09</td>
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<td></td>
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<td>-0.23</td>
<td>0.33</td>
<td>1.18</td>
<td>3.09</td>
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<td></td>
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<td>0.33</td>
<td>1.18</td>
<td>3.09</td>
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<td></td>
<td>-0.83</td>
<td>-0.53</td>
<td>-0.23</td>
<td>0.33</td>
<td>1.18</td>
<td>3.09</td>
</tr>
</tbody>
</table>

**Note:**
- Apparatus and instrumentation.
- Study limitations.
- Water in null position or orientation of probe introduction.
- 't' is positive on side from which probe is introduced. See instrumentation.
- Total net driving force taken as the sum (i.e.) of all forces from the given (out).
**Traverse Instrumentation**

**Traverse stroke:** 0.978 in.

**Basic Cross-section:**

<table>
<thead>
<tr>
<th>Length</th>
<th>Width</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>107.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Probe Angle:**

<table>
<thead>
<tr>
<th>Angle</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>2.0</td>
</tr>
<tr>
<td>90°</td>
<td>0.38</td>
</tr>
<tr>
<td>180°</td>
<td>-0.59</td>
</tr>
</tbody>
</table>

**Probe Length:**

<table>
<thead>
<tr>
<th>Length</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>107.4</td>
<td>0.91</td>
</tr>
</tbody>
</table>

**Probe Width:**

<table>
<thead>
<tr>
<th>Width</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>107.4</td>
<td>0.87</td>
</tr>
</tbody>
</table>

**Probe Height:**

<table>
<thead>
<tr>
<th>Height</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>107.4</td>
<td>0.73</td>
</tr>
</tbody>
</table>
### Table II

<table>
<thead>
<tr>
<th>Piston Stroke, in.</th>
<th>Depth of Observation, in.</th>
<th>Visual Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.054</td>
<td>1.6</td>
<td>(See Fig. 1)</td>
</tr>
<tr>
<td>0.202</td>
<td>1.5</td>
<td>(See Fig. 2)</td>
</tr>
<tr>
<td>0.542</td>
<td>1.0</td>
<td>(See Fig. 3)</td>
</tr>
<tr>
<td>0.765</td>
<td>1.1</td>
<td>(See Fig. 4)</td>
</tr>
<tr>
<td>0.978</td>
<td>1.2</td>
<td>(See Fig. 5)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Piston Stroke, in.</th>
<th>Observed Particle with Dough, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch. 6</td>
<td>Ch. 7</td>
</tr>
<tr>
<td>0.052</td>
<td>0.2</td>
</tr>
<tr>
<td>0.202</td>
<td>0.4</td>
</tr>
<tr>
<td>0.542</td>
<td>0.8</td>
</tr>
<tr>
<td>0.765</td>
<td>Qualitative</td>
</tr>
</tbody>
</table>

New particle path determined. The path is directly above the original path. The path is very erratic and irregular. The particle is observed to move in a wavelike manner, appearing in the original position after each path change. The path is characterized by rapid, erratic movements.
FIG. 7  MEAN PRESSURE DISTRIBUTION IN JET ALONG RESONATOR AXIS OF SYMMETRY. 
DATA FROM TABLES III, XI, XII, X, VIII, AND XI.
Piston stroke = 0.976 IN.

Distance along resonator axis of symmetry, in

-60 -54 -45 -42 -36 -30 -24 -18 -12 -6 0 4 12 18 24 30 36 42

Mean static pressure, internal probe (2). 
Mean total pressure, internal probe (4), facing piston.
Mean total pressure, internal probe (5), facing away from piston.

External probe (1).
External probe (3).
External probe (5), facing away from piston.

External probe (6), facing from piston.
**FIG. 8** RESONATOR WALL STATIC PRESSURE DISTRIBUTION FOR VARIOUS MAGNITUDES OF PISTON STROKE
(DATA FROM TABLE IV)

\[ x = 0.054 \text{ INCHES PISTON STROKE} \]

\[ \times = 0.292 \]

\[ \times = 0.562 \]

\[ \triangle = 0.762 \]

\[ \circ = 0.976 \]

\[ \times \text{ MARS EXEPRIMENTAL ERROR} \]

**DISTANCE FROM OPEN END OF RESONATOR, IN. (INTERNAL)**
Fig. 10  Effect of open end shape on mean static pressure at the resonator surface

(Data from Table IV)

Experimental error

Piston stroke = 0.978 in.

Distance from open end of resonator, in.

Gage mean static pressure, in. H₂O
Fig. 11. Effect of frequency on mean static pressure at the resonator surface for fixed resonator length (data from Table III).

- △ 1848 R.P.M.
- ○ 1703 R.P.M. (Resonance)
- □ 1961 R.P.M.

△ ○ □ Experimental error

Piston stroke = 0.778 in.

Distance from open end of resonator, in.
FIG. 12  EFFECT OF FREQUENCY ON MEAN STATIC PRESSURE AT THE RESONATOR WALL FOR SELECTED STATIONS
(DATA FROM TABLE III)
PISTON STROKE = 0.778 IN.
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

1600  1825  1850  1875  1900
FREQUENCY (R.P.M.)
FIG. 15  THRUST FOR BASIC RESONATOR CONFIGURATION.
(DATA FROM TABLE VI)

L = 107.4 IN.
D = 5.5 IN.
FIG. 16  INTERNAL RADIAL TRAVERSE,
MEAN STATIC PRESSURE
(DATA FROM TABLE VII)
PISTON STROKE = 0.918 IN.

\[ D = 0^\circ \]
\[ X = 30^\circ \]
\[ \theta = 90^\circ \]
\[ \Delta = 270^\circ \]
FIG. 17  MEAN PRESSURE PROFILES IN JET OUTSIDE OF RESONATOR OPEN END.

DATA FROM TABLES XII, XIIa.
PISTON STROKE = 0.778 IN.

GAGE MEAN PRESSURE, IN H2O.

DISTANCE FROM RESONATOR AXIS IN.

º GAGE MEAN STATIC PRESSURE.
º GAGE MEAN TOTAL PRESSURE, FACING PISTON.
º GAGE MEAN TOTAL PRESSURE, FACING AWAY FROM PISTON.
º EXTERNAL DISTANCE FROM RESONATOR OPEN END, MEASURED ALONG CENTRAL AXIS, IN.
º 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

Δ ESTIMATED FROM PHOTOGRAPHS
FIG. 30 ESTIMATED DUST PARTICLE PATH LENGTH FOR DIFFERENT MAGNITUDES OF PISTON STROKE.
(DATA FROM TABLE XII, VISUAL ESTIMATIONS)

- Ø = 0.054 IN.
- △ = 0.292 IN.
- ▽ = 0.542 IN.

INTERNAL DISTANCE FROM OPEN END OF RESONATOR, IN.

FIG. 31 VARIATION OF ESTIMATED DUST PARTICLE PATH LENGTH WITH PISTON STROKE.
(DATA FROM TABLE XII, VISUAL ESTIMATIONS)

- Ø STATION 3.
- △ STATION 17.
- ▽ PISTON.
Fig. 32. 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:

\[ \pi = 2.75 \text{ in.} ; \quad L = 107.4 \text{ in.} ; \quad t = 88^\circ \text{F (Table I)} ; \]
\[ f = \frac{12 \cdot 1148}{4 \left[ 107.4 + 0.6 \left( 3.75 \right) \right]} = 31.63 \text{ c.p.s.} = 1898 \text{ R.P.M.} \]

VELOCITY:

\[ h_o = -0.67 \text{ in. H}_2\text{O (Table I, Sta. 1)} \]
\[ h_s = -3.68 \text{ in. H}_2\text{O (Table VIII, Sta. 1)} \]
\[ V = \sqrt{\frac{2 \left( h_o - h_s \right)}{\rho}} = \sqrt{\frac{2 \left( 6.42 \right) \left( 3.68 - 0.67 \right)}{\left( 12 \right) \left( 0.002378 \right)}} = 116 \text{ ft/sec.} \]

THRUST:

\[ H_a = 29.42 \text{ in. H}_2\text{O} = 400 \text{ in. H}_2\text{O (Table IV)} . \]
\[ h_s\text{ (piston)} = h_s = +6.6 \text{ in. H}_2\text{O (Fig. 8, uncorrected)} \]
\[ h_s\text{ (open edge)} = h_s e = -3.6 \text{ in. H}_2\text{O (Fig. 8, uncorrected)} \]
\[ T = \frac{h_s}{\rho_p} \cdot A_p + \frac{h_s e}{\rho_e} \cdot A_e - \rho_a \pi \left( \frac{1}{2} \right)^2 \]
\[ \rho_p = \text{absolute pressure on piston, lbs/in}^2 \]
\[ \rho_s e = \ldots \ldots \ldots \ldots \text{open-end edge, lbs/in}^2 \]
\[ \rho_a = \ldots \ldots \ldots \ldots \text{atmospheric assumed acting externally on unit} \]
\[ A_p = \text{piston area} = \pi \left( 2.75 \right)^2 = 23.80 \text{ in}^2 \]
\[ A_e = \text{open-end edge area} = \pi \left( 3 \right)^2 - A_p = 4.48 \text{ in}^2 \]
\[ T = \frac{624}{12.144} \left[ 406.6 \left( 23.8 \right) + 376.4 \left( 4.48 \right) - 400 \left( 28.28 \right) \right] \]
\[ = 6.06 \text{ lbs.} \]