PULSEJET EJECTORS

by

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TABLE OF CONTENTS

Text

Illustrations

PULSEJET EJECTORS

INTRODUCTION

The rapid development of jet powerplants for aircraft propulsion during recent years has focused attention on the problem of inducing cooling air-flow through the ejector action of the jet exhaust. The exhaust jet pump may also be used to provide suction for aerodynamic boundary-layer control. The latter is a technique for reducing drag on an aircraft surface, or increasing lift on a wing, by sucking the turbulent air that contributes to high drag or reduces lift on a wing, in through slots in the surface. Rather limited ejector data is available pertaining to hot continuous-flow gas jets, such as turbojets and ramjets, and pulsating-flow jets, like the exhausts from reciprocating engines. Apparently nothing has been published pertaining to pulsejet ejectors, or at least nothing unclassified by national defense standards and available to the public.

Although no reports on the subject of pulsejet ejectors have been found in the literature, it is known to the author that some investigators, experimenting with ducted pulsejets and pulsejet ejectors, have formed the opinion that a pulsejet cannot be used successfully as a jet pump or ejector. This was apparently due to the fact that the pulsejet will pump satisfactorily only over a narrow range of mixing-chamber lengths (Figure 1) and this range was not discovered by those investigators who concluded that the pulsejet had no appreciable ejector action. This investigation will show that satisfactory pumping may be obtained with pulsejet ejectors, when proper mixing-chamber lengths are used.

GENERAL THEORY OF EJECTOR ACTION

An ejector, Figure 1, is essentially a duct through which a high velocity jet is discharged. The high kinetic energy of this primary jet is used to pump a second fluid. Most authorities consider that the mixing in the duct of the primary and secondary gases is the source of the pumping action. Since it is well-known that such mixing is a relatively slow process, it is commonly assumed that a long mixing-chamber is necessary to assure adequate mixing. Gustav Flügel's general studies of jet pumps (3,p.13) in Germany up to the year 1939 recommended a ratio of mixing-chamber length to primary jet nozzle diameter (L/D ratio) of approximately 10 L/D, in order to assure practically complete mixing.

Theoretical assumptions of complete mixing and absence of wall friction are also made by Manganiello and Bogatsky (5, p.4), but they are careful to point out that in an actual ejector both the degree of completeness of mixing and the wall friction losses increase with increasing ejector length so as to produce an optimum length. The work of Manganiello and Bogatsky in 1944 was primarily an experimental investigation of rectangular exhaust-gas ejectors applicable for cooling aircraft reciprocating engines.

A general theoretical treatment of compressible flow in ejectors by Ellerbrock (2, p.7) also includes, as a basic relation, complete mixing of air and gas before reaching the mixing tube exit. The Ellerbrock publication was issued in 1947 as a RESTRICTED Research Memorandum but has since been de-classified like the preceding reference. The widespread acceptance of the idea that the interaction between mixing and wall-friction requirements results in an optimum mixing-chamber length between about 4 and 8 L/D is further strengthened by the results disclosed by McClintock and Hood (4, p.566) in 1946. This extensive research, carried out by United Aircraft Corporation, includes equations which, with the aid of empirical coefficients, enable one to estimate both the performance of steady flow and intermittent flow ejectors. It is not surprising then if some investigators of pulsejet ejectors have concentrated their efforts in this L/D region, and when achieving little success, have concluded that the pulsejet is impractical as a jet pump.

Only one publication was found that disclosed the use of short ejectors for optimum steady flow pumping. Towle and Judd (10, pp.20-24), describing experiments at Republic Aviation, attribute the pumping action primarily to the effect of high viscous shear forces existing between the primary and secondary gases along the boundary of a free jet (Figure 1). Their paper indicated that changing the L/D ratio from 4.5 to 0.78 for parallel-walled mixing-chambers had little effect on the suction, especially for high pressure ratios. On the other hand, this same report mentions what are called the first comprehensive tests on cooling air ejectors. These tests were undertaken at General Electric Company in 1945 by Timbie and Alford. The results of the tests had apparently not been published previously since no reference was cited. Timbie and Alford experimented with convergent conical mixing-chambers that were very sensitive to L/D ratio in the range from 0.75 to 5, with the best results in the region close to L/D 1. The tests were performed with area ratio values of 1.15 to 1.35 for the ratio of mixing-chamber cross-sectional area to primary jet cross-sectional area. It is also of interest to note that the final design of turbojet ejector for the Republic Aircraft F-84 fighter aircraft had a L/D ratio of only 0.85.

The premise upon which most investigators have based their arguments for long mixing-chambers seems to be that the long chamber is required in order that adequate mixing of primary and secondary gases may take place. However, factors such as wall friction and shear forces outweigh the need for complete mixing. In fact, in the case of the pulsejet it appears that no appreciable mixing occurs, as will be explained later. It is the opinion of the author that the classical requirement of complete mixing in the so-called "mixing-chamber" is not realistic for aircraft jet ejectors. Instead of complete mixing in the mixing-chamber for optimum pumping, it is suggested that the source of the pumping action is primarily the turbulent mixing associated with the viscous shear forces that occurs along the boundary of the free jet (Figure 1). If this is true, then theoretical optimum pumping may occur in many cases for both continuous and alternating flow with such short mixing lengths that the divergent primary jet barely strikes the downstream edge of the mixing tube.

The experiments at Republic Aviation and General Electric Company with continuous flow ejectors, and the experiments with pulsejet ejectors reported herein, constitute limited verification of the proposed theory. However, pulsejet ejectors have characteristics that indicate very marked differences between the action of alternating and continuous flow ejectors. In order to understand the unique action of pulsejet ejectors it is helpful first to describe the operation of the pulsejet engine itself.

THEORY OF PULSEJETS

The pulsejet consists essentially of a tube open at one end and fitted at the other with one-way valves. The pulsejet depends for operation upon resonating columns of gases. For this reason it is sometimes called a "resojet" and classified as a wave engine. When a combustible mixture of fuel and air is introduced through the valves into the combustion chamber and ignited initially by a spark, pressure builds up that first closes the valves, then accelerates the hot gases out the tail-pipe. The inertia of the exhaust gases causes the combustion chamber to be partially evacuated, at which time atmospheric pressure forces open the intake valves and a new charge flows into the combustion chamber. At the same time air also flows back into the tail-pipe toward the combustion chamber. When the new charge is ignited the cycle is repeated. The engine cycle frequency is roughly proportional to engine length. For instance, the normal frequency is about 240 cycles per second for the Dynajet engine used in this investigation.

The spark can be turned off after the first cycle is completed. This is one of the peculiarities of the pulsejet. At first, spark-off ignition was thought to be caused by burning gases that remained in the combustion chamber from the previous cycle. Recent shock-tube research in the United States and Canada discussed by Rand (8, p.21-23), and post-war revelations concerning the experiments of Schmidt (9, p.378) in Germany prove that a combustible mixture can be ignited by a shock wave. Some investigators now assume that a strong shock, associated with the reverse flow into the tail-pipe, initiates the combustion for the new cycle.

For some time, judging by Edelman's (1, p.11) study of pulsejet progress up to the summer of 1946, it was thought that the reverse flow into the tail-pipe during flight was detrimental to the thrust output of the engine. More recent investigations by Project SQUID (7, pp.6-8) at Cornell Aeronautical Laboratories under the combined sponsorship of the U.S. Navy and Air Forces suggest that tail-pipe reverse flow by its nature is not detrimental, in fact, it makes a definite contribution to the thrust. The reasoning is that the reverse-flow is so-called "potential flow" that comes from the sides of the tail-pipe exit rather than a reversal of flow from the rear by the exhaust gases that have just left the tail-pipe during the previous cycle.

Various attempts have been made by noted scientists to write mathematical analyses of pulsejet operation.

These attempts have thus far achieved little success due to the obvious difficulties of analyzing such rapidly varying pressures, temperatures, gas velocities, and gas densities. Until recently, no test instruments had ever been constructed that were capable of recording the extremely rapid variations of pressure and temperature in pulsejets. The problem is further complicated by incomplete understanding of the following: the effect of interaction between the combustion front and the pressure waves; the influence of valve characteristics, tube shapes, fuel injection and mixing; and the true nature of the combustion process (which is somewhat similar to a Lenoir or constant volume process). It is not surprising that pulsejet designers still lean heavily on empiricism.

THEORY OF PULSEJET EJECTORS

The tests described in this report show that parallel-walled or cylindrical pulsejet ejectors will pump satisfactorily only when a very short "mixing-chamber" length is used, approximately equal to the diameter of the primary jet (Figure 1). The physical reasoning presented to explain this phenomenon considers that there is practically no mixing in the pulsejet ejector; instead, "plugs" of secondary air are caught between pulses of primary air and forced out of the mixing-chamber, somewhat like corks out of a toy popgun. Flow of secondary air is then thought to be due to the sudden drop in pressure in the mixing-chamber caused by the inertia of the primary jet and the entrapped secondary air as it moves out of the mixing-chamber, as well as due to the shear forces between the divergent primary jet and the secondary air.

The phenomenon of pulsejet cooling-jacket back-pressure, or net reverse flow of secondary air, from the tail-pipe exhaust toward the nose, associated with long mixing-chambers, is also explained by this concept. It is thought that the greater inertia due to the greater mass of the gases, and wall friction, in the long mixing-chambers requires a pressure build-up in order to accelerate the mixing-chamber gases. The pressure build-up in the mixing-chamber then causes a reverse flow of secondary air in the cooling-jacket and a net pressure in the cooling-jacket, rather than a vacuum as would be the case if the ejector was working as a pump. Optimum pumping is obtained when the mixing-chamber length is such that the divergent primary jet barely strikes the downstream edge of the mixing tube.

PRELIMINARY INVESTIGATIONS

The original pulsejet investigations at Oregon State College began in the fall of 1950 as Engineering Experiment Station Project no. 109 under the joint direction of Assistant Professors Herbert H. Rook and Raymond M. Lockwood. The purpose of the project was twofold: (1) to determine the problems involved in placing a pulsejet within a shroud or duct, which could be streamlined in order to reduce the drag of the engine at flight speeds; and (2) to find if the pulsejet exhaust could be used as an ejector to provide suction that in turn might induce airflow both to cool the engine and provide boundary-layer control. Of course, the investigators were also hopeful of running across information that might lead to improvement in the basic engine itself. The research philosophy was to discover as much as possible with the least possible expenditure for equipment.

The program was first one of familiarization with conventional pulsejet static operation. Next the search was extensive rather than intensive, a search for general trends rather than minute details. The discovery of the requirements for successful pulsejet ejector action, which is the particular subject of this paper, was a result of the general study. The critical range of ejector L/D for successful pulsejet pumping was almost missed because of the idea, absorbed from study of the literature, that optimum mixing-chamber L/D ratio would lie between about 4 and 8 and drop off sharply below a minimum of about 4 L/D.

Small commercial pulsejet engines, of the type used to power model airplanes and boats, as well as for study of pulsejet operation, were procured for the tests. A Dynajet engine (Figure 5) 21 inches long and 2½ inches maximum diameter was used for most of the tests. The tail-pipe was 1¼ inches in diameter with a flair to about 1½ inches in diameter at the exit. The flair was removed for some of the tests in order to determine if it affected the results. The engine weighed 16 ounces and had an average thrust output slightly over three pounds, at a normal operating cycle frequency of about 240 cycles per second.

In a search for general trends, ducts of varying lengths and diameters were placed over the engine tail-pipe and the effects noted. A long two-piece duct was constructed so that one piece telescoped inside the other, permitting variation of duct length during pulsejet operation.

An effect of varying the cooling duct length during operation was an audible change of engine frequency, indicating that the engine was forced to take the natural frequency of the duct that was placed about it. High-temperature nodes (glowing bands) spaced about 8 or 9 inches apart also were noticed when ducts as long as two or three feet were used. The pulsejet did not act as an ejector in any of the tests with long cooling ducts. Instead the cooling jacket was pressurized and the net flow seemed to be forward from the jet exhaust to the nose.

A special test stand (Figure 2) was then constructed which permitted direct measurement of the following: engine thrust, using a special device designed and constructed by assistant professor H. H. Rook (Figure 3, left center, small cylinder on base plate), that gave variable thrust readings with practically no engine motion; the external skin temperature at a point on the combustion chamber near its transition into the tail-pipe, and at a point on the tail-pipe about 1/3 of its length forward of the exhaust exit; the temperature of the air in the cooling jacket about one inch forward of the exhaust exit; and total and static air pressure in the cooling jacket about one inch forward of the exhaust. The temperature readings were obtained with thermocouples connected to the gauges on the test stand shown in Figure 2.

Tests using this set-up indicated that there was some cooling effect for lengths of mixing-chamber from a length of one foot down to zero length. Two-inch increments were taken through most of the range, but it was fortunately decided to take shorter increments for chamber lengths less than three inches. It was discovered by observation of tufts attached at the upstream entry of the cooling duct that both the net cooling flow seemed to reverse and a strong pumping action to occur somewhere in the region of mixing-chamber length of about one inch. A new three-inch long mixing-chamber with adjustable thread pitch of 20 threads to the inch was constructed in order to carefully determine the optimum mixing-chamber length for ejector action. The variation of static and downstream total pressure with ejector L/D ratio for the series of tests is shown in Figure 4.

At this stage of the investigations it was decided to check the expected effect on the optimum pumping of variation of the ratio of ejector cross-sectional area to primary jet cross-sectional area. According to the proposed theory of pulsejet ejector action, an increase in area ratio would require an increase in ejector length, because the line of intersection between the boundary of the free jet and the edge of the ejector would be located farther downstream. Experiments verified the theory, as indicated in Figure 6. The range of L/D for optimum suction was wider and less distinct for the larger area ratios, as might be expected. All of these tests were conducted without the flaired end on the tail-pipe.

At this time, during the Spring term of 1952, a small group of senior students in Aeronautical Engineering, who had been following the experiments with considerable interest, asked permission to assist with some pulsejet experiments for credit in their Aeronautical Laboratory course. It was decided to investigate the flow through both the engine and the ejector by using sharp-edged orifices at the entries. Anticipating that the back-and-forth flow through the orifices would cause errors if a standard steady flow coefficient was used to calculate the net flow rate, it would nevertheless be of interest to note if the same region of critical L/D ratio would be revealed.

A new cooling duct (Figure 5) was constructed to accommodate the sharp-edged orifices. A 1.25-inch diameter orifice was to be installed at the entry of a 6-inch intake duct for the engine and a 1.00-inch diameter orifice for measuring the ejector flow was mounted on a 3-inch long side-entry duct near the front end of the combustion chamber. However, the engine could not, at first, be started with the open-ended 6-inch intake duct in place. Then it was discovered that it would start if most of the intake was covered by the fingers. When the 1.25-inch diameter orifice was soldiered on, it was found that the engine would start only if one finger was placed across the intake orifice. Apparently the intake duct was functioning as a tuned inlet and waves in the inlet duct were interfering with the valve timing of the engine. As soon as the engine operation became established, it was no longer necessary to partially cover the engine intake duct. Peak ejector flow was again recorded in the range of L/D ratio between 0.25 and 1.0.

The use of standard sharp-edged orifice coefficients (for steady flow) gave a calculated flow of 52 cubic feet per minute through the engine and 29 cubic feet per minute induced by the ejector. These calculations alone could not be relied upon because of the back-and-forth nature of the flow through the orifices. A value of 36 cubic feet per minute (2.68 lb air per minute) engine air flow was calculated using the measured engine fuel flow rate and an assumed air-fuel ratio of 15 to 1. The next logical step seemed to be to find a reliable way to measure the net flow induced by the ejector, and the following section is primarily devoted to that project which was conducted in April and May, 1953.

MEASUREMENT OF NET EJECTOR FLOW

A peculiarity of pulsejet ejector flow is that there is always a back-and-forth motion of the air in the cooling duct at engine frequency, even though the net flow is zero. Thus it is that there may be some cooling of the shrouded pulsejet engine when the net flow is zero. Recalling the difference between the jet flow out of the tail-pipe and the reverse "potential" flow back into the tail-pipe, makes this easier to understand. When there is zero net flow in the cooling duct there is still a back-and-forth flow in the cooling duct at the frequency of the engine. At each end of the cooling duct the flow out has the form of a jet but the flow into the duct is "potential" flow which introduces fresh air into the duct from the regions beside the duct entry.

A problem in instrumentation was posed: that of determining the net flow through the cooling duct in order to get a measure of the ejector action. Ram air tubes were placed to give separate ram pressure readings in both the fore and aft directions at locations in the cooling duct near the ejector end of the duct and in the cooling air entry near the nose of the pulsejet. Static pressure readings were also taken at these same locations in the cooling duct (Figure 5).

Finally, a Durley Drum setup was used to measure the net ejector pumping flow. This is a standard device for measuring the flow of gases, especially those that are pulsating. For these tests it consisted primarily of a standardized intake nozzle of one-inch diameter mounted in the end of a large (55 gallon) drum. The drum is connected by a 3½-inch diameter pipe to a second drum equipped with rubber diaphragms placed over the ends of the drum. The effect of the large air chambers and the rubber diaphragms is to absorb the pulsations in the flow on the engine side so that the flow through the nozzle will be steady. The measurement of the pressure drop through the nozzle permits the weight rate of flow of the engine to be calculated by standardized formulas that will not be described herein. A detailed discussion of standardized measurements of gas flow may be studied in any good textbook on thermodynamics such as Obert (6, pp.253-307).

MAJOR EXPERIMENTAL DIFFICULTIES ENCOUNTERED

Three major problems made the test runs difficult and often required many hours of repair and construction between runs. These problems were short engine valve life (Figure 5), high engine shell temperature and severe vibration. Valve life varied from less than a minute to as high as 15 minutes. In order to study a range of representative ejector lengths during static engine operation it was often necessary to operate with very limited cooling flow, thus hastening valve failure. With such short valve life, it was a problem to make reasonably certain that the engine was operating normally during a test run, so that the data would indicate the variables desired, rather than be distorted by approaching engine failure. A higher pitched engine tone and glowing particles in the exhaust stream were the usual indications of engine failure. If the engine was not stopped promptly, the burned and broken steel flapper valves would deeply score the aluminum valve seats. It would then be necessary to re-grind the valve seats to a smooth flat surface.

One series of tests was halted by high-temperature failure of the stainless steel engine shell (Figure 5). A two-inch slit blew open about eight inches forward of the exhaust and the engine would no longer operate.

The heat also made it quite difficult to get reasonably good temporary seals on the variable-length ejector connections (Figure 5), since the longer ejectors became red-hot. The heat and vibrations combined to loosen connections and fasteners, unless special precautions were taken. A fourth factor, the intense noise output of the engine, made it necessary to conduct test runs in the evenings and on weekends when classes in the Engineering laboratory and adjacent areas would not be disturbed.

RESULTS AND CONCLUSIONS

The Durley Drum set-up provided an excellent means of determining the net flow through the ejector, when it was pumping. The results are shown graphically in Figure 7. In order to plot the parameters in dimensionless form, the calculated air weight flow rate through the ejector was divided by the value of normal calculated air weight flow through the engine and plotted against the ratio of ejector length to primary jet diameter (L/D ratio). It is apparent from Figure 7 that good pumping will be obtained in the narrow range of L/D ratio from zero to about one for this particular ejector, that has a ratio of ejector cross-sectional area to tail-pipe cross-sectional area of 2.57 (called area ratio).

The effect of an increase in area ratio is to increase the L/D ratio required for optimum pumping. Such an effect might be expected from the proposed pulsejet ejector theory that predicts optimum pumping in the L/D range in which the boundary of the jet, either barely misses the downstream edge of the ejector, or only strikes enough of the downstream edge of the ejector to seal it against backflow. Figure 6 shows the experimentally determined ejector lengths for optimum pumping at three different area ratios. The idealized drawing shows the jet boundary intersecting the downstream edge of the ejector. The preceding test results constitute a measure of experimental verification of the proposed theory.

It may be noted that, due to the practically linear spreading of the free jet, an approximately constant number may be obtained for all of the ejectors tested, by dividing the ejector L/D ratio by the area ratio. This "characteristic" number, which is approximately 1/3 for the cylindrical ejectors tested, is suggested as a means for pulsejet ejector comparison and prediction of optimum ejector lengths for various area ratios.

No large changes in engine thrust were noted during the tests. The effects on thrust due to ejector action were concealed by the rather erratic thrust output of the engine itself. No definite conclusions were drawn from these experiments, regarding the effect of the ejector action on engine thrust, except to say that it did not appear to be detrimental. Unfortunately, the ejector air hose connection to the Durley Drum prevented the simultaneous measurement of thrust and ejector air flow.

The effect of heating the cooling air, as the engine shell heated up, is shown in Figure 7. It resulted in a drop in ejector mass flow, as well as a shift in the critical L/D range for optimum pumping. It is thought that the former is due to the reduced density of the heated secondary cooling air, and the reduced viscous shear forces at the boundary between the primary jet and the secondary air. The reason for the shift of the critical L/D range is not so clear. It may be due to greater spreading or divergence of the primary jet as it becomes hotter.

The erratic action of runs P, Q, R, and S, and the apparent reversal of position of the hot and cold flow curves shown in Figure 7, are thought to be due to the loss of seal in the ejector connections and warping of the longer ejectors. Leakage in the ejector connections would reduce the pressure build-up that is thought to be the cause of the net reverse flow in the cooling jacket. It was especially noticeable, during these test runs, that the longer ejectors became red-hot. They were merely strapped onto the end of the cooling jacket (Figure 5) in order to permit adjustment of ejector length and facilitate removal, so that it was difficult to retain a seal when the ejectors became red-hot. The net reverse flow is not shown quantitatively in Figure 7, but merely indicated by arrows, because such readings went off the scale on the Durley Drum manometer. Furthermore, the drum nozzle was not calibrated for such reverse flow. Examples of the effects of the high heat in the long ejectors, that were not indicated on Figure 7, were readings taken at an L/D ratio of 6.2. Both hot and cold air flows were reversed throughout the run until suddenly a suction reading on the drum manometer was observed. When the engine was stopped it was noticed that the heat and vibration had caused the ejector to slip back to a shorter ejector length. The screw fasteners had failed in the stainless steel ejector shell, so that the ejector had warped and leaked along a longitudinal seam and was now conical, with the large opening downstream, like an ejector diffuser.

There is some evidence that the addition of long ejectors to pulsejets may considerably change the engine characteristics. There is a very definite change of audible frequency. Also it appears that the long ejectors may be acting as after-burners. The further burning of fuel in the long ejectors could account for the high heat. In addition, there is some evidence to indicate that there may be cyclic variations of ejector air flow, pressures, and heating. Support of the latter is furnished by the observation of evenly spaced hot regions or bands on the long telescoping ejectors used in the early investigations. Such cyclic effects in the longer ejectors might be detrimental to the engine operation, since it is generally accepted that an engine's valve characteristics must be matched to the engine's characteristics for optimum engine operation.

Many readings of total and static pressures at various stations in the cooling duct were recorded but they were not thought to provide conclusive evidence on which to base ejector air flow calculations. The reason that these readings may be misleading is that the air flow is not only pulsating but actually reverses direction cyclically. The significance of the steady "average" readings, on the manometers connected with these pressure pick-ups, is not completely understood, but they do very definitely indicate the region of ejector L/D ratio for optimum pumping. A single total and static pressure pick-up, as shown in Figure 4, might be calibrated against ejector flow, as measured with a Durley Drum set-up, and then used alone to give a good estimate of the ejector flow.

RECOMMENDATIONS CONCERNING FUTURE RESEARCH

Some general background information has been gained concerning the operation of pulsejet ejectors, including verification of the proposed theory. It is suggested that pulsejet experimentation might now be expanded, by future researchers with more elaborate equipment, to include the following:

1. Measure the net flow in both directions in the ejector by calibrating the flow in both directions through an air drum nozzle or orifice.

2. Construct a new cooling duct that will provide better flow over the nose of the pulsejet, and possibly contribute to longer valve life. Care should be taken to provide for convenient replacement of valves. (An improved valve system for the basic pulsejet engine would be of very great assistance in the investigations).

3. Compare the effects of various ejectors on engine frequency, ejector air flow rate, engine fuel and air flow rate, ejector area ratio, engine skin temperatures, and combined thrust.

4. Take maximum readings of ejector pressure and suction in the "no flow" condition.

5. Test the effects of various types of cooling fins or wavy cooling duct surfaces on engine skin temperatures.

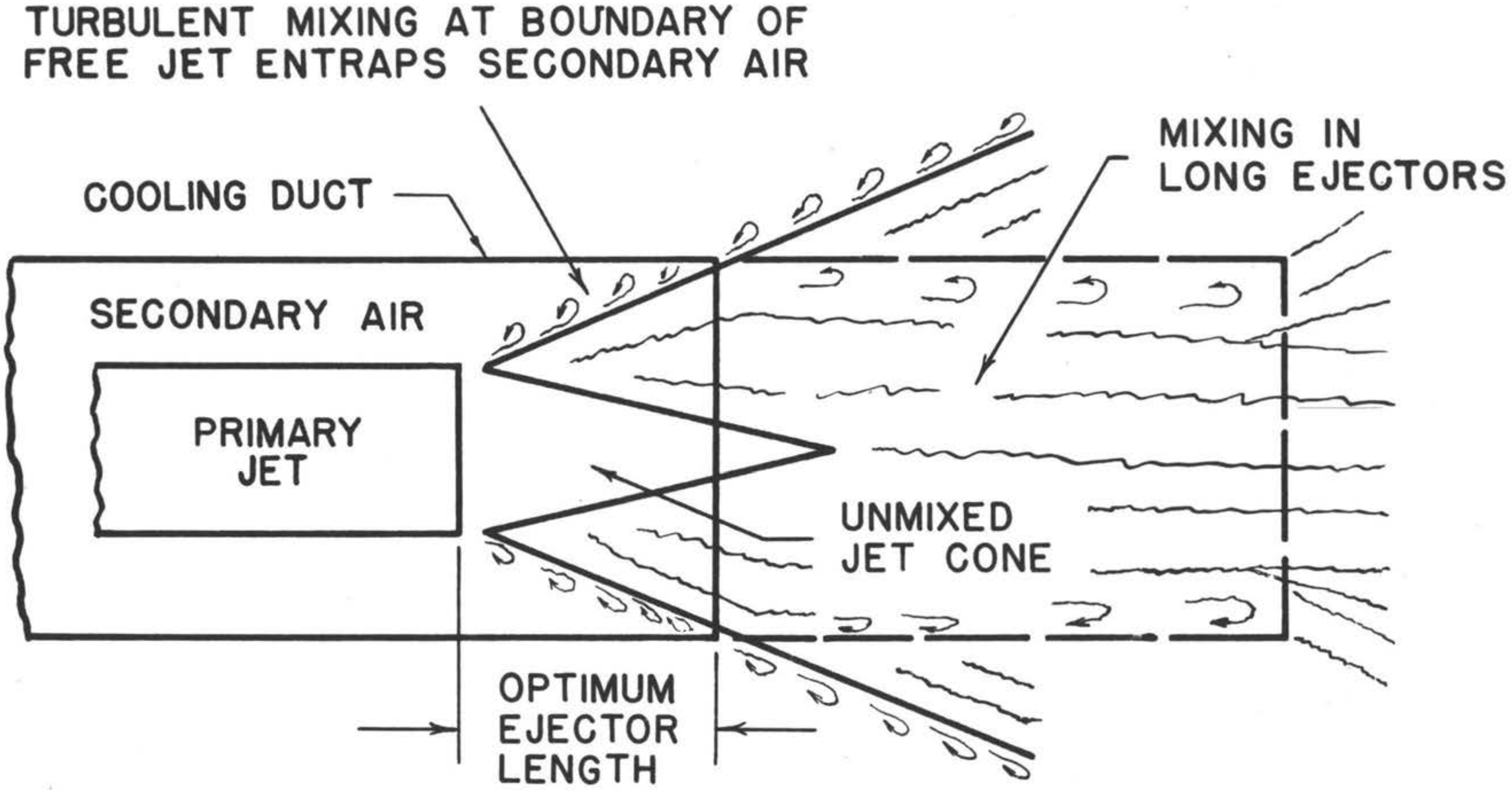

FIG. I. THEORETICAL EJECTOR ACTION

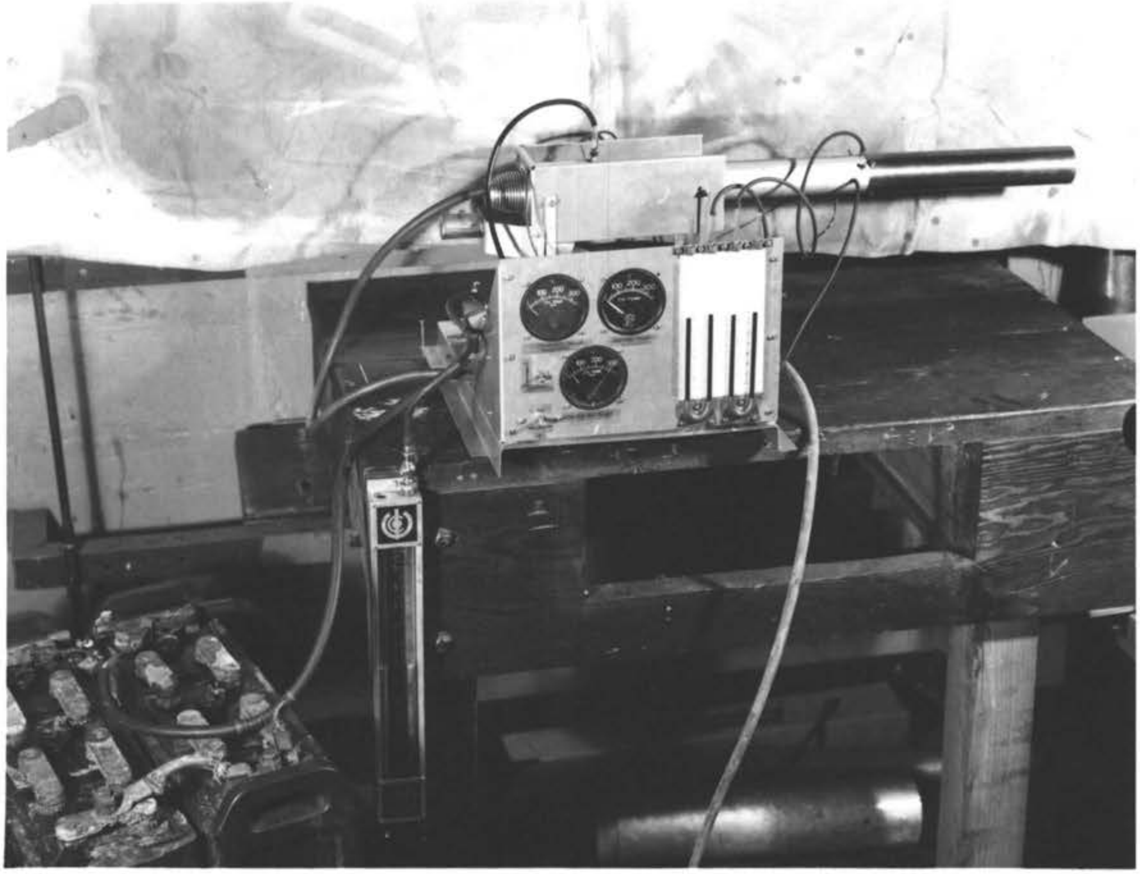

Figure 2. Pulsejet Ejector Test Stand.

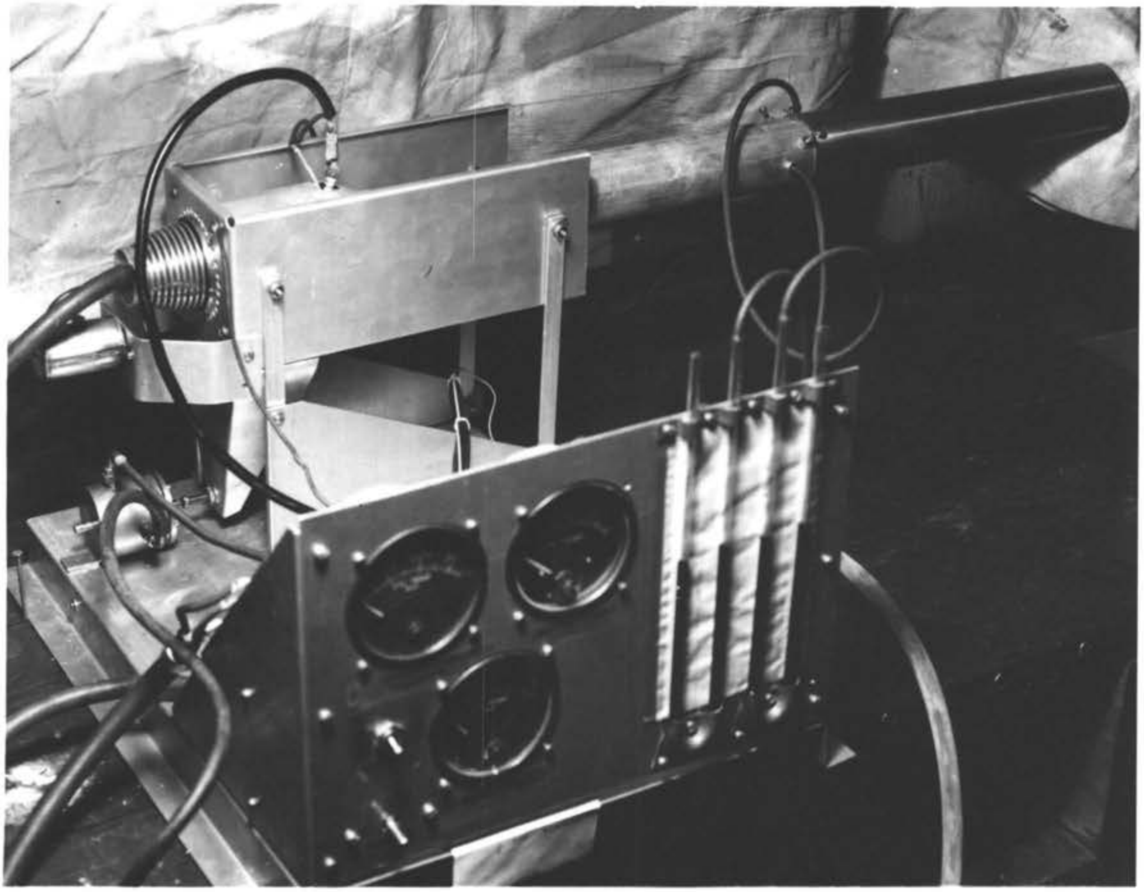

Figure 3. Thrust Measuring Device. (Left center, small cylinder on base plate)

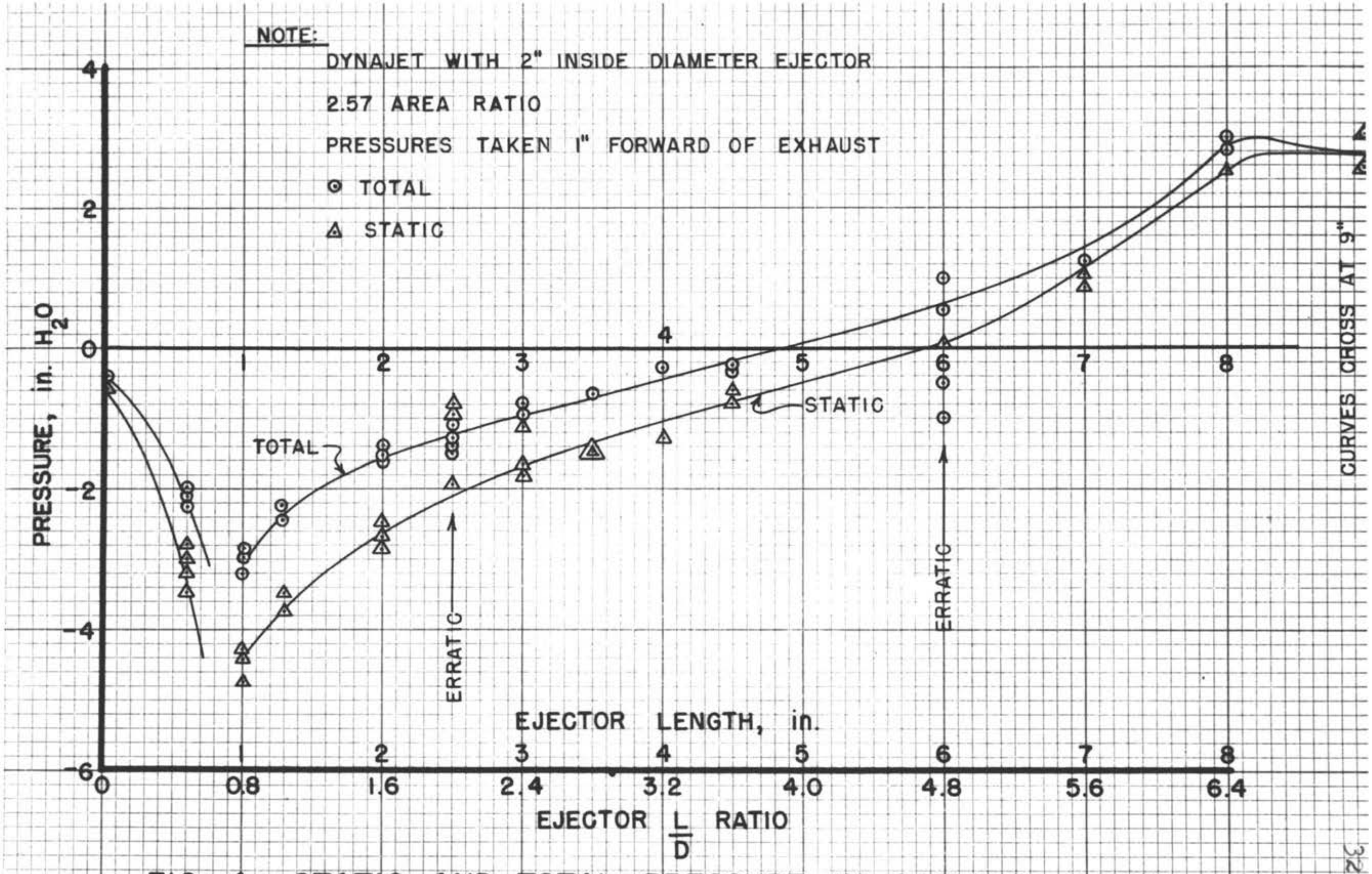

FIG. 4. STATIC AND TOTAL PRESSURE IN COOLING JACKET

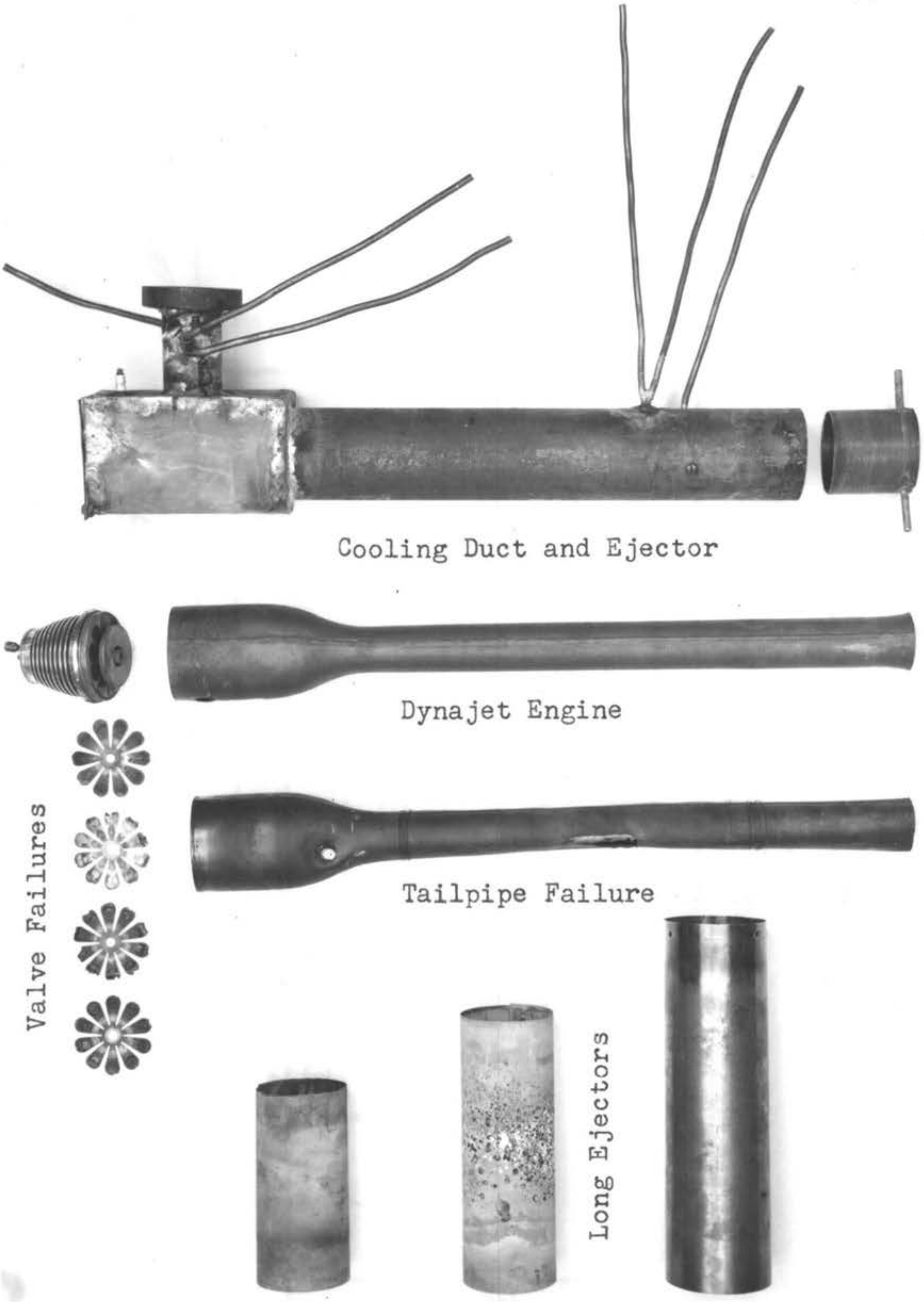

Figure 5. Pulsejet and Ejectors.

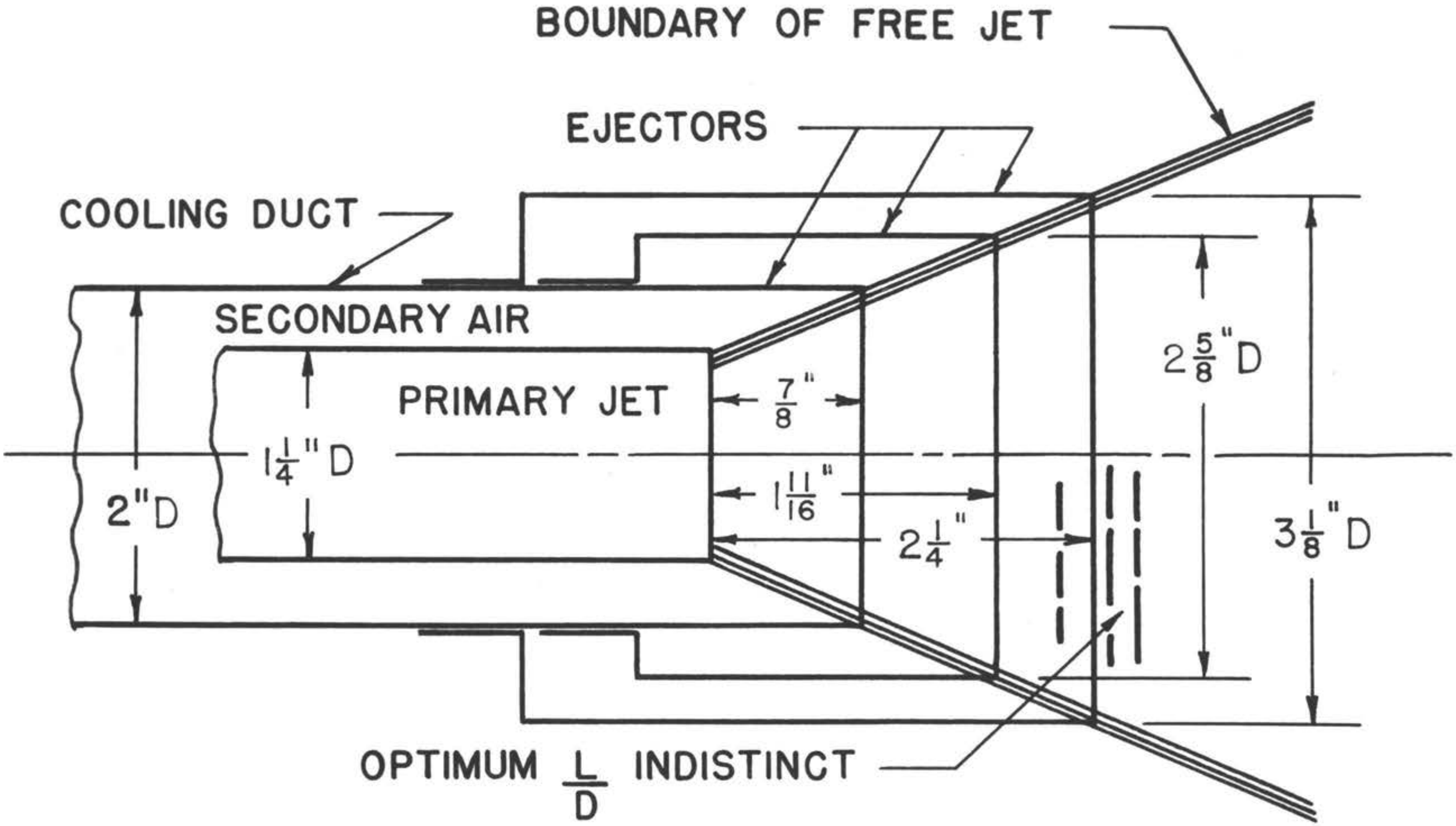

FIG. 6. LENGTHS FOR OPTIMUM PUMPING FOR THREE EJECTOR DIAMETERS

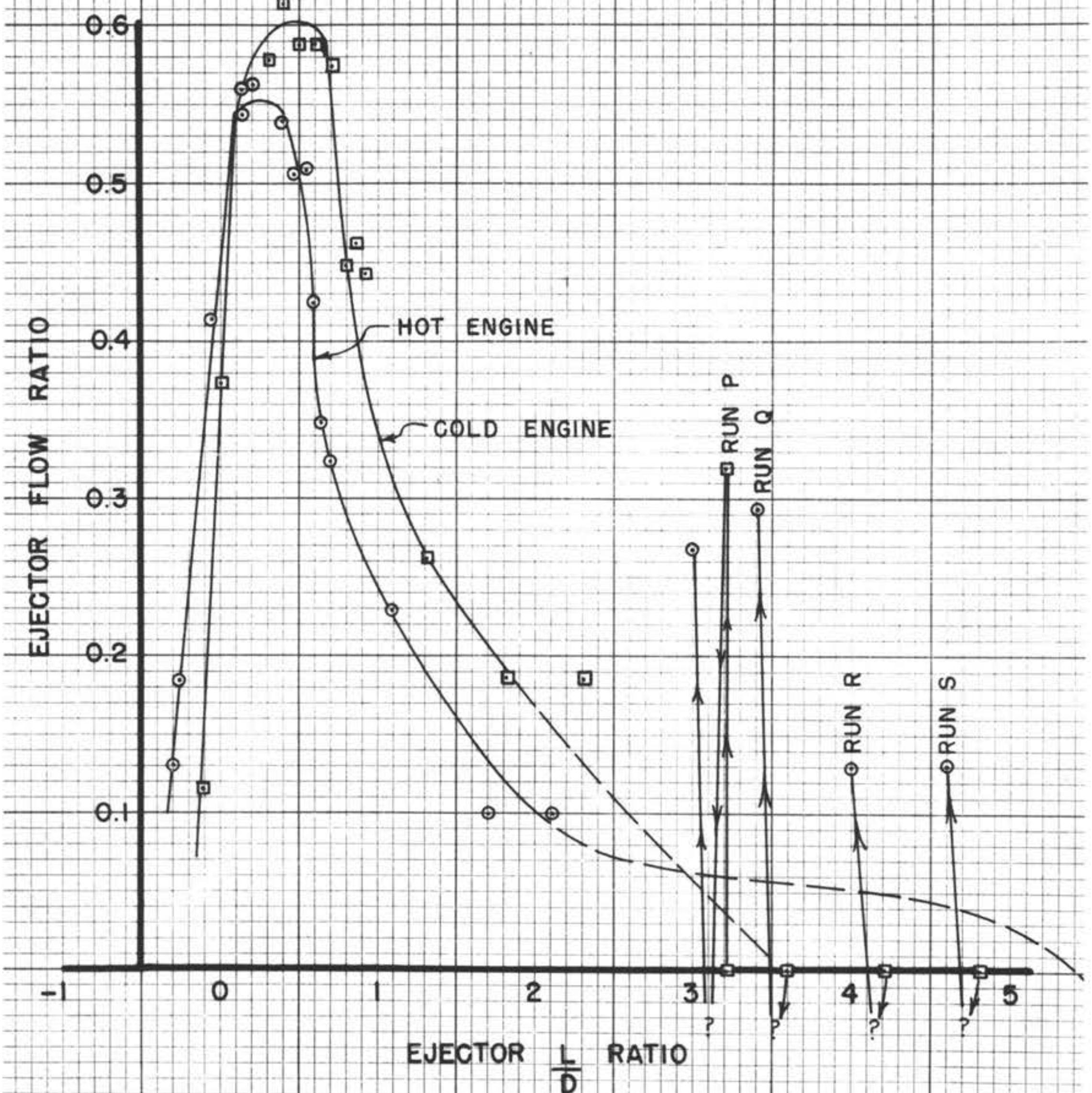

FIG. 7. EJECTOR FLOW

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