

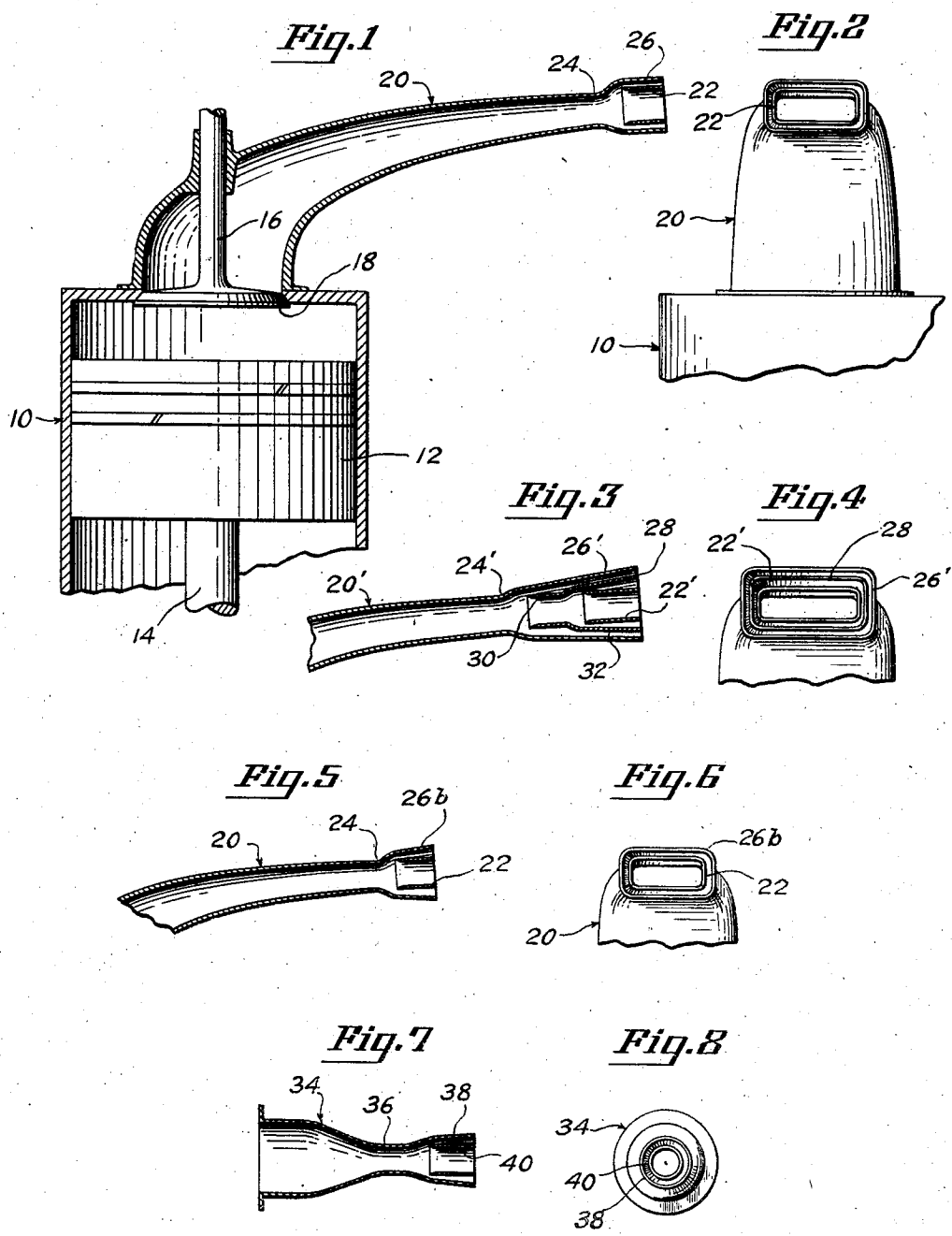
March 20, 1945.

P. J. CAMPBELL

2,372,058

EXHAUST NOZZLE

Filed Sept. 27, 1941



INVENTOR
Paul J. Campbell
BY *Harris G. Luther*
ATTORNEY

UNITED STATES PATENT OFFICE

2,372,058

EXHAUST NOZZLE

Paul J. Campbell, South Glastonbury, Conn., assignor to United Aircraft Corporation, East Hartford, Conn., a corporation of Delaware

Application September 27, 1941, Serial No. 412,674

4 Claims. (Cl. 60—35.6)

This invention relates to improvements in fluid jet producing nozzles and has particular reference to an improved nozzle for directing the exhaust gases of an internal-combustion engine into a reaction jet.

An object of the invention resides in the provision of an improved fluid nozzle of the character indicated arranged to produce reaction jets of maximum efficiency when the pressure differential between the gas within the nozzle and the air at the nozzle exit is both above and below the critical value.

A further object resides in the provision of an improved fluid jet directing nozzle of the character indicated which acts as a convergent nozzle under some circumstances and as a convergent-divergent nozzle under different circumstances.

Other objects and advantages will be more particularly pointed out hereinafter or will become apparent as the description proceeds.

In the accompanying drawing, in which like reference numerals are used to designate similar parts throughout, there is illustrated in several slightly modified forms a suitable mechanical embodiment for the purpose of disclosing the invention. The drawing, however, is for the purpose of illustration only and is not to be taken as limiting or restricting the invention since it will be apparent to those skilled in the art that various changes in the illustrated embodiment may be resorted to without in any way exceeding the scope of the invention.

In the drawing,

Fig. 1 is a somewhat diagrammatic sectional view of a fragmentary portion of an engine cylinder with an exhaust gas jet directing nozzle constructed according to the invention applied thereto.

Fig. 2 is an end elevational view of the nozzle shown in section in Fig. 1.

Fig. 3 is a longitudinal sectional view of the exit end portion of a somewhat modified form of fluid jet directing nozzle.

Fig. 4 is an end elevational view of the nozzle shown in Fig. 3.

Fig. 5 is a sectional view of the exit end portion of a still further modified form of nozzle.

Fig. 6 is an end elevational view of the nozzle illustrated in Fig. 5.

Fig. 7 is a longitudinal sectional view of a still further modified form of nozzle, and

Fig. 8 is an end elevational view of the nozzle illustrated in Fig. 7.

Referring to the drawing in detail, and par-

ticularly to Figs. 1 and 2, the numeral 10 indicates an internal-combustion engine cylinder within which there is a reciprocable piston 12 connected by a suitable connecting rod 14 to the engine crankshaft, not illustrated, in a manner well known to the art. The engine may have a plurality of cylinders all of the same general form and construction and each cylinder may be connected with an exhaust gas jet directing nozzle constructed according to the invention.

The cylinder 10 is also provided with an intake valve, not illustrated, and an exhaust valve 16 controlling the opening of an exhaust gas port 18 in the closed end of the cylinder. The intake and exhaust valves may be operated by suitable valve gear mechanisms, not illustrated in the accompanying drawing but of some suitable form known to the art.

When the exhaust gases are ejected from the cylinders of an internal-combustion engine these gases retain a considerable amount of energy which the engine has been unable to absorb and transmit into mechanical power. This energy is in the form of pressure, velocities, and heat energy and the complete waste of this residual exhaust gas energy has previously been considered a necessary condition to the operation of internal-combustion engines. Recent experiments with high speed aircraft have indicated that a portion of this residual exhaust gas energy may be recovered by directing the exhaust gases rearwardly in a high speed jet adding the reactive thrust of the exhaust gas jets to the propulsive effort of the engine. In order to obtain this conversion of exhaust gas energy the exhaust gases are led through a rearwardly directed conduit which terminates in a convergent restricted nozzle which emits the exhaust gases at high velocity in a rearward direction. Such previous installations have utilized a separate nozzle for each engine cylinder and have also utilized compound nozzles through which the exhaust gases from several cylinders are ejected, and some have gone so far as to eject all of the exhaust gas from an engine through a single nozzle connected with the engine cylinders by means of a suitable exhaust conduit. For various reasons, such as lightness and maximum efficiency, the arrangement in which a separate nozzle is provided for each engine cylinder is thought to be superior and it is among the objects of this invention to provide an improved nozzle form for such an arrangement. The improved nozzle may, however, be used with an exhaust manifold or collector ring in cases where it is not

desired to provide a separate nozzle for each cylinder.

The pressure of the exhaust gas leaving the engine cylinder varies greatly over the time of the exhaust stroke, particularly in modern engines in which the exhaust valves may be left open for as much as two hundred and sixty degrees of crankshaft revolution. At the beginning of the exhaust stroke the exhaust gas is highly compressed in the cylinder and, as soon as the exhaust valve has been partly opened, the exhaust gases leave the cylinder at a high velocity. However, as the pressure of the exhaust gas in the cylinder is relieved this velocity decreases and approaches zero toward the end of the exhaust stroke. The pressure of the air at the nozzle exit also varies to some extent with changes in altitude. With the nozzle connected to the exhaust port we have a condition in which the exit end of the nozzle represents an aperture, the pressure within the nozzle represents the fluid pressure at one side of the aperture and the pressure of the air at the nozzle exit represents the fluid pressure at the opposite side of the aperture. According to well-known physical principles a gas flowing from a region of high pressure to a region of lower pressure through a convergent passage will expand with decreasing pressure and increasing velocity. The final pressure to which it can expand within the convergent passage depends on the ratio of pressures in the regions ahead of and after the nozzle. When the pressure ahead of the nozzle is less than approximately twice the pressure after the nozzle, the gas will expand to a pressure equal to that of the region into which it discharges. However, if the pressure ahead of the nozzle is greater than approximately twice the pressure after the nozzle, the gas will expand within the nozzle only until it reaches a pressure equal to approximately half the initial pressure. It will, therefore, issue from the nozzle at a pressure above that of the surrounding atmosphere. Since the velocity is determined by the expansion ratio, the velocity of discharge from a convergent passage is limited to the velocity obtained by expansion through a pressure ratio of approximately two to one. It is known that to expand a gas through pressure ratios of more than two to one, it is necessary to add a divergent exit to the convergent passage. The gas can thus be expanded to a pressure equal to that of the surrounding atmosphere, and the discharge velocity is then determined by the ratio of initial to final pressures rather than the critical ratio of two to one.

In the case of a nozzle attached to the exhaust port of an aircraft engine, the ratio of pressures before and after the nozzle fluctuates rapidly from very high values to less than two to one. In order to expand the exhaust gas completely to atmospheric pressure for all values of this fluctuating pressure ratio, it is necessary to provide a nozzle which will operate efficiently under various pressure ratios above and below the critical value of approximately two to one. From the preceding discussion, it will be seen that a convergent passage is sufficient for expansion through pressure ratios of less than two to one, but that a divergent exit is required for greater pressure ratios.

With these considerations in view, it is among the objects of this invention to provide an improved exhaust gas directing nozzle which will act as a convergent nozzle or orifice as long as the pressure differential between the exhaust gas in

the nozzle and the outside atmosphere does not exceed the critical ratio of approximately two to one, and which will act as convergent-divergent nozzle when the pressure of the exhaust gases is more than twice as great as the pressure of the air at the nozzle exit.

In accomplishing this object the nozzle, generally indicated at 20, is provided at its exit end with one or more inner partition members, such as the members shown in Figs. 1 and 2 and indicated by the numeral 22. The nozzle 20 has side walls which converge to a location of minimum cross sectional area illustrated in the drawing as a neck 24. This neck 24 constitutes an exit or aperture for the convergent channel ahead of it and beyond this aperture the nozzle is somewhat expanded to provide an enlarged end portion 26. The inner member 22 is uniformly spaced from the inner surface of the end portion 26 and has an internal cross-sectional area substantially the same as the cross-sectional area of the neck or throat portion 24. The inner end of the member 22 terminates somewhat short of the neck 24 in order to provide an additional gas passage from the neck between this inner member and the enlarged end portion 26, and the inner end of the member 22 is preferably somewhat rounded to provide a smooth entrance for exhaust gas flowing through this member from the neck portion 24.

With this arrangement, when the pressure differential of the gas within the nozzle 20 and the outside atmosphere is below the critical value the gas will flow from the neck directly through the inner member 22 and the nozzle will act as a straight or simple convergent nozzle but, when this pressure differential exceeds the critical value, a portion of the gas will be forced to flow through the space between the inner member 22 and the enlarged end portion of the nozzle. As the cross-sectional area of this space plus the cross-sectional area of the inner member 22 is greater than the cross-sectional area of the neck portion 24 the nozzle then becomes a divergent nozzle and increases the jet velocity as the pressure differential between the gas within the nozzle and the outside atmosphere increases up to the expansion capacity of the nozzle. This nozzle will, therefore, act both as a simple convergent nozzle and as a convergent-divergent nozzle depending upon the value of the pressure differential between the gas within the nozzle and the outside atmosphere.

In the form of the invention shown in Figs. 3 and 4 the principles involved are the same as those explained above but the expansion capacity of the nozzle has been increased by incorporating therein an additional inner member 28 disposed between the inner member 22' and the enlarged end portion 26' extending beyond the neck 24' of the main nozzle 20'. This intermediate member 28 is provided with a straight entrance portion 30 and an enlarged divergent portion 32 surrounding the inner member 22' and uniformly spaced therefrom as well as from the interior of the enlarged end portion 26'. With this arrangement, when the above mentioned pressure differential is below the critical value the gas will flow through the neck 24' of the main nozzle, through the straight portion 30 of the intermediate member 28 and through the straight inner member 22' to the atmosphere and the nozzle will then act as a simple convergent nozzle. When the pressure differential is slightly above the critical value the gas may flow from the neck portion

24' of the main nozzle through the straight portion 30 of the intermediate member 28 and from thence through the inner member 22' and through the space between the inner member and the expansion portion 32 of the intermediate member 28 thus providing a modified convergent-divergent nozzle and, when the pressure differential is materially above the critical value the gas may flow through the space between the intermediate member 28 and the enlarged end portion 26' in addition to the space between the members 22 and 28 and through the member 22 thus providing a further divergent effect to take advantage of the increased pressure differential.

In the form shown in Figs. 5 and 6 the principles are the same as those described for Figs. 1 and 2 and the only material difference is that the enlarged end portion 26b of the main nozzle 20 is flared outwardly towards the open end of the nozzle thus giving an increased expansion effect to the space between this enlarged end portion and the inner member 22.

The form shown in Figs. 7 and 8 is the same as that shown in Figs. 1 and 2 except that the nozzle is given a somewhat different form being relatively straight instead of curved as shown in Figs. 1 and 2, and having a circular cross-section rather than the substantially rectangular cross-section shown in Figs. 1 and 2. In this last form of the invention the nozzle is generally indicated at 34 and has a somewhat elongated neck portion 36 leading into the enlarged end portion 38 within which is located the circular inner member 40. The principles of operation of this modified form of nozzle are, however, in all respects similar to the principles described above in connection with Figs. 1 and 2.

While a suitable mechanical embodiment has been hereinabove described and illustrated in the accompanying drawing, in several slightly different forms, for the purpose of disclosing the invention, it is to be understood that the invention is not limited to the particular embodiments so illustrated and described but that such changes

in the size, shape and arrangement of the various parts may be resorted to as come within the scope of the sub-joined claims.

Having now described the invention so that others skilled in the art may clearly understand the same, what it is desired to secure by Letters Patent is as follows:

1. A fluid ejection nozzle comprising, a convergent portion having a restricted neck, an enlarged end portion beyond said neck portion in the direction of fluid flow, and a tubular member of substantially the same cross-sectional area as said neck within said enlarged portion and radially spaced therefrom, said member also being axially spaced from said neck in the direction of fluid flow whereby fluid may flow from said neck portion through said tubular member or through both said tubular member and the space between said tubular member and said enlarged end portion.

2. A nozzle for directing engine exhaust gases into a rearwardly directed high velocity jet comprising, a convergent nozzle portion for receiving the exhaust gas from the engine, a divergent nozzle portion connected to the convergent nozzle portion for expanding said exhaust gas, and a cylindrical tubular member within said divergent portion and spaced radially from said divergent portion and axially from said convergent portion.

3. A nozzle comprising, a convergent nozzle portion for receiving gas, a divergent nozzle portion connected to the convergent nozzle portion for expanding said gas, and a member within said divergent portion and spaced therefrom to form an exit passage therebetween, said member having a non-divergent exit channel therein.

4. A nozzle as set forth in claim 3 including at least one auxiliary member which increases uniformly in cross-sectional area in the direction of fluid flow located between said non-divergent channel member and said divergent portion.

PAUL J. CAMPBELL.