A. TAUB ETAL

3,098,352

ADJUSTABLE JET PROPULSION NOZZLE WITH SECONDARY AIR FLOW CONTROL

Filed April 1, 1960

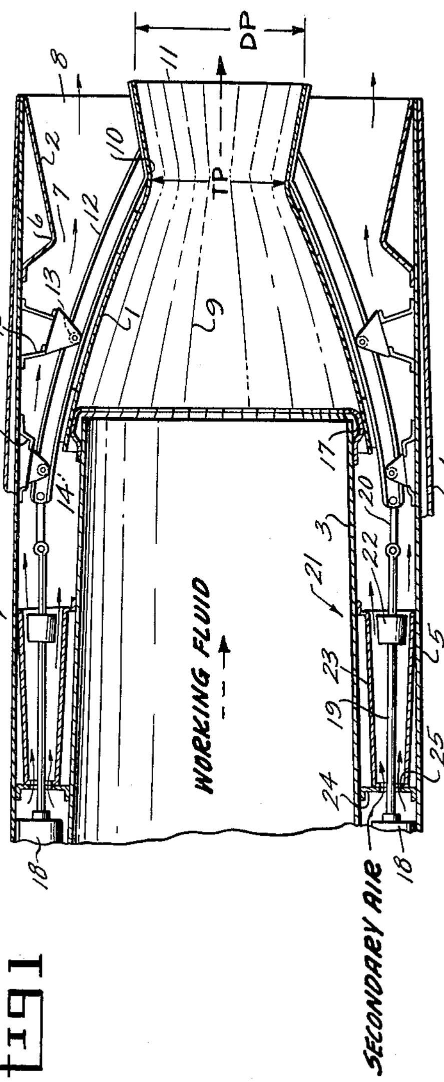

Fig 1

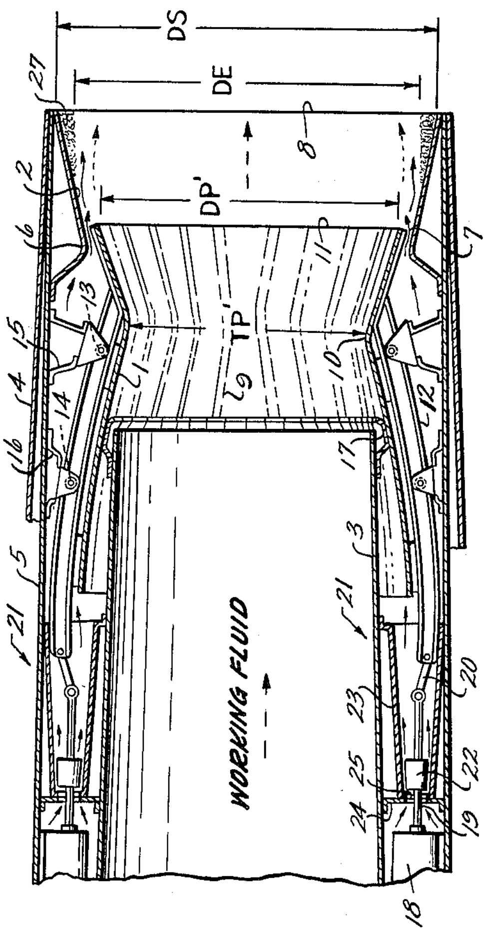

Fig 2

INVENTORS.
MARTIN M. FELDMAN
CLARENCE E. LeBELL
ALVIN TAUB

BY William L. Ericson
ATTORNEY

United States Patent Office

3,098,352

Patented July 23, 1963

3,098,352

ADJUSTABLE JET PROPULSION NOZZLE WITH SECONDARY AIR FLOW CONTROL

Alvin Taub and Martin Mayer Feldman, Wakefield, and Clarence Edgar Le Bell, Peabody, Mass., assignors to General Electric Company, a corporation of New York

Filed Apr. 1, 1960, Ser. No. 19,421
2 Claims. (Cl. 60—35.6)

This invention relates to adjustable fluid nozzles for jet propulsion engines, and more particularly to improved means for controlling secondary air flow in a nozzle having an ejector passage for introducing secondary air into a stream of working fluid. The invention has particular utility in a nozzle of the type described and claimed in application Serial Number 776,387 to W. W. Carlton et al., now Patent No. 3,044,258, issued July 17, 1962, and assigned to the assignee of this application, but its application is not limited thereto. A nozzle of the type described in the application to Carlton will hereinafter be referred to as a "Carlton nozzle" for convenience.

The Carlton nozzle is an adjustable converging-diverging nozzle whose effective discharge orifice area is not only mechanically, but also aerodynamically, variable in accordance with the pressure of working fluid discharged through the nozzle by a jet propulsion engine. A primary convergent-divergent nozzle section is formed of slidably-mounted flaps, such that the throat area and discharge orifice area are adjustable in a predetermined relationship to accommodate a wide range of engine working fluid temperatures and pressure ratios. The "critical" pressure ratio is that at which fluid velocity in the nozzle throat becomes sonic. At super-critical nozzle pressure ratios, a divergent nozzle portion becomes necessary to realize the full thrust available from expansion of the working fluid. In the Carlton nozzle, pressure ratios substantially exceeding the critical value are accommodated by a fixed secondary nozzle section, forming a divergent extension of the adjustable primary section in an expanded condition of the latter. An ejector passage is formed between the sections, and is thus spaced along a divergent portion of the combination nozzle. A supply of subsonic secondary fluid to the ejector passage causes the working fluid to separate from the nozzle at points, which may be spaced upstream from the secondary discharge orifice, at which equilibrium with atmospheric pressure is reached. Thus the effective discharge orifice area is aerodynamically varied to prevent overexpansion and provide the correct nozzle form for realization of maximum thrust, over a wide range of super-critical working fluid pressure ratios.

The supply of secondary fluid may conveniently be air bled from a compressor of the associated jet propulsion engine, or may comprise ram air that is reduced to subsonic velocity. The rate of flow of secondary air into the secondary section of a Carlton-type nozzle is determined by the area of the ejector passage, as determined by the adjusted position of the primary section, and by the pressure ratio of the secondary air across the passage. The pressure of the secondary air supply depends upon flight velocity, being dependent upon ram effect. However, the rate of flow theoretically required depends upon nozzle position, and the latter is controlled in accordance with working fluid temperature and pressure, rather than flight velocity. Furthermore, the design requirements of the primary nozzle form result in a variation in ejector passage area which does not directly conform to the variation in secondary air flow rate which is theoretically required. As a result of the failure of ram pressure and ejector passage area to conform correctly to nozzle position, the rate of secondary air flow in a Carlton-type nozzle has been found to exceed the requirement for proper nozzle operation under certain conditions, especially at super-sonic flight speeds.

The energy loss required to ram ambient air is substantial at high flight speeds, and a material loss in thrust results from a relatively small increase in the quantity of air rammed. For example, an increase of 1% in the mass flow rate of rammed air may produce a decrease in thrust of about 3½%. Therefore, any excess of ram air flow induced by a Carlton-type nozzle results in an appreciable loss of thrust.

It is the primary object of our invention to provide means for controlling the rate of supply of secondary air to an adjustable nozzle of the type having an ejector passage for introducing secondary air into a stream of working fluid, with improved response to nozzle setting, so that the mass flow rate is limited in accordance with predetermined requirements for proper nozzle operation.

Further objects and advantages of our invention will become apparent as the following description proceeds.

Briefly stated, in accordance with one embodiment thereof, we carry out our invention by providing an adjustable fluid nozzle with means for adjustably throttling secondary air supplied to an ejector passage thereof. Since reduction in the pressure of secondary air due to throttling effect is proportional to the ram pressure, the effect of flight velocity on the pressure is reduced. The adjustable fluid nozzle includes a primary section which is movable by actuating means, the actuating means including an actuating member connected to the primary nozzle section. The throttling means is comprised of at least one throttling duct having varying cross section along its length and a movable throttle body mounted therein to vary the flow area, the throttle body being fixed to the actuating member for movement therewith. The rate of flow of secondary fluid is thus more nearly limited to that necessary for proper operation of the nozzle, and the loss in thrust associated with excess flow is substantially reduced.

While the specification concludes with claims particularly pointing out and distinctly claming the subject matter which we regard as our invention, it is believed that the invention will be better understood from the following description taken in connection with the accompanying drawing, in which:

FIG. 1 is an elevation in section of a fluid nozzle made in accordance with our invention, shown in a first or closed position; and

FIG. 2 is a similar view, showing the nozzle in a second or open position.

Referring to the drawing, a fluid nozzle made according to the aforementioned Carlton et al. application Serial No. 776,387 is shown to illustrate our invention, which is not, however, necessarily limited in application to a nozzle of this specific type. The Carlton-type nozzle generally comprises an adjustable primary nozzle section **1**, and a fixed secondary nozzle section **2**. These nozzle sections define fluid passageways receiving a flow of working fluid, designated by broken arrows, from a jet propulsion engine through a conventional exhaust collector **3** of cylindrical form. The working fluid is passed to the exhaust nozzle by the exhaust collector for the conversion of pressure and temperature energy internally contained therein into a kinetic or velocity form in the exhaust nozzle, thereby generating a useful thrust reaction upon the exhaust nozzle. The jet propulsion engine, exhaust nozzle, and exhaust collector are enclosed by an aircraft skin **4**, in order to minimize the resistance of the atmosphere to their pasage therethrough. The aircraft skin may follow any form suitable to specific aircraft applications. A cylindrical duct **5** is circumferentially spaced about exhaust collector 3, and extends axially therefrom into overlapping engagement with skin 4, for the purpose of supporting the nozzle structure and conducting secondary fluid (air) thereto.

Secondary nozzle section 2 is formed as a sheet metal annulus diverging in a downstream direction, and is supported in a fixed position by duct 5. The secondary section includes a throat portion 6, defining a variable area secondary fluid ejector passage 7 in cooperation with adjustable primary section 1. At its downstream end, the secondary section forms a fixed-area secondary discharge orifice 8, whose diameter is designated DS in FIG. 2.

The adjustable primary nozzle section 1 is comprised of a circumferentially disposed set of overlapping flaps 9, which are relatively slidable axially and circumferentially. Flaps 9 are of convergent-divergent form, and include a throat portion 10 and a primary discharge orifice 11, both of whose areas are varied by sliding motion of the flaps. The diameters of throat 10 and orifice 11 are designated TP and DP, respectively, in the closed position of FIG. 1, and TP' and DP', respectively, in the open position of FIG. 2.

Flaps 9 are mounted for sliding motion along predetermined curved paths upon a plurality of curved track elements 12, each of which is supported in rolling engagement by a pair of rollers 13 and 14. A track element may be provided for each flap 9, or for alternate flaps only, as described in the aforementioned Carlton et al. application. Rollers 13 and 14 are rotatably mounted in carriage frames 15 and 16, respectively, whose positions and lengths combine with the form of track elements 12 to determine the relative areas of throat 10 and primary orifice 11 over the range of movement of the flaps. Frames 15 and 16 are stationarily mounted in duct 5. A theoretically optimum nozzle form would require independent adjustability of the throat area in accordance with working fluid temperature, and of the primary orifice area in accordance with the pressure ratio of the working fluid to the ambient atmosphere. However, it has been found in practice that the predetermined program of relative values of these areas established by a Carlton nozzle provides a satisfactory approximation to optimum nozzle form.

An annular sliding seal 17 of conventional type is interposed between flaps 9 and exhaust collector 3 to seal the working fluid passage while permitting sliding movement of the flaps relative thereto.

Means for adjusting flaps 9 to vary the configuration of the primary nozzle section are provided, comprising a plurality of fluid actuating motors 18 mounted circumferentially about duct 5. Each of motors 18 controllably actuates a drive rod 19 for axial reciprocation, and may comprise any suitable type of hydraulic, mechanical, or electric motor well known in the art. Each drive rod 19 is drivingly connected with one of track elements 12 by means of a pivotally-connected link 20. Alternatively, a smaller number of motors than flaps may be provided, and driving connection may be established through a unison ring (not shown) circumferentially spaced about exhaust collector 3.

The adjustable fluid nozzle which has thus far been described in itself forms no part of the present invention, and is disclosed and claimed in the aforementioned application Serial No. 776,387 to W. W. Carlton et al.

The rate of secondary air flow through the ejector passage 7 of the Carlton-type nozzle as thus far described is controlled by two factors: the area of the passage, as varied by movement of flaps 9, and the pressure ratio of the secondary air across the passage. Neither of these factors corresponds directly to the secondary air requirement of the nozzle, which is established by the position of the primary nozzle section relative to the secondary nozzle section. The inherent form of flaps 9 does not permit control of the area of passage 7 in direct conformity to the varying flow requirements in the form of the primary

nozzle section is adjusted. Furthermore, the secondary air ram pressure is directly affected by flight velocity, which is not dependent upon nozzle position. We have found that the resulting secondary air flow in practice exceeds the nozzle requirements under certain conditions of flight speed and nozzle setting, resulting in loss of thrust caused by the excess ram effect.

Our invention is directed to the provision of means, in combination with an adjustable nozzle having an ejector passage, such as illustrated by the Carlton type nozzle, for controlling the secondary air flow in more direct conformity with nozzle requirements. In the embodiment shown, we carry out our invention by providing a plurality of adjustable throttling means generally designated 21, each of which comprises a throttle body 22, and a throttling duct 23 arranged in serial flow relation with duct 5 for transmitting secondary air to ejector passage 7. Duct 23 is generally frusto-conical as shown, and is mounted upon an end wall 24 of duct 5, in communication with an opening 25 therein. Throttle body 22 is mounted upon drive rod 19 for reciprocating axial movement relative to passage 23, to provide a secondary air throttling area which is directly controlled by the nozzle setting. As shown, both passage 23 and body 22 are frusto-conical in form, providing a throttling area variation which is linear with respect to nozzle movement. However, it will be apparent that any desired relationship between throttling area and nozzle position may be established by suitably forming passage 23, e.g. paraboloidally, hyperbolically, or according to any desired function.

Low Temperature, Closed-Nozzle Operation

The fully-closed position of primary nozzle section 1, shown in FIG. 1, is employed when the temperature of the working fluid is at a minimum, corresponding to a condition in which no afterburning is taking place, and the pressure ratio in the sub-critical range. Optimum propulsive efficiency is achieved with a primary discharge orifice 11 which is only slightly larger than throat 10, so that the nozzle has a minimum divergency. The working fluid expands substantially to atmospheric pressure in throat 10, developing maximum thrust with less than sonic flow velocity. In this position, the primary discharge orifice 11 is located substantially in the plane of the secondary discharge orifice 8; overexpansion of the working fluid in the "base" region down stream of orifice 8, and surrounding orifice 11 (known as "base-drag"), is prevented by a maximum flow of secondary air through throttling means 21. The flow area defined between throttle body 22 and duct 23 is therefore at a maximum in the position of FIG. 1, being determined experimentally for specific applications to provide a sufficient subsonic flow to permit transmission of atmospheric pressure into the base region, and thus prevent overexpansion of the working fluid.

High Temperature, Open Nozzle Operation

If the temperature of the working fluid is increased as by increased injection of fuel, the primary nozzle section is moved toward the fully open position of FIG. 2. In intermediate positions, as well as in the open position of FIG. 2, the secondary nozzle section cooperates with the divergent portion of the primary nozzle section to form an extended divergent nozzle section, along which is spaced the ejector passage 7. The introduction of a subsonic flow of secondary air through passage 7 causes the working fluid to separate from the diverging nozzle walls, and thus to discontinue the expansion process, at those points at which the pressure of the working fluid is in equilibrium with atmospheric pressure, with the result that overexpansion and resultant drag are prevented. As more fully explained in the aforementioned Carlton et al. application, the effective discharge orifice area is thus aerodynamically varied between the adjusted area of primary orifice 11 and the fixed area of secondary orifice

8 as limits, converting the pressure of the working fluid most effectively into useful thrust. By way of example, the working fluid is shown in FIG. 2 to separate from the secondary nozzle section at points designated by diameter DE. While the theory of this separation phenomena is not fully understood, it is believed that the layer of subsonic velocity secondary air permits the transmission of atmospheric pressure upstream from orifice **8** forming an eddy **27** within nozzle section **2** and permitting the working fluid to separate as it reaches atmospheric pressure. Since the working fluid attains supersonic velocity after leaving throat **10**, the upstream transmission of atmospheric pressure could not occur other than through a subsonic flow of secondary air surrounding the working fluid stream.

The rate of flow of secondary air through ejector passage **7**, in the absence of our improved throttling means, would be determined by the cross-sectional area of passage **7**, and by the pressure ratio of the secondary air entering and leaving this passage. As previously explained, the area of the passage is determined in part by the form of the primary nozzle section **1**, and consequently the air flow does not conform uniformly to the requirements for proper nozzle operation. Furthermore, the ram pressure of the secondary air varies with flight speed, which bears no direct relationship to nozzle position.

Our improved throttling means tends to minimize flight velocity as an extraneous influence on secondary air flow, because the throttling effect increases with increasing pressure. The form of throttling duct **23** is established to provide a correct flow restriction, in cooperation with throttle body **22**, for all positions of the primary nozzle section intermediate those shown in FIGS. 1 and 2. In this manner, it is possible to insure a correct rate of secondary air flow to establish separation of the working fluid at an atmospheric equilibrium pressure over the entire range of movement of the primary nozzle section, while at the same time minimizing any excess secondary air flow induced by the ram effects of a varying flight speed.

It will be apparent from the foregoing description that we have provided improved means for controlling the rate of supply of secondary air to an adjustable nozzle of the type having an ejector passage, as illustrated by the Carlton type nozzle which limits the supply in accordance with predetermined requirements for proper nozzle operation. It should be understood that our invention is not limited to specific details of construction and arrangement thereof herein illustrated, and that changes and modifications may occur to those skilled in the art without departing from the spirit of our invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. In an exhaust nozzle for a reaction engine: a primary nozzle section receiving working fluid from said engine, means supporting said primary nozzle section and actuating means for moving said primary nozzle section to vary the form thereof and the area of discharge therefrom, said actuating means including an actuating member connected to said primary nozzle section, a secondary nozzle section circumferentially spaced about said primary nozzle section, said primary and secondary nozzle sections forming a circumferential ejector passage therebetween, duct means connected to said ejector passage to supply secondary fluid at subsonic velocity thereto, adjustable throttle means in said duct means upstream of said ejector passage for throttling the flow of secondary fluid, and means directing the entire flow of secondary fluid through said adjustable throttling means, said adjustable throttling means comprising at least one throttling duct having varying cross section along its length and a movable throttle body mounted therein to vary the flow area defined between said throttling duct and said throttle body in accordance with the position of said throttle body, said movable throttle body fixed to said actuating member for movement therewith, whereby the amount of throttling of the secondary fluid is controlled in accordance with the position of said actuating member and said primary nozzle.

2. In an exhaust nozzle for a reaction engine: a set of circumferentially disposed flaps shaped to form a primary nozzle section receiving working fluid from said engine, said flaps formed successively, in the direction of working fluid flow therethrough, with a convergent portion, a throat portion, and a divergent portion, a secondary divergent nozzle section circumferentially spaced about said primary nozzle section, means supporting said flaps and actuating means for moving said flaps along predetermined curved paths to a first position in which said working fluid is exhausted to atmosphere directly from said primary nozzle section and to a second position in which said working fluid is exhausted to atmosphere through said secondary nozzle section from said primary nozzle section, said actuating means including an actuating member connected to said flaps, said primary and secondary nozzle sections forming a circumferential ejector passage therebetween and said secondary nozzle section forming a divergent extension of said primary nozzle section in said second position of said flaps, duct means connected to said ejector passage to supply secondary fluid at subsonic velocity thereto, adjustable throttle means in said duct means upstream of said ejector passage for throttling the flow of secondary fluid, and means directing the entire flow of secondary fluid through said adjustable throttling means, said adjustable throttling means comprising at least one throttling duct having varying cross section along its length and a movable throttle body mounted therein to vary the flow area defined between said throttling duct and said throttle body in accordance with the position of said throttle body, said movable throttle body fixed to said actuating member for movement therewith such that throttling is at a maximum in said second position and at a minimum in said first position, the throttled secondary fluid supplied to said ejector passage when said flaps are in said second position inducing separation of the working fluid from said secondary divergent nozzle section at points at which the pressure of the working fluid has reached equilibrium with ambient atmospheric pressure, thereby preventing overexpansion of the working fluid.

References Cited in the file of this patent

UNITED STATES PATENTS

2,729,937	Hausmann	Jan. 10, 1956
2,770,944	Jordan	Nov. 20, 1956
2,869,321	Welch et al.	Jan. 20, 1959
2,910,828	Meyer et al.	Nov. 3, 1959
2,974,481	Smith	Mar. 14 1961
2,984,068	Eatock	May 16, 1961
3,049,873	Weeks	Aug. 21, 1962

FOREIGN PATENTS

203,092	Australia	June 21, 1956
1,140,440	France	Mar. 4, 1957

OTHER REFERENCES

Pearson: Journal of the Royal Aeronautical Society, volume 62, No. 573, page 662, September 1958.

Pearson: Journal of the Royal Aeronautical Society, vol. 62, No. 573, page 661, September 1958.