

May 31, 1955

H. R. NILSSON ET AL
JET PROPULSION UNITS EMBODYING POSITIVE DISPLACEMENT
COMPRESSOR AND ENGINE COMPONENTS

2,709,336

Filed Aug. 2, 1949

4 Sheets-Sheet 1

Fig. 1

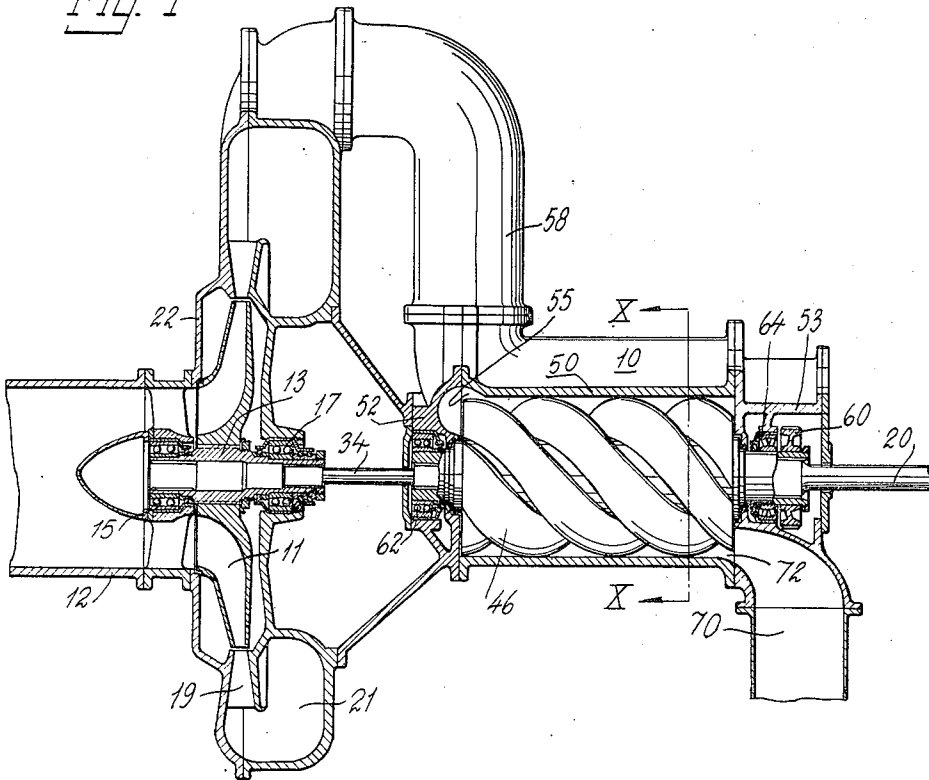
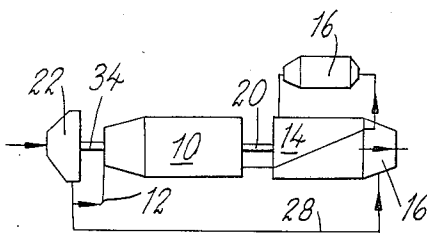


Fig. 3

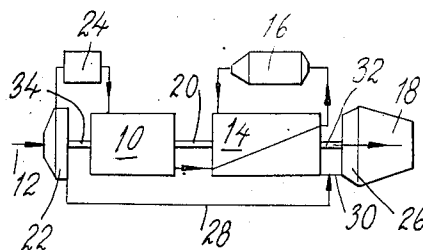


Fig. 4

INVENTORS
Hans Robert Nilsson
Teodor Emanuel Lindberg
BY
Jarvis C. Whittle
their Attorney

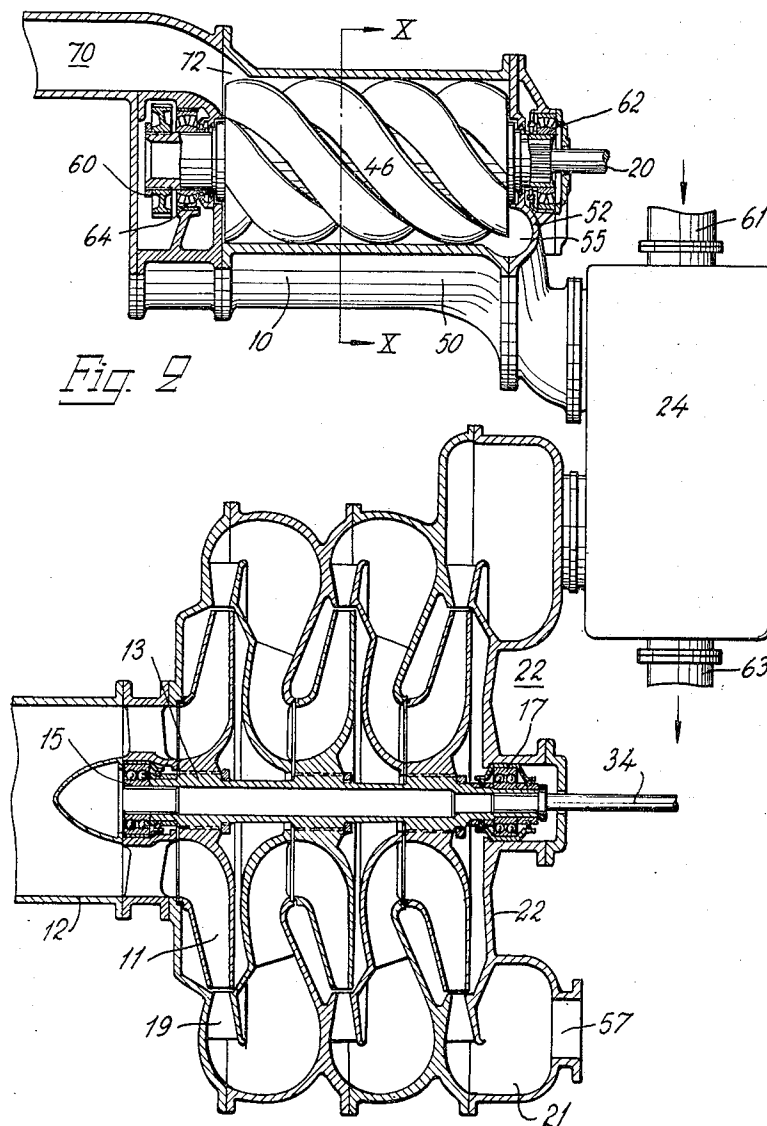
May 31, 1955

H. R. NILSSON ET AL
JET PROPULSION UNITS EMBODYING POSITIVE DISPLACEMENT
COMPRESSOR AND ENGINE COMPONENTS

2,709,336

Filed Aug. 2, 1949

4 Sheets-Sheet 2



INVENTORS
Hans Robert Nilsson
Lester Emmanuel Lindberg
BY *Jarvis C. Marble*
their Attorney

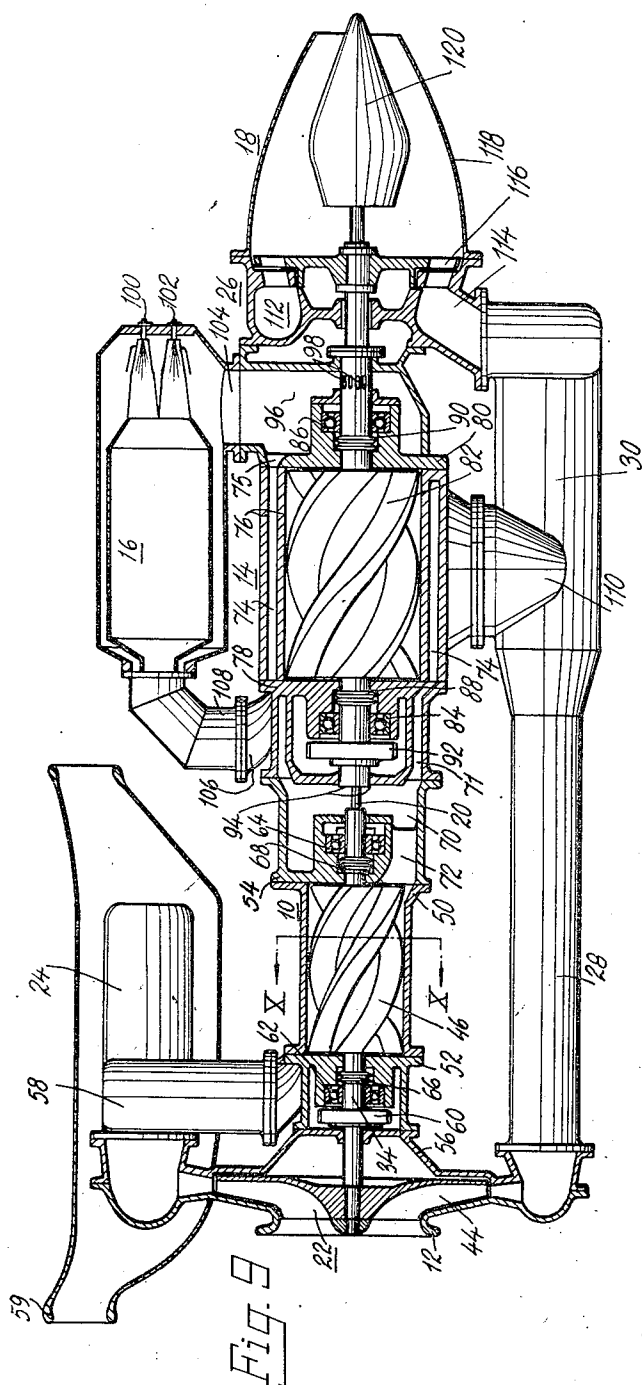
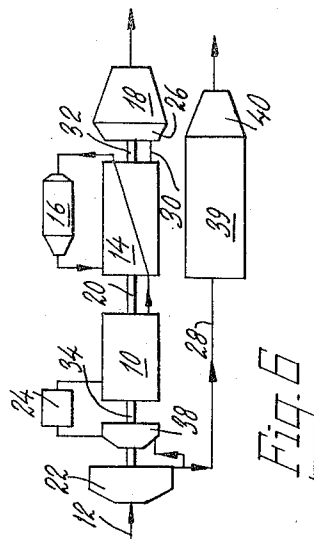
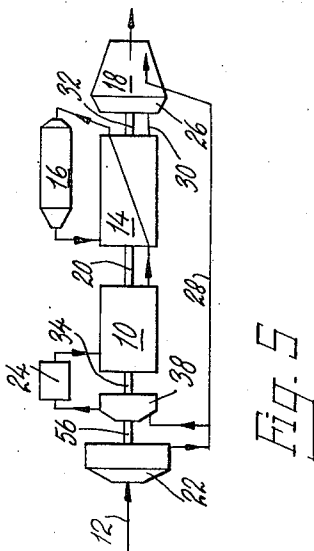
May 31, 1955

H. R. NILSSON ET AL
JET PROPULSION UNITS EMBODYING POSITIVE DISPLACEMENT
COMPRESSOR AND ENGINE COMPONENTS

2,709,336

Filed Aug. 2, 1949

4 Sheets-Sheet 3



INVENTORS
Hans Robert Nilsson
Leslie J. and J. M. Hagg
BY *Garvie M. M. M.*
their Attorney

May 31, 1955

Filed Aug. 2, 1949

H. R. NILSSON ET AL
JET PROPULSION UNITS EMBODYING POSITIVE DISPLACEMENT
COMPRESSOR AND ENGINE COMPONENTS

2,709,336

4 Sheets-Sheet 4

Fig. 7

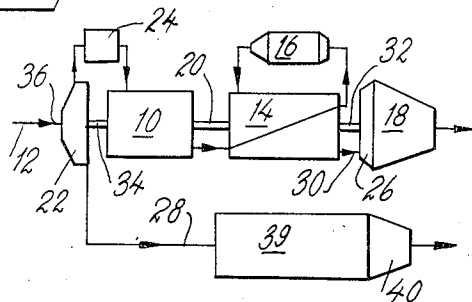


Fig. 8

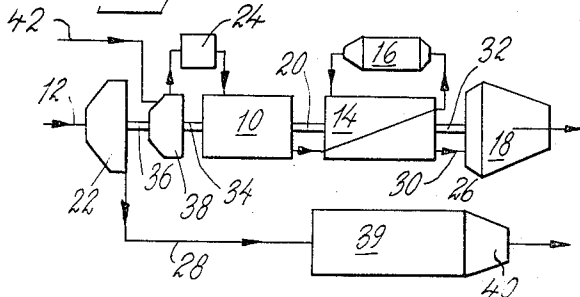
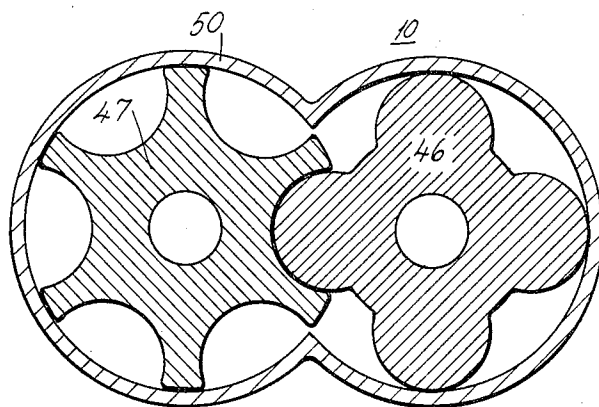


Fig. 10

INVENTORS.
Harry Robert Nilsson
Theodor Immanuel Lundhagen
BY
Jarvis O. Wadley
their attorney

1

2,709,336

**JET PROPULSION UNITS EMBODYING POSITIVE
DISPLACEMENT COMPRESSOR AND ENGINE
COMPONENTS**

Hans Robert Nilsson and Teodor Immanuel Lindhagen,
Stockholm, Sweden, assignors, by mesne assignments,
to Jarvis C. Marble, New York, N. Y., Leslie M. Mer-
rill, Westfield, N. J., and Percy H. Batten, Racine, Wis.,
trustees

Application August 2, 1949, Serial No. 108,118

Claims priority, application Sweden August 4, 1948

15 Claims. (Cl. 60—35.6)

The present invention relates to reaction engines, the useful power of which is exclusively or at least partly produced by jet nozzles.

The most common embodiment of such engines hitherto known consists of a dynamic compressor driven by a turbine in which all the compressed medium after heating is expanded to give necessary power for the compression. The remaining heat drop is utilized in a jet nozzle coupled after the turbine for producing for instance the thrust needed. Such a reaction engine fulfills the demands for low engine weight per thrust unit. The best utilization of the fuel at the gas temperatures allowed by the turbine system is obtained at moderate gas velocities (500–700 m./sec.) from the jet nozzle. These velocities in turn require only comparatively small compression and expansion ratios in compressor, turbine and jet nozzle respectively. The compressor, therefore, may advantageously be of the single wheel centrifugal type and the turbine of the one stage type. As the capacity, i. e. the quantity of gas passing per time unit, can be kept very high for both these types of engines in relation to their size, the reaction engine attains a low ratio weight/thrust. The drawback of this engine primarily is to be found in high specific fuel consumption, partly depending on the relatively low maximum gas temperature allowable for the turbine, considering the strength of the material of the blading. A further drawback is that upon changes in load, particularly when rapidly accelerating from low speed and low gas temperature to high speed and high temperature operation, the dynamic compressor can easily become subject to so-called surging when the fuel supply to the combustion chamber is increased, a phenomenon which has in many cases resulted in extinguishing the flame in the combustion chamber. An aircraft provided with such a reaction engine will lose its speed to such an extent that before ignition starts again through measures taken by the pilot, the indicated deficiency (the tendency for surging) may become fatal. As herein employed, the term dynamic compressor, as distinguished from the term positive displacement or displacement compressor, is intended to be generic to those kinds of compressors in which the pressure of the medium compressed is raised by imparting energy of velocity to the medium and converting such energy to static pressure energy. Of such types, centrifugal compressors and so-called axial flow compressors are the most common.

By using a displacement instead of a dynamic compressor the risk of surging will be avoided but the ratio weight/thrust will increase on account of the difficulty in building known types of displacement compressors as light-weight constructions.

The present invention relates to a new combination of the aggregate feeding the jet nozzles by means of which the above-mentioned drawbacks can be avoided. For this purpose there is utilized as driving engine for the

2

compressor part, or if the engine is of the multiple stage type at least in its high pressure stage, a displacement engine of the type described in our copending U. S. Patent No. 2,627,161 granted February 3, 1953, on our application No. 289,161 filed May 21, 1952, as a continuation-in-part replacing our application No. 776,928 filed September 30, 1947 (now abandoned) and which is especially intended for high temperature driving media. For the compression there is used at the same time a compressor aggregate which consists in the combination of a dynamic compressor, preferably a centrifugal compressor, and a positive displacement compressor, the dynamic compressor being coupled in front of the displacement compressor (in the direction of flow). Such a compressor aggregate is so light that it may also, in respect of weight, advantageously be used for aeroplanes. The use of a displacement compressor immediately before the combustion chamber of the compressor driving engine at the same time eliminates the risk of extinguishing the flame and thus the risk of engine failure.

The displacement engine, however as well as the displacement compressor, has the drawback that it cannot be built for large gas volumes without being inconveniently heavy. Therefore, when high admission pressures and temperatures of the driving medium are to be used according to the present invention, it may occur that the whole quantity of the driving medium cannot be expanded to the pressure and temperature values which are most suitable for the jet nozzles. This difficulty may, however, be overcome by simple measures within the scope of the invention.

One of these measures consists in coupling a turbine between the displacement engine and the jet nozzle or nozzles extracting from the turbine that surplus of pressure and heat drop in the exhaust gases from the displacement engine which exceeds the values most suitable for the jet nozzles. Thus, the output of the turbine may be utilized as additional power for driving the compressor or for other purposes as, for instance, the driving of a propeller.

Another means of serving the same purpose is to lead only part of the air compressed in the compressor aggregate through the displacement compressor, and the remainder directly to the jet nozzle coupled after the displacement compressor or possibly to a separate jet nozzle. Under certain circumstances a combination of both these steps is most suitable.

Particularly in those cases when part of the compressor air is led past the displacement engine and supplied to a turbine coupled after same, or is led directly to one or more jet nozzles, it is advantageous to compress the air in a compressor aggregate of the type referred to above. The by-pass conduit is thereby connected to the dynamic compressor operating as the low pressure stage and only part of the air compressed therein is led to the displacement compressor operating as the high pressure stage.

Alternatively a separate compressor can be used for compressing the air passing through the by-pass conduit and in such case a control valve may be arranged in said by-pass conduit for adjusting the air quantity.

The supply of cool air before the turbine or the jet nozzle has for its purpose not only to decrease the temperature of the exhaust gases from the displacement engine to a value which the material of the turbine can resist and which gives the best working conditions for the jet nozzle, but at the same time to improve the fuel economy of the reaction engine.

An increase of the working medium temperature in a reaction engine of normal design only results in a decrease of the air quantity necessary for a certain thrust,

whereas the fuel consumption remains practically unchanged, provided that the comparison is made at the most suitable pressure ratio with respect to the gas temperature. In this way, however, only a reduction in weight of the reaction engine itself is obtained, while the fuel quantity necessary for a certain distance and flying weight remains unchanged.

By designing the compressor with two compression stages or by using a separate compressor as set forth above, whereby air compressed to a pressure suitable for the jet nozzles is mixed with the exhaust gases after the compressor driving engine, a reaction engine with low fuel consumption is obtained. This decrease in fuel consumption, however, is gained independently of the admission temperature of the working medium, but in previously known types of reaction engines this means for improving the fuel economy, to the best of our knowledge, has not been put to practical use. It is also doubtful if in a gas turbine driven reaction engine the system described can be advantageously utilized, having regard to its limited properties in other respects.

The maximum size of a reaction engine of a certain type is primarily restricted by the maximum capacity of the compressor type employed. In gas turbine driven reaction engines with their low working medium temperature—max. 800° C.—this limit size lies at a minimum thrust corresponding to the thrust obtainable in a reciprocating aeroplane engine of medium size. By utilizing the by-passing of air the obtainable thrust decreases with increasing by-passed air added so that favourable fuel economy is obtained at the expense of the other properties of the reaction engine such as weight/thrust and maximum thrust per engine unit which thus becomes unfavourable as compared to the corresponding values of the reciprocating engine.

In order to overcome these deficiencies we have found that the only possible way is to increase the motive fluid temperature of the engine driving the compressor to about 1200–1400° C. This has been made possible by using an engine according to our above mentioned copending application allowing considerably higher motive fluid temperatures than have been possible to utilize in gas turbines.

Investigations have shown that for the same thrust a reaction engine of the turbine type with a working medium temperature of 800° C. needs an air quantity twice as large as that of a displacement motor having 1200° C. working medium temperature, provided the ratio of added air as well as the fuel consumption is the same in both cases. In other words, for a given compressor size the last-mentioned alternative can be built for a thrust twice as large as that of the first mentioned one and thus compete with or even surpass the properties of the reciprocating engine. In the example previously given the additional air quantity amounts to 75% of the total air quantity being compressed by the low pressure stage of the compressor part and the fuel consumption is only half of that required for a gas turbine driven reaction engine of normal design without air by-pass.

In the following, the invention will be described more in detail, reference being had to the accompanying drawings which by way of example show some preferred embodiments, though not limiting the invention thereto.

Fig. 1 is a longitudinal section of a compressor aggregate composed of a single wheel, a centrifugal compressor as low pressure stage, and a displacement compressor as high pressure stage, the two compressors being driven by the same input shaft.

Fig. 2 is a longitudinal section through a compressor aggregate consisting of a low pressure multiple wheel, a centrifugal compressor, and a high pressure displacement compressor, arranged according to the principles of the invention.

Fig. 3 illustrates schematically a reaction engine comprising a centrifugal and a displacement compressor driven

by a displacement engine as well as jet nozzle for jet propulsion and a device for mixing the exhaust gases from the displacement engine with cool air.

Fig. 4 illustrates schematically a reaction engine having the compressor part built up of a dynamic compressor and a displacement compressor, which are driven by a displacement engine with an after-coupled turbine. The exhaust gases from the displacement engine are mixed with cool air from the centrifugal compressor before entering the turbine.

Fig. 5 shows a reaction engine according to Fig. 4 but with a two-stage dynamic compressor, air from the first stage of the dynamic compressor being mixed with the exhaust gases from the turbine.

Fig. 6 shows a reaction engine of the same type as illustrated in Fig. 5, but with the modification that the air discharged after the first stage of the dynamic compressor is conducted to a separate combustion chamber and jet nozzle.

Fig. 7 shows a reaction engine similar to the embodiment according to Fig. 4 but with the modification that the air discharged after the dynamic compressor is utilized in a separate discharge nozzle with forecoupled combustion chamber.

Fig. 8 shows a reaction engine which differs from the engine according to Fig. 6 in that the dynamic compressor-part is divided into two units working in parallel.

Fig. 9 shows in longitudinal section an embodiment of an engine according to Fig. 4.

Fig. 10 is a section on line X—X of Figs. 1, 2 and 9.

In Fig. 1, 10 designates the displacement compressor and 22 the centrifugal compressor. In this case the centrifugal compressor 22 consists of an impeller wheel 11 splined on the shaft 13, which in turn is journaled in the compressor casing at 15 and 17. The compressor casing encloses a diffuser blade row 19 and a collector spiral 21 from which the air is conducted via the piping 58 to the displacement compressor 10. The centrifugal compressor is driven by means of shaft 34.

The displacement compressor 10 is preferably designed according to the same principles as the engine type, which has been described in copending U. S. applications Nos. 684,495 filed July 18, 1946, now abandoned, and 761,265, filed July 16, 1947, now Patent No. 2,622,787. It is characteristic for this type of compressor that the casing 50 is composed of two intersecting, cylindrical bores each containing one of the two engaging compressor rotors 46 and 47 provided with helical lands and grooves, one of these rotors, the so-called male rotor 46, having lands and grooves lying substantially outside its pitch circle, whereas the other rotor, the so-called female rotor, has lands and grooves lying substantially inside its pitch circle. The wrap angle of the two rotors is less than 360°. The compression takes place in the working chambers formed between the rotors, the casing 50 and the end plates 52, 53, said chambers by rotation of the rotors travelling from the inlet port 55 to the outlet port 72, whereby a continuous decrease of their volume takes place, i. e. the compressor is working with internal compression during those periods of time when the working chambers are cut off from both the inlet and the outlet ports.

The rotor 46 is mounted in bearings 62 and 64, which are located in the endplates 52 and 53 respectively. In a corresponding way the female rotor 47 is mounted in its two bearings. As the rotors work with clearance not only between themselves and the casing and the end plates, but also between each other, a synchronizing gear 60 is arranged between the shafts of the rotors. The power necessary for the compression is delivered by the input shaft 20 which, in the embodiment according to Figs. 1 and 2, is shown connected to the shaft end of the rotor 46 by splines.

The air is sucked into the centrifugal compressor 22 through the inlet 12 and is conducted from its collector

5

spiral 21 to the inlet 55 of the displacement compressor via the duct 58. The compressed air exhausts through the outlet 72 to the duct or chamber 70.

In the embodiment shown in Fig. 2 the centrifugal compressor 22 is principally of the same design as before, though the number of impeller wheels is increased from one to three and, furthermore, the collector spiral 21 is provided with a separate outlet 57, through which fluid compressed by the centrifugal compressor can be removed for special purposes.

A cooler 24 is located between the centrifugal compressor 22 and the displacement compressor 10 for cooling the air already compressed in the centrifugal compressor, thereby decreasing the power consumption for compression in the displacement compressor. The cooling medium enters the cooler at 61 and leaves at 63.

The two compressors have in this case separate driving engines, the centrifugal compressor 22 being driven by the shaft 34 and the displacement compressor 10 by the shaft 20. The latter compressor is of the same design as shown in Fig. 1.

Referring to Fig. 3, 10 designates a displacement compressor and 12 a diffusor-shaped inlet duct, while 14 indicates a displacement engine with combustion chamber 16. The exhaust gases from the engine leave the apparatus through the jet nozzle 18. The air is sucked in through the inlet duct 12, compressed in the compressor 10 and via the cooling system of the engine 14 conducted to the combustion chamber 16, where through heating by means of direct combustion of injected fuel it is converted into working medium. The working medium is then supplied to the working chamber of the engine and, by expansion therein, part of its content of energy is transformed into mechanical work, which in turn is transmitted to the compressor 10 via the driving shaft 20. The remaining expansion takes place in the jet nozzle 18, to which the discharge from the engine 14 is directly connected. In front of the displacement compressor 10 there is coupled, by means of a shaft 34, a centrifugal compressor 22, delivering compressed air to the exhaust gases of the engine 14 via a bypass, conduit 28, which additional air is used in the final expansion and, according to the principles described in the preamble, contributes to decreasing the fuel consumption of the engine, at the same time moderating the gas temperature before the jet nozzle.

In a construction according to Fig. 4, the compression of the working medium for the displacement engine is carried out in two steps, using a dynamic compressor 22, preferably a centrifugal compressor, as the low-pressure stage which for one thing delivers the air quantity intended for the displacement engine 14, and for another supplies directly to the exhaust gases from the engine 14 an air quantity so adjusted that the operating temperature of the after-coupled turbine 26 obtains a value suitable for the blade material. This mixing is carried out by the aid of conduit 28. The device operates as follows:

The whole quantity of air passes the inlet diffusor 12 and is compressed in the dynamic compressor 22, from which part of the compressed air after having passed an intermediate cooler 24 is further compressed in the displacement compressor 10, heated in the combustion chamber 16, and caused to expand in the displacement engine 14. The gases from the engine are discharged through the conduit 30 to the turbine 26, before which, however, it is mixed with air directly supplied from the compressor 22 via the conduit 28. After the expansion in the turbine 26, a further expansion takes place in the jet nozzle 18. The different engines of the aggregate are all mechanically coupled together by means of the shafts 20, 32 and 34. Various combinations are, however, possible, the compressor 22, by way of example, being driven by the turbine 26 only and the compressor 10 solely by the engine 14.

6

The aggregate according to Fig. 5 differs from the one previously described in that a dynamic compressor 38 has been inserted as an intermediate stage between the compressor 22 and the displacement compressor 10 for further compression of the air quantity passing through the displacement machines 10 and 14. Furthermore, the air to be admixed is supplied after the turbine as will appear from the connection of the conduit 28 to the jet nozzle 18. The prerequisite for such an arrangement is that the exhaust gases from the engine 14 to the turbine 26 have a moderate temperature.

Figs. 6 and 7 are modified embodiments of the aggregates according to Fig. 5 and Fig. 4 respectively. Instead of admixing cool compressed air through the conduit 28 either after or before the turbine 18, in these two cases it is led to a separate combustion chamber 16 with subsequent jet nozzle 40.

The aggregate set forth in Fig. 8 differs from the construction according to Fig. 6 only in the detail that the compressor 38 instead of compressing air from the conduit 28 takes in air directly from the atmosphere through a separate inlet diffusor 42.

Which type of aggregate is preferred depends inter alia on the amount of power required, i. e. the size of the aggregate, on allowed working temperature of the integrating expansion machines, on mounting circumstances, etc.

The longitudinal section of the engine in Fig. 9 illustrates a practical solution of the arrangement diagrammatically shown in Fig. 4, wherein like reference characters have also been used to indicate members corresponding to those of Fig. 9.

In the embodiment shown the dynamic compressor 22 consists of a single wheel centrifugal compressor with the impeller 44 mounted directly upon the extension of the one rotor shaft end (extending from the rotor 46) of the displacement compressor 10. The displacement compressor 10 comprises a rotor 46 and a slide (on the drawing concealed by the rotor), mounted in the housing 50 with the end casings 52 and 54 of which the end casing 52 carries the casing 56 of the centrifugal compressor with diffusors and which in turn supports the intermediate cooler 24, that, however, is also supported by the supply pipe 58 from the cooler to the displacement compressor 10.

The compressed medium is cooled in the intermediate cooler 24 by means of the relative (draft) wind and this cooler therefore is enclosed in a suitable casing 59 with a diffusor-shaped inlet and nozzle-shaped outlet in order to reduce the pressure drop through the apparatus.

The male rotor 46 has convex, helically extending lands, which lie substantially outside the pitch circle, of the rotor, while the female rotor intermeshing the male rotor has concave, helically extending grooves, which lie substantially within the pitch circle of the said rotor. It is furthermore characteristic for these rotors that the wrap angle is less than 360°, through which compression chambers are formed between the lands of the rotors, the housing and the end casings, and on rotation of the rotors decrease in volume during the path from the inlet to the outlet port. The rotors operate with a certain clearance, for which reason synchronizing gears, the one belonging to the male rotor being shown at 60, are needed in order to keep the rotors in a space packed relationship to each other. Each rotor is mounted in two bearings one of which at the same time serving as a thrust bearing. Thus the male rotor, as shown, is journaled in the ball bearings 62 and 64, seals 66 and 68 being provided for reducing the outward leakage from the compression chambers. The air supplied from the inlet 58 passes during compression diagonally through the compressor and discharges into the chamber 70 via the outlet port 72 in the end casing 54.

The engine 14 is built up in a way analogous to the com-

pressor 10, but the housing and rotors are effectively cooled by the working medium. In the casing 76 which is traversed by cooling ducts 74 and provided with the end casings 78 and 80, respectively, there are journaled two rotors of the same type as described for the compressor. Thus the rotor (male) 82, provided with helical lands, is supported in the bearings 84 and 86 and sealed by means of the seals 88 and 90. The synchronizing gears for the rotors are indicated at 92. The driving shaft 20 between the male rotors of the engine and the compressor is constructed as a torsion shaft and gives room at 94 for admission of the cooling air to the cooling system of the male rotor 82, said cooling system preferably being constituted by ducts or bores extending closely below the rotor surface, which bores communicate with the two hollow rotor shafts. The cooling air afterwards is collected in the chamber 96, into which the holes 98 in the rotor shaft open. The female rotor is cooled in an analogous way.

Part of the air from the chamber 70 is transmitted through the duct 71 to the cooling channels 74 of the engine housing, from where it passes through ducts 75 to the chamber 96 and further to the combustion chamber 16.

The combustion chamber 16 is of ordinary construction with double walls. Fuel is injected through the nozzles 100 and 102 and burns in the air entering through the port 104. The heated working medium formed is conducted to the engine inlet 106 via the conduit 108 and after expansion in the engine is exhausted through the outlet 110 to the mixing chamber 30, to which also cool air is supplied from the compressor 22 through the conduit 28, which air has for its purpose to reduce the temperature of the exhaust gases from the engine, and simultaneously to increase the quantity of working medium through the turbine 26 and the jet nozzle 18. The inlet chamber to the turbine 26 is designated by 112, the guide vanes by 114 and the disc with moving blades by 116. The turbine thus is of single stage type with an overhanging disc mounted on the extended shaft of the male rotor 82.

The exhaust gases from the turbine 26 are exhausted through the jet nozzle 18, which consists of a casing 118 with a cone 120 preferably axially displaceable therein for adjustment of the through flow area and thus also of the degree of expansion in the nozzle.

We claim:

1. A propulsion unit embodying jet propulsion comprising a compressor section for compressing air, combustion chamber means for heating air compressed in said compressor section to provide high temperature gaseous motive fluid, an engine section for expanding motive fluid delivered thereto from said combustion chamber means to provide power for driving the compressor section and nozzle means for developing jet propulsive thrust from gases ejected from the unit, said engine section comprising a rotary positive displacement engine having working chambers defined by parts provided with cooling passages connected to receive compressed air from said compressor section and to exhaust the same to said combustion chamber means for conversion to motive fluid, said compressed section comprising a rotary positive displacement compressor and having sufficient capacity to compress air in excess of that required to provide the motive fluid produced to operate said engine, connections for causing only a portion of the air compressed in said compressor section to be converted to motive fluid in said combustion chamber means and expanded in said rotary positive displacement engine, and connections for causing both motive fluid expanded in said positive displacement engine exhausted from said engine and excess air from said compressor section not expanded through said engine to be discharged through said nozzle means.

2. A propulsion unit embodying jet propulsion comprising a compressor section for compressing air, combustion chamber means for heating air compressed in said compressor section to provide high temperature gaseous motive fluid, an engine section for expanding mo-

tive fluid delivered thereto from said combustion chamber means to provide power for driving the compressor section and nozzle means for developing jet propulsive thrust from gases ejected from the unit, said engine section comprising a rotary positive displacement engine having working chambers defined by parts provided with cooling passages connected to receive compressed air from said compressor section and to exhaust the same to said combustion chamber means for conversion to motive fluid, said compressor section comprising a low pressure dynamic compressor and a high pressure positive displacement compressor receiving air compressed in said low pressure compressor and said low pressure compressor having sufficient capacity to compress air in excess of that required to provide the motive fluid produced to operate said engine, connections for causing only a portion of the air compressed in said compressor section to be converted to motive fluid in said combustion chamber means and expanded in said rotary positive displacement engine, and connections for causing motive fluid exhausted from said engine and excess air from said low pressure compressor to be discharged through said nozzle means.

3. A propulsion unit embodying jet propulsion comprising a compressor section for compressing air, combustion chamber means for heating air compressed in said compressor section to provide high temperature gaseous motive fluid, an engine section for expanding motive fluid delivered thereto from said combustion chamber means to provide power for driving the compressor section and nozzle means for developing jet propulsive thrust from gases ejected from the unit, said engine section comprising a rotary positive displacement engine for initially expanding said motive fluid and a turbine receiving motive fluid exhausted from said engine, said compressor section comprising a low pressure dynamic compressor and a rotary positive displacement compressor receiving air compressed in said low pressure compressor and said compressor section including a low pressure part having sufficient capacity to compress air in excess of that required to operate said engine, and connections for causing excess air from said dynamic compressor and motive fluid exhausted from said engine section to be discharged through said nozzle means.

4. A propulsion unit embodying jet propulsion comprising a compressor section for compressing air, combustion chamber means for heating air compressed in said compressor section to provide high temperature gaseous motive fluid, an engine section for expanding motive fluid delivered thereto from said combustion chamber means to provide power for driving the compressor section and nozzle means for developing jet propulsive thrust from gases ejected from the unit, said engine section comprising a rotary positive displacement engine for initially expanding said motive fluid and a turbine receiving motive fluid exhausted from said engine, said compressor section comprising a low pressure dynamic compressor and a high pressure positive displacement compressor receiving air compressed in said low pressure compressor and said compressor section including a low pressure part having capacity to compress air in excess of that required to provide the motive fluid produced to operate said engine, and connections for causing excess air from said dynamic compressor and motive fluid exhausted from said turbine to be discharged through said nozzle means.

5. A propulsion unit embodying jet propulsion comprising a compressor section for compressing air, combustion chamber means for heating air compressed in said compressor section to provide high temperature gaseous motive fluid, an engine section for expanding motive fluid delivered thereto from said combustion chamber means to provide power for driving the compressor section and nozzle means for developing jet propulsive thrust from gases ejected from the unit, said engine section compris-

ing a rotary positive displacement engine for initially expanding said motive fluid and a turbine receiving motive fluid exhausted from said engine, said compressor section comprising a low pressure dynamic compressor and a high pressure positive displacement compressor receiving air compressed in said low pressure compressor and said compressor section including a low pressure part having capacity to compress air in excess of that required to provide the motive fluid produced to operate said engine, and connections for supplying excess air from said dynamic compressor to said turbine and for discharging the gases exhausted from said turbine through said nozzle means.

6. A propulsion unit embodying jet propulsion comprising a compressor section for compressing air, combustion chamber means for heating air compressed in said compressor section to provide high temperature gaseous motive fluid, an engine section for expanding motive fluid delivered thereto from said combustion chamber means to provide power for driving the compressor section and nozzle means for developing jet propulsive thrust from gases ejected from the unit, said engine section comprising a rotary positive displacement engine for initially expanding said motive fluid and a turbine receiving motive fluid exhausted from said engine, said compressor section comprising a low pressure dynamic compressor and a high pressure positive displacement compressor receiving air compressed in said low pressure compressor and said low pressure compressor having capacity to compress air in excess of that required to provide the motive fluid produced to operate said engine, said nozzle means comprising a first nozzle and a second nozzle, a second combustion chamber communicating with said second nozzle, and connections for supplying gases exhausted from said turbine to said first nozzle and for supplying excess air from said dynamic compressor to said second combustion chamber for heating therein and discharge through said second nozzle.

7. A propulsion unit embodying jet propulsion comprising a compressor section for compressing air, combustion chamber means for heating air compressed in said compressor section to provide high temperature gaseous motive fluid, an engine section for expanding motive fluid delivered thereto from said combustion chamber means to provide power for driving the compressor section and nozzle means for developing jet propulsive thrust from gases ejected from the unit, said engine section comprising a rotary positive displacement engine for initially expanding said motive fluid and a turbine receiving motive fluid exhausted from said engine, said compressor section including a low pressure part having capacity to compress air in excess of that required to provide the motive fluid produced to operate said engine and said compressor section comprising a high pressure positive displacement compressor and dynamic compressor means providing said low pressure part and an intermediate pressure part, connections for flow of air through said low pressure part, said intermediate pressure part and said high pressure compressor in the order named, and connections for causing excess air from said low pressure part and gases exhausted from said turbine to be discharged through said nozzle means.

8. A propulsion unit embodying jet propulsion comprising a compressor section for compressing air, combustion chamber means for heating air compressed in said compressor section to provide high temperature gaseous motive fluid, an engine section for expanding motive fluid delivered thereto from said combustion chamber means to provide power for driving the compressor section and nozzle means for developing jet propulsive thrust from gases ejected from the unit, said engine section comprising a rotary positive displacement engine for initially expanding said motive fluid and a turbine receiving motive fluid exhausted from said engine, said compressor section including a low pressure part having capacity to compress

air in excess of that required to provide the motive fluid produced to operate said engine and said compressor section comprising a high pressure positive displacement compressor and dynamic compressor means providing said low pressure part and an intermediate pressure part, connections for flow of air through said low pressure part, said intermediate pressure part and said high pressure compressor in the order named, said nozzle means comprising a first nozzle and a second nozzle, a second combustion chamber communicating with said second nozzle, a connection for exhausting gases from said turbine to said first nozzle and a connection for supplying excess air from said low pressure part to said second combustion chamber for heating therein and discharge through said second nozzle.

9. A propulsion unit embodying jet propulsion comprising a compressor section for compressing air, combustion chamber means for heating air compressed in said compressor section to provide high temperature gaseous motive fluid, an engine section for expanding motive fluid delivered thereto from said combustion chamber means to provide power for driving the compressor section and nozzle means for developing jet propulsive thrust from gases ejected from the unit, said engine section comprising a rotary positive displacement engine for initially expanding said motive fluid and a turbine receiving motive fluid exhausted from said engine, said compressor section including a low pressure part having capacity to compress air in excess of that required to provide the motive fluid produced to operate said engine and said compressor section comprising a high pressure positive displacement compressor and dynamic compressor means providing two separate low pressure compressors, a connection for delivering air from one of said low pressure compressors to said high pressure compressor, said nozzle means comprising a first nozzle and a second nozzle, a second combustion chamber communicating with said second nozzle, a connection for exhausting gases from said turbine to said first nozzle and a connection for supplying excess air from the second of said low pressure compressors to said second combustion chamber for heating therein and discharge through said second nozzle.

10. A propulsion unit embodying jet propulsion comprising a compressor section for compressing air, combustion chamber means for heating air compressed in said compressor section to provide high temperature motive fluid, an engine section for expanding motive fluid delivered thereto from said combustion chamber means to provide power for driving the compressor section and nozzle means for developing jet propulsive thrust from gases ejected from the unit, said engine section comprising a rotary positive displacement engine having a casing and rotors forming expansion chambers for said motive fluid, said casing and rotors having passages therein for cooling fluid to cool the working surfaces forming said chambers, said compressor section comprising a rotary positive displacement compressor and including a low pressure part having sufficient capacity to compress air in excess of that required to provide the motive fluid produced to operate said engine, and connections for supplying a part of the compressed air to said passages to cool said working surfaces and for supplying another part of the compressed air and gases exhausted from said engine section to said nozzle means for discharge therefrom.

11. A propulsion unit embodying jet propulsion comprising a compressor section for compressing air, combustion chamber means for heating air compressed in said compressor section to provide high temperature motive fluid, an engine section for expanding motive fluid delivered thereto from said combustion chamber means to provide power for driving the compressor section and nozzle means for developing jet propulsive thrust from gases ejected from the unit, said engine section comprising a rotary positive displacement engine having a casing and rotors forming expansion chambers for said motive fluid,

said casing and rotors having passages therein for cooling fluid to cool the working surfaces forming said chambers, said compressor section comprising a low pressure dynamic compressor and a high pressure positive displacement compressor receiving air compressed by said low pressure compressor and said low pressure compressor having sufficient capacity to compress air in excess of that required to provide the motive fluid produced to operate said engine, connections for delivering air from said high pressure compressor through said passages to said combustion chamber means and connections for causing excess air from said low pressure compressor and gases exhausted from said engine section to be discharged through said nozzle means.

12. A propulsion unit embodying jet propulsion comprising a compressor section for compressing air, combustion chamber means for heating air compressed in said compressor section to provide high temperature motive fluid, an engine section for expanding motive fluid delivered thereto from said combustion chamber means to provide power for driving the compressor section and nozzle means for developing jet propulsive thrust from gases ejected from the unit, said engine section comprising a rotary positive displacement engine and a turbine receiving gases exhausted from said engine, said engine having a casing and rotors forming expansion chambers for said motive fluid and said casing and rotors having passages therein for cooling fluid to cool the working surfaces forming said chambers, said compressor section comprising a low pressure dynamic compressor and a high pressure positive displacement compressor receiving air compressed by said low pressure compressor and said low pressure compressor having sufficient capacity to compress air in excess of that required to provide the motive fluid produced to operate said engine, connections for delivering air from said high pressure compressor through said passages to said combustion chamber means, and a connection for delivering excess air from said low pressure compressor to said turbine for expansion and exhaust therefrom together with said gases to said nozzle means.

13. A continuous combustion power plant providing jet thrust comprising; a relatively high pressure, high temperature part having a rotary positive displacement compressor, a rotary positive displacement engine having cooling passages therein for driving said compressor, a combustion chamber and connections for delivering air from said compressor through said cooling passages to said combustion chamber to be heated therein to form high temperature motive fluid for delivery to and expansion in said engine; a relatively low pressure, a low temperature part comprising a turbine for further expanding gases exhausted from said engine, a dynamic compressor mechanically connected with said high pressure compressor and having sufficient capacity to compress air in excess of that required to supply said high pressure compressor; jet nozzle means and connections for causing excess air from said dynamic compressor and the gases exhausted from said turbine to be discharged through said jet nozzle means.

14. A continuous combustion power plant providing jet thrust comprising; a relatively high pressure, high temperature part having a rotary positive displacement compressor, a rotary positive displacement engine having cooling passages therein for driving said compressor, a combustion chamber and connections for delivering air

from said compressor through said cooling passages to said combustion chamber to be heated therein to form high temperature motive fluid for delivering to and expansion in said engine; a relatively low pressure, low temperature part comprising a turbine for further expanding gases exhausted from said engine, a dynamic compressor mechanically connected with said high pressure compressor and having sufficient capacity to compress air in excess of that required to supply said high pressure compressor; a jet nozzle, a connection for delivering excess air from said dynamic compressor to said turbine and a connection for delivering the exhaust from said turbine to said nozzle.

15. A continuous combustion power plant providing jet thrust comprising; a relatively high pressure, high temperature part having a rotary positive displacement compressor, a rotary positive displacement engine having cooling passages therein for driving said compressor, a combustion chamber and connections for delivering air from said compressor through said cooling passages to said combustion chamber to be heated therein to form high temperature motive fluid for delivery to and expansion in said engine; a relatively low pressure, low temperature part comprising a turbine for further expanding gases exhausted from said engine, a dynamic compressor mechanically connected with said high pressure compressor and having sufficient capacity to compress air in excess of that required to supply said high pressure compressor; a jet nozzle, a connection for delivering the exhaust from said turbine to said nozzle, a second jet nozzle, a second combustion chamber communicating with said second nozzle, and a connection for delivering excess air from said dynamic compressor to said second combustion chamber for heating therein and discharge through said second nozzle.

References Cited in the file of this patent

UNITED STATES PATENTS

132,891	Bailey	Nov. 12, 1872
1,006,907	Buchi	Oct. 24, 1911
2,248,639	Miksits	July 8, 1941
2,390,161	Mercier	Dec. 4, 1945
2,404,954	Godsey	July 30, 1946
2,409,177	Allen	Oct. 15, 1946
2,411,227	Planiol et al.	Nov. 19, 1946
2,414,828	McCollum	Jan. 28, 1947
2,418,911	Smith	Apr. 15, 1947
2,458,600	Imbert et al.	Jan. 11, 1949
2,464,724	Sédille	Mar. 15, 1949
2,468,157	Barlow	Apr. 26, 1949
2,476,397	Bary	July 19, 1949
2,485,687	Bailey	Oct. 25, 1949
2,487,514	Boestad et al.	Nov. 8, 1949
2,488,867	Judson	Nov. 22, 1949
2,509,555	Youhouse	May 30, 1950
2,548,609	Johansson	Apr. 10, 1951
2,553,548	Canazzi et al.	May 22, 1951
2,593,523	Bauger	Apr. 22, 1952
2,618,120	Papini	Nov. 18, 1952

FOREIGN PATENTS

519,933	Germany	Mar. 5, 1931
663,873	Germany	Aug. 15, 1938
464,475	Great Britain	Apr. 16, 1937
538,022	Great Britain	July 17, 1941