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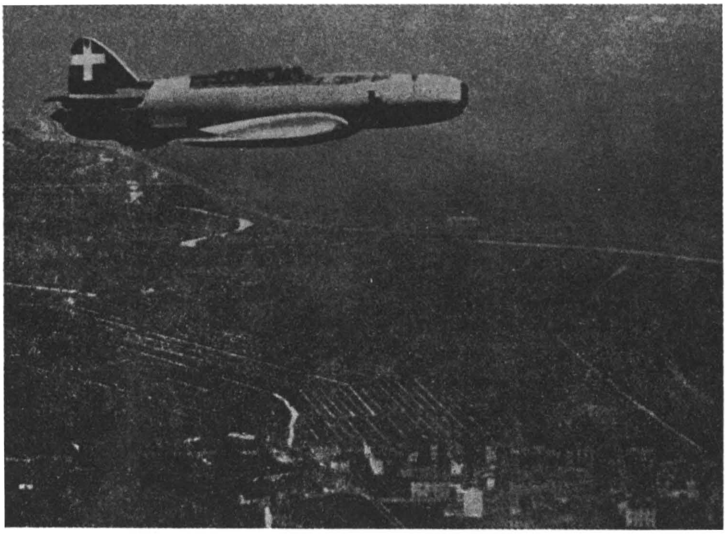

FIRST JET PROPELLED PLANE — Italy's widely publicized Caproni-Campini CC2 in flight between Milan and Rome. Dispensing with the usual aircraft engine-propeller combination this unorthodox airplane is propelled by the reaction to a thermal-air jet emerging from its tail cone.

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NOTES AND NEWS

In response to a large number of inquiries from our members about the Caproni-Campini thermal-air jet-propelled airplane we are pleased to reprint a very thorough survey on this subject which appeared in the February 1942 issue of "The Aircraft Engineer." As noted it has been translated from "Flugsport" the German periodical in which it originally appeared.

At a recent meeting of the Board of Directors of the American Rocket Society appointment was made of the officers listed in the box at left. A vote of thanks was tended Mr. H. Franklin Pierce for his excellent administration of the duties of President for the last two years.

One of the most important factors in the Russian's feat of stopping and throwing back the Nazi hordes has been the former's use of the deadly Stormavik dive bomber. News has leaked through the tight Red censorship of the use, by this airplane, of rocket powered projectiles. Capable of piercing the armor of the German heavy tanks these projectiles seem more effective than the small cannon previously used by aircraft against tanks.

THERMAL-AIR JET-PROPULSION

By Gohlke†

EVERY BODY travelling in air or water by its own power applies the reaction or "repulse" principle, that is to say, it either takes up parts of masses contained within itself or, by means of suitable organs, gathers up parts of the surrounding fluid medium and accelerates these masses at a speed greater than its own travelling speed, and this generally in the direction opposite to that in which it desires to travel; whilst in certain cases, in addition to the force produced by the repulse, a further force is obtained through the forward suction of the fluid medium. Devices intended to utilize only the negative pressure produced by suction, e.g. through lateral ejection by means of radial surfaces running at very high (five-figure) r.p.m. have not, in spite of repeated endeavors, proved successful.

The characteristic feature of every propulsive or power system employing the reaction or repulse principle is the "jet". The term applicable when speaking of devices producing hydrodynamical or aerodynamical forces in connexion with both air or water screws, as with others, is therefore "jet propulsion". In present-day usage, however, this term is generally reserved for a definite class; namely, for those reaction systems which, for the production of the jet require the development or the input of heat. Strictly speaking therefore, in addition to "cold air jet propulsion systems[1]" we have "hot air" or thermal jet propulsion systems"; the latter class again comprising two main groups—those still known as "rocket" systems, i.e. those which contain within them all the masses necessary for the production of the jet (e.g.) explosives or fuel plus oxygen in liquid or gaseous form) and those that may be called "thermal or (hot air) jet propulsion systems" which derive the oxygen from the surrounding air and hence carry the fuel only.

Whereas rocket propulsion systems (although owing to their wastefulness and very short combustion period they have only been realized for use in the film "Raumschiffe" ("space ships") and for war purposes (rocket projectiles); in both of which cases money did not enter into consideration) have at any rate acquired a certain practical interest as light and lifesaving rockets; thermal air jet propulsion systems on which scientists have been working for many years are still only in the embryo stage but are nevertheless perceptibly approaching the threshold of usefulness and are making their appearance as a suitable means whereby the problem of increasing the speed of aircraft beyond 700 k.p.h. (400 m.p.h.) may be solved.

As far as the author is aware, no comprehensive summary has hitherto been compiled of the existing patents dealing with this subject.

There are three structural elements common to all thermal jet propulsion systems: the air compressor, the combustion chamber and the expansion tunnel (diffusor). The essential difference between them lies in the methcd of compression.

In 1909 Marconnet, in the French Patent specification 412478, gave ex-

*R.T.P. Translation; No 922 (by M. Flint) from Flugsport, Vol. 31' No. 1, 4.1.39, pp. 1-5; No. 2, 18.1.39, pp. 31-37; No. 3, 1.2.39' pp. 70-75; No. 4, 15.2.39, pp. 100-104.

† In accordance with a common Continental custom, the author's initials are not given in the original.

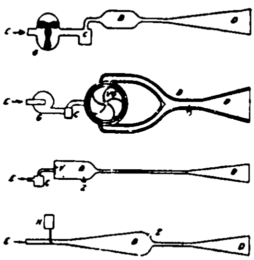
(1) As far as aeronautical technique is concerned, besides airscrews (including those whose slip stream is led through a tube), which have not yet reached the stage where they can be employed for flight, these include beating wings (e.g. with flaps), oscillating wings (e.g. with controlled variation of setting) and rotor wings (e.g. Rohrbach, Strandgren).

(5) A Method of reaching extreme altitudes. Washington, 1919. A book which gave rise to the "space ship" fever ten years ago.

(3) cf. N.A.C.A. Report 431. (Experiments with compressed air without heat induction).

(4) Scherschevsky. Die Raket fur Fahrt und Flug. Charlottenburg. 1929. Also Scherschevsky Das Rumschiff Flugsport. 1927. Nos. 20 and 21.

(2) c f. Everling-Lademann in Verkehrstechnische Woche. 1929. pp. 604-607.



FIGS. 1-4. Thermal air jet propulsion systems by Marconnet 1909.

B—combustion chamber
C—carburetor
D—diffusor
E—air admission
G—blower
K—fuel container
VG—distributor, also acting as blower
V—flap valve
Z—ignition device

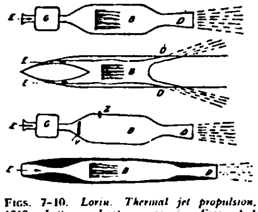
amples of that method in which the compression is effected by means of compressors or blowers; he differentiates already between systems with constant pressure (Figs. 1 and 4) and those with constant volume (Figs. 2 and 3). In the former a continuous jet is produced by the (Roots) blower (Fig. 1) and led by way of the carburetor through the combustion chamber into the diffusor, which, in order to be able to regulate thrust and jet velocity in accordance with the different conditions in the take-off and in flight, must be of variable length (with the same conical angle). According to Fig. 4, the compressed air thus supplied by a blower (not shown in the drawing) is provided with fuel, and traveling at a high velocity, enters a combustion chamber widening in the form of a hollow cone, in the course of which it expands so that it can be ignited at the end. As a flame can only propagate when its velocity of propagation is greater than the velocity of escape of the surrounding combustible medium, the combustion of the mixture in the tapered parts of the conical chamber ceases at the position where the velocity of the passage through is greater than that of the flame travelling in the opposite direction.

In the discontinuous working, according to Fig. 2, one blower delivers mixture by way of the carburetor into a second blower designed to act at the same time as a distributor, which, in the form of a vane cylinder provided with traversing orifices, is surrounded by a housing, likewise provided with orifices. From each orifice a channel leads to the combustion chamber fitted with a spark-plug. Each time the mixture passes the orifices a quantity escapes, which immediately fills the combustion chamber, becomes ignited whilst the orifices are momentarily closed and expands in the diffusor. If, for example, the distributor runs at 1,200 r.p.m., when there are 2 orifices it will produce 20 double ignitions per sec, and when there are 4 orifices instead of 2, it will produce 40.

With another form of discontinuous system, as shown in Fig. 3, a flap valve is fitted in place of the distributor blower. After fuel enrichment in the carburetor the mixture passes through the valve into the combustion chamber. Here it is ignited, thereby closing the valve; the gases travel at a high velocity through a long tube into the diffusor. As a result of the momentum of the out-flowing gas column, and its inertia, a negative pressure is produced in the chamber, which suffices to suck a fresh charge of mixture through the valve and the carburetor and bring it into the chamber. In this way also motive impulses in rapid succession can be obtained; here again, by varying the length of the diffusor, the velocity of the jet and the thrust can be regulated. Further suggestions put forward by Marconnet for the realization of systems of this kind as gas or air compressors for arbitrary purposes need not be mentioned here.

Marconnet, in 1909, thus published the essentials of the thermal jet propulsion system, and this, moreover, at a time when an aircraft speed of 200 km. was looked upon as a far-off, almost unattainable achievement. Lorin, the French engineer, who is often mentioned in literature as the inventor of this system, first described this kind of reaction in **Aerophile** in 1913; since 1908 he certainly had written a number of papers in order to promote interest in the notion of "propulsion by direct reaction," as opposed to the indirect method by means of engine and airscrew, and in 1908 patented a suggestion for an intermediate solution. The patent specifications (French patent 390256) contain, in addition to other suggestions, the notion of using a cylinder plus crank system of the combustion engine type for suction, compression and ignition simultaneously and producing reaction with the gases leaving an outlet funnel (e.g. by way of an automatic or controlled valve). It was here that for the first time the notion was evolved of using part of the combustion gas energy of the reaction system for purposes of compression. In the form of realization, the motor serves solely for the production of the repulse; thus no power is taken from the crank-shaft. This form of utilization of exhaust gases can naturally be effected also in the case of engines of otherwise usual construction, as has been proved by quite recent experiments. The "battery" arrangement of the cylinders renders it possible easily to install propulsive units of this kind in the wings of aeroplanes.

Lorin contributed two articles to **L'Aerophile** in 1913 in which he described devices which in part cover the suggestions of his predecessor Marconnet; thus, the hot air jet propulsion systems with constant pressure and constant volume represented in Figs. 7 and 9 are of the nature of those in Figs. 1 and 3. Fig. 8 shows how, in principle, the air can be pre-compressed without a mechanical device (compressor, blower) by a suitable formation of the air-inlet opening. Here apparently the air is also derived from the boundary layer zone of a streamlined body, its kinetic energy being converted into potential energy by expanding the inlet opening and then emerging from diffusors and supplying the reaction. The purpose of the divergence of the gas jets recognizable from Fig. 8, is to cause the latter to meet continuously renewed layers of the outside air as it sweeps past. When starting, propulsive systems of this kind need an initial acceleration by some auxiliary means (catapult, starting rocket or airscrew). Experiments with them had already been made as long ago as 1886 by Ciurcu, a Roumanian, in Paris on the Seine, and about 1908 by Chanute, the aviation pioneer in America; no useful results, however, were recorded. In Fig. 10, which dates from 1913, Lorin gave to this reaction system, working with steady jet, hence constant pressure, its more or less classical stream-lined form; without however going essentially beyond the form according to Marconnet's design as represented in Fig. 4.



Figs. 7–10. *Lorin. Thermal jet propulsion, 1913. Letter indications as in Figs. 1–4*

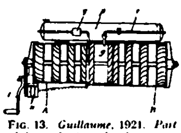


Fig. 13. *Guillaume, 1921. Part of the combustion chamber energy is used to drive a gas-turbine compressor*

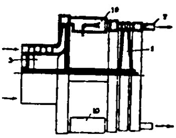


Fig. 14. *Whittle, 1935. Exhaust jet drives a gas-turbine compressor*

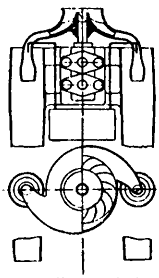


Fig. 17. *Harris, 1917. Long air mixing tube of decreasing cross-section*

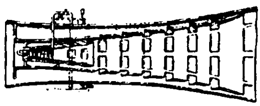
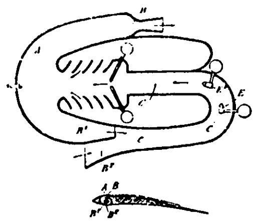


Fig. 16. *Lake, 1909. Thermal air jet propulsion with air entry in the diffusor*



Figs. 11–12 *(left). Hayot (1913). Thermal jet propulsion; part of the exhaust gas is split up and used, through the medium of the injector B¹ to suck in the air. According to Fig. 12, the emerging gas jet is also used to increase the velocity of the flow on the upper side of the wing*

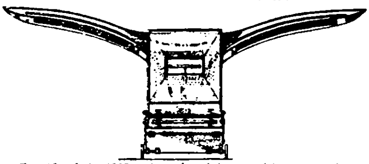


Fig. 15. *Lake, 1909. Aircraft with jet propulsion systems in body and wings*

A further development of the thermal jet propulsion system is presented by Hayot's invention, likewise of French origin, for which a patent was applied in 1913, the German patent being granted under No. 330014. (Figs. 11 and 12.) According to the specification, the main feature of the invention consists in the fact that part of the combustion gases produced in the bent pipe C is led through an injector nozzle B1 into the air inlet channel B2, so as to carry along the air, which is then supplied at E with fuel and at E1 with water, before combustion of the mixture takes place in the chamber A. The remainder of the gases emerges from the diffusor B and produces back pressure. With the arrangement in an aeroplane wing, as shown in Fig. 11, in addition to the back-pressure in the horizontal direction, the lift of the wing is increased, in a manner already previously known, owing to the fact that the jets of gas distributed over the span further increase the circulation velocity existing on the upper side of the wing.

In Lorin's suggestions the notion was already submitted of dividing off part of the heat from the combustion chamber and causing it to perform mechanical (crank) work for the pre-compression of the combustion air. In the French Patent Specification No. 534801, applied for by M. Guillaume, in 1921, this principle is applied for the first time to a turbine compressor; a form of realization which on several occasions recently has been further developed. On the forward end of a shaft running through the combustion chamber **g** (Fig. 13) and in a tubular housing open at both ends, a compressor (Rateau-type) A is mounted, and on the after end a gas turbine B; both being multiple-stepped and interspersed with guide vanes. A tube (r) provided with regulators leads from the fuel container (p) into the combustion chamber; a valve (q) in a second tube of similar kind can be used as an accelerator and as an aid in the difficulty of starting; for which purpose the starting crank (l), connected with the magneto, is also employed.

A patent was applied for in England in 1930 and obtained under No. 347206 for a similar device evolved by F. Whittle. Here again (Fig. 14) a blower compressor (3) is mounted at the forward end and a gas turbine (1) at the after end of the same shaft, (1) being supplied by part of the combustion chamber (10) energy. Between the annular housings of the rotary elements, and in line with a number of combustion chambers distributed over the circumference, are situated the nozzles (7) providing for the remainder of the expansion, which can be made to swivel if desired for control purposes. Whittle has recently developed the thermal jet propulsion system further; this will be referred to later.

The suggestions of the American inventor Lake belong to the same period as Marconnet's. In 1909 Lake applied in U.S.A. for patents in which, as far as the author is aware, the notion appeared for the first time of mixing air in the combustion gas jet (see Figs. 15 and 16, taken from his Austrian Patent No. 63081); his jet propulsion systems were thus the forerunners of the Melot "propulseur a trompe" ("multiple nozzle propulsion") which appeared about ten years later and became much better known. The heat-resisting combustion chamber, open forward for the air entry, runs out into a diffusor which allows air to enter through oblique slots in the sides and opens into a further tube of increasing diameter, likewise provided with oblique, side air slots. Both diffusors are surrounded by a third tube of widening diameter which serves both to guide the air and to retain the heat. Fig. 16 shows a longitudinal section through the rectangular main combustion chamber; the transverse section, Fig. 15, shows a second, similar, combustion chamber in the lower part of the aircraft and others in the wings. The latter are fitted with Venetian blind flaps with "aileron" effect, controlled by a pendulum device. The purpose of the air admixture is to increase the outflow mass; by this means the velocity of the jet in the nozzle mouth section is naturally reduced. An unrecognized advantage associated with the reduction of the outlet velocity consists in bringing the latter into unison with the speed of the aircraft(2) and thereby rendering it possible considerably to increase the efficiency of the propulsion system.

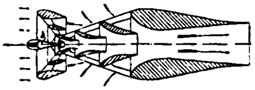


FIG. 18. Mélot, 1920. Jet nozzles with lateral air aspiration

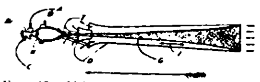
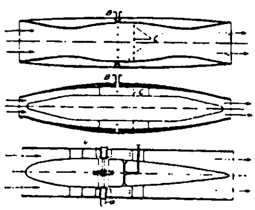
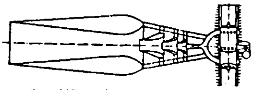


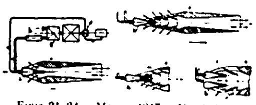
FIG. 19. Mélot nozzle drive; experimental arrangement
A = combustion air admission
B = spark-plugs for starting
Br. = burners
C = fuel admission
D = nozzles
G = gas jet
L = mixture air
T = combustion chamber mouth



FIGS. 25-27. Fonó, 1928. Thermal air jet propulsion for supercritical flight speeds



20. Mélot. Compressor with free running pistons



FIGS. 21-24. Morize, 1917. Nozzle jet propulsion

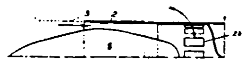
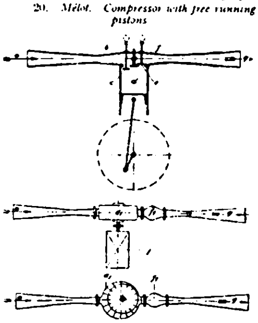
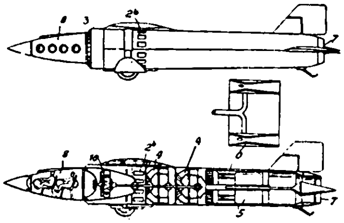


FIG. 31. Campini, 1932. Self-compression space adjustable for sub-critical and super-critical speeds



FIGS. 28-30. Fonó, 1928. Compressor arrangements



FIGS. 32 and 33. Campini aeroplane with thermal-air jet-propulsion; the high-altitude chamber (8) is releasable by parachute

Another who may be regarded as a forerunner of Melot is the British inventor H. St. Harris, who described the device shown in Fig. 17 in British patent Specification No. 118123 of 1917. Connected to a low-pressure blower with aspiration mouth opening in the direction of flight, there are combustion chambers which open into further pipes of considerable length and narrowing in the rearward direction. These pipes, which, as in Lake's idea, may be provided with special air inlet slits distributed along their length (not shown in the drawing), likewise serve to increase the jet mass. The constriction of the jet due to the cooling of the combustion bases in the tubes is intended to have a suction effect; the expansion of the combustion chamber, indicated in the drawing, is intended to take up the increase in the volume in such a way that the gases emerge from it without pressure increase.

On January 19, 1920, Melot applied in France for a patent (No. 523427) for his nozzle ("trompe") system, after the French Military authorities had already experimented (during the War) with his device, which apparently failed to give satisfaction. Behind a combustion chamber b, into which relative wind enters with forward speed decreasing, there is a series of nozzles of continuously increasing dimensions which suck in air at the sides. In addition, the combustion chamber is surrounded by a system consisting of a number of concentric nozzles, originally imagined as a "multiplicateur de depression" ("negative pressure augmenter") but apparently omitted later. Fig. 19 (taken from **La Nature** 1920, p. 368) represents a bench test arrangement, which does not show the nozzle ring round the combustion chamber. Owing to the aspiration of the additional air, the efficiency, as was shown, is improved compared with that of the free jet[3], but apparently not to such an extent as to render the system capable of competing seriously with the screw-propeller.

Since the efficiency improves with increasing pre-compression of the combustion mixture, Melot later evolved a combustion-motor system, which in some respects resembles that devised by Lorin. Instead of a crank drive, however, a free piston (Fig. 20) with two concave heads is provided, which, when in operation, after it has compressed the mixture entering at the centre in one cylinder space, and this has been ignited, compresses the mixture by its centrifugal force in the opposite space and so on. The combustion gases, whose two-way exit is controlled by the piston, enter the Melot multiple-nozzle system to produce the back-pressure. Starting is effected with the aid of compressed air and spark-plug; the latter can be switched off for continuous running, because spontaneous combustion then takes place.

At about the same time as the Melot jet propulsion system appeared, Morize applied in France for a patent for his nozzle-propeller (July 26, 1917) described briefly below from British Patent Specification No. 124736 (Figs. 21-24) which requires a little further explanation. The motor (Fig. 21) drives a fuel pump (d) and a compressor (g), which delivers compressed air by way of an equalizing chamber (h) into the combustion chamber (b). Air is aspired in front through the nozzle tube (a) and the combustion gas plus air mixture is retarded as far as the after end. In Fig. 22 additional air nozzles are interposed, in Fig. 23 the number of combustion nozzles is increased, in Fig. 24 an annular nozzle (i) is shown. Whilst the systems hitherto described were devised for flight speeds below the critical speed, i. e. below the speed of sound (330 m/sec.), the intricate problem of super-critical velocities[4] first dealt with by the ballisticians (Mach, Cranz, etc.) and also investigated experimentally at the Gottingen Aerodynamical Laboratory (Prandtl) now entered into the development of the thermal jet propulsion system. Whereas hitherto the self-compression of the air, in accordance with Bernouilli's Law, could be effected by expanding the entry cone rearwards, the variations of another kind in the state of the fluid medium which occur with critical velocities now called for other devices.

In 1928, Dr-Ing. A. Fono of Budapest applied for a patent, No. 554906, Class 46 (Figs. 25-27), for his invention of an air jet motor for high altitude flight for aircraft with high, supercritical speeds, consisting, as is known, of a body lying in the direction of motion, which possesses at the forward end an air intake opening, behind it a compression nozzle with fuel delivery **B** and ignition **C** near the position of maximum pressure and followed by an expansion nozzle, and whose characteristic feature consisted in the fact that "the cross-section of the compression nozzle tapers at the front in the direction of the flow." As shown by a comparison of Fig. 10 with Fig. 25, taken from the not altogether clear patent specification mentioned above, all the features contained in Fono's principal claims already existed in Lorin's suggestions published in 1913. It will suffice here to show the more or less detailed drawings which appear in the patent specifications.

The supplementary Fono patent specification 560075/46 constitutes a secondary claim additional to that of the principal patent, in that "a compressor is interposed" "in the narrowest cross-section" (this would apparently mean between the narrowest cross-sections of the inlet and outlet cones), in jet propulsion systems of the kind mentioned. When, in accordance with the principal patent (Fig. 27), the compressor (b) is driven by (relative) wind vanes (a), in this case, in order to be able to compress also when the aircraft is at rest, (Fig. 28 to 30) the compressor (d), provided in addition to the self-compression cone (a), will be driven by a special power unit. The air approaching at (a) Fig. 28, enters the chamber (b) precompressed and at reduced speed and after the opening of the suction valve (c) into the cylindrical space (d) fills the latter as the piston descends. On the return the air is compressed, fuel is delivered and ignited, after which the piston is repelled and energy is transmitted to the crankshaft. When the expansion with the descending piston has reached the stage when the work performed, taking the efficiency into account, corresponds to the work of compression, the exhaust valves (c) open and the exhaust gases still under high pressure and at high temperature enter the collector chamber (f) and the expansion nozzle (g); from which, after complete expansion, they reach the open air. In Figs. 29 and 30 the compressor (d^1) driven by the motor (j) is separated from the combustion chamber (f^1).

The same problem concerning the adaptation to super-critical flight speeds was also in the mind of S. Campini, the Italian inventor. Reference will be made here to his French Patent Specification No. 741858 (Figs. 31-33) applied for in 1932, in so far as this concerns aircraft. The extensive descriptions deal **inter alia** with jet propulsion for seaplanes and contain many details of design and construction which, owing to lack of space, cannot be included in the present review.

The main problem which Campini seeks to solve consists in the possibility of employing the propulsion for both sub-sonic and super-sonic speeds.

From what has already been said, it is clear that the air nozzle in the former case must widen from the inlet opening onwards and in the second case it must converge. Campini wanted to do both arbitrarily with the same apparatus. The relative wind in general is allowed to enter at the circumference of a body (8) of roughly ovoid form, which at the same time constitutes a high-altitude cabin, at a position where, owing to friction (dynamic pressure, boundary layer), its speed is relatively low. For sub-critical speed, the circular entry slit formed by the body (8) and a trapping cylinder (2) has its smallest cross-section; it widens out backwards in known manner in order to convert the kinetic energy of the air into pressure energy. If the speed of flight is increased to a supersonic value, the ring (3) is pushed forward beyond the former mouth (indicated by the dotted line), so that the relative wind now enters a funnel which first becomes narrower and then widens, a device whereby account is taken of the peculiar conditions of flow associated with super-sonic velocities. Air will be admitted by the displacement of controllable lateral orifices (2b) when negative pressure is produced (e. g. on starting) in the inlet chamber, which Campini calls the "recuperator." The air, compressed in the recuperator, passes through a centrifugal compressor (4), driven by a motor (10) or a fuel gas turbine, and a motor radiator which also acts as a rectifier into the wide combustion chamber space (5); there in an annular channel (O) of venturi cross-section it is supplied with fuel; finally it flows in a known manner through a swivel diffusor (7) of adjustable cross-section into the open air. The largest diameter of the power plant envelope which is of the shape of a slightly tapered cylinder, occurs at the position of the entry of the relative wind.

The admixture of air serving to increase the mass of the jet and, combined with this, the reduction of its velocity (adaptation to the speed of flight) in the manner adopted by Melot and others, namely by utilizing the propulsive action of the flowing, already expanded fuel gases, did not prove to be particularly effective.

Dipl-Ing. Paul Schmidt of Munich, explains the losses of energy incurred in his German Patent Specification 523655/62b (applied for on April 23, 1930) as follows:

"With an ejector (jet apparatus) the acceleration of the admixed masses takes place in accordance with the laws of plastic impact; thus the momentum (mass times velocity) of the whole mass leaving the ejector is always equal to the momentum of the energy jet by which the ejector is driven. Since, however, the momentum is also equal to the reaction force, which can be produced by the flow of a mass, the reaction force is unchanged by the interposition of a jet apparatus. On the contrary, owing to the mixing process, a loss of energy of such a high value occurs, that the increase of the mass is cancelled by the reduction of the velocity."

If on the contrary, the pressure action of the fuel gases is utilized for the acceleration of a relatively very large additional air mass, as Schmidt explains, a very considerable and useful increase of the reaction force is obtained, the value of which is proportional to the expelled mass and its speed. The energy that must be expended for the acceleration of the mass depends similarly on the mass, but is proportional to the square of the speed, so that the greatest economy in the production of reaction forces is obtained with relatively small speeds and relatively large masses which are subjected to these speeds.

The principal claim of Schmidt's patent, No. 523655 accordingly is as follows:

"A method for the production of driving forces (reaction forces) on aircraft by the detonation of combustible mixtures, characterized by the fact that a quantity of air, the weight of which exceeds that of the combustible mixture by a multiple, is accelerated directly through the force of the excess pressure of the mixture exploded." The expression "multiple" is defined in a subsidiary claim to the extent that the mass of the air subjected to the acceleration should be about 10 to 15 times greater than that of the combustible mixture.

Further secondary claims are concerned with the filling of the tubular reaction space with new air masses.

An additional patent No. 567586/62b (applied for February 20, 1931) refers also to this: viz.: the air entry of the tubular reaction space (a) is fitted with flaps, valves, or the like, (b) which, during the action of the pressure force on the air masses, close the opening. The course of the acceleration of the air masses is explained in Figs. 34-37; this takes place in four phases.

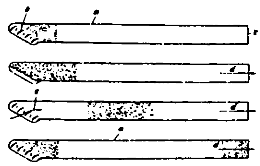
1. The combustible mixture admitted through the opened flaps occupies a very small fraction only of the total space (Fig. 34).

2. The flaps are closed, explosion and expansion take place, the expanded mixture still occupying only a relatively small fraction of the volume of the tubular space. As a result of the pressure of the ignited gases a flow of the air column is set up in the direction of the arrow (d) (Fig. 35).

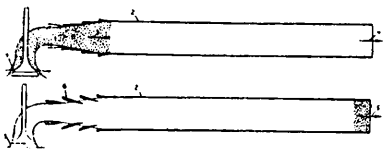
3. The flaps are again opened, the air and the expanded combustion gases proceed in the direction of the arrow (d) and produce a suction force which causes an inflow of new air masses into the pipe (a) in the direction of the arrow (e). Fig. 36).

4. The expanded mixture is about to leave the tube completely filled with a fresh column of aspired air. (Fig. 37). The working cycle thereupon begins afresh.

Another supplementary patent No. 558113/62b (applied for November 9, 1931) concerns a development of the principal invention for purposes of high altitude flight. Combustion takes place in a combustion-engine system; in this a partial expansion to a mean pressure accompanied by the performance of



FIGS. 34-37. *P. Schmidt, 1931. Reaction pipe according to specification D.R.P. 567586*



FIGS. 38 and 39. *P. Schmidt, 1931. Reaction pipe according to specification D.R.P. 558113*

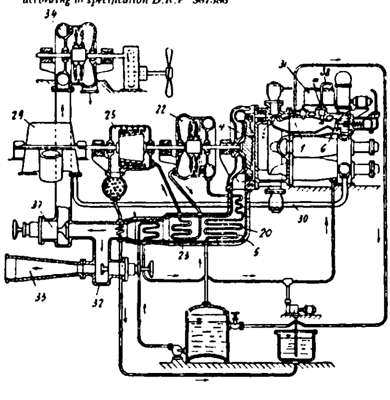
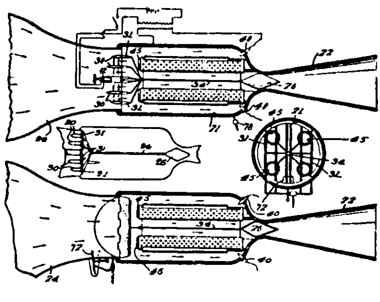


FIG. 40 *(left) Meininghaus-Holzwarth 1932. The heat withdrawn from the driving jet is utilized for the pre-compression of the combustion air. D.R.P. 644633*



FIGS. 41-44 *(below). Goddard, 1931. Inlet and outlet shutters are regulated automatically according to the pressure existing inside the combustion chamber* mechanical work first takes place and then the residual expansion only is employed for the direct acceleration of an air column. According to Schmidt, this manner of application of the notion underlying the principal invention is advantageous for high-altitude aircraft, because with combustion-engine systems in these aircraft the small atmospheric pressure prevailing in the upper air layers cannot be rendered directly useful for the performance of mechanical work. The pressure energy which is still contained in the explosion gases after expansion to a mean pressure of, say, 3 to 4 atm. at a height of say, 15 km., is roughly of the same value as the energy absorbed by the combustion-engine system from the explosion gases. The fundamental advantages of the method however, also appear at lower altitudes. Figs. 38 and 39 show the reaction portion of a system according to D.R.P. (German Patent) 558113. The explosion gases expanded in accordance with the invention to a mean pressure are led through the valve 1 (Fig. 38) to the reaction space (2) and accelerate the air column contained in it in the way indicated by the arrows (3) and (4). In Fig. 39 the valve (1) is closed and the air mass in tube (2), owing to the kinetic energy imparted by the force of the excess pressure of the explosion gases, is caused to flow in the direction of the arrow 5). This flow (running with decreasing speed), on the opening of the flaps (6) causes a new air mass to be sucked in, the suction continuing till the tube (2) is filled with air, whereupon a fresh acceleration is brought about by a fresh pressure impulse of explosion gases after the flap (6) is closed, and so on. Use can naturally be made of jet masses as well for driving a turbine for the air pre-compressor of the combustion engine system and the latter for driving an airscrew propeller. The combined working of the combustion-engine with the reaction system results in a good utilization of fuel with a small expenditure of plant and weight.

The German Holzwarth Patent No. 644633/468 (Inventor: Dipl. Ing. Dr. W. Meininghaus) applied for on March 30, 1932 (cf. also the more comprehensive French Patent Specification No. 751949) concerns a method of propulsion on the reaction principle, in which the fuel would be utilized to the extreme limit. The heat is withdrawn completely from the driving jet so that before its exit the temperature is already that of the outside air; the heat withdrawn is converted into energy which is employed for the pre-compression of the combustion air. According to the principal claim, the feature constituting the novelty of the method consists in the fact that this energy is withdrawn from the whole of the driving medium after leaving the explosion chamber, but before the ejection acceleration.

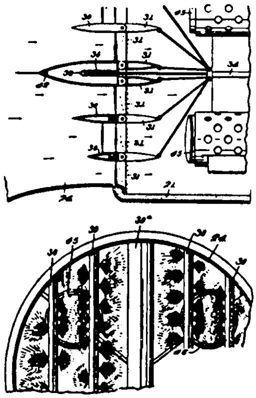
In the example illustrated in Fig. 40 showing how the method could be realized, combustion air is conveyed from the compressor (29) through the valve (6) and the pipe (30) to the combustion chambers (1) and liquid fuel from the fuel pump (31) through the pipe (38) and the valve (a). After ignition with the chamber shut off the nozzle valve (2) opens and allows the combustion gases at high pressure and high temperature to stream towards the vanes of a turbine wheel (4). When the combustion chamber gases have expanded sufficiently, the air valve (6) opens and the air admitted will eject the remainder of the combustion gas. The turbine (4) is coupled directly with the charging air compressor (29), but supplies only part of the energy required to drive the latter. The remainder is supplied by two steam turbines (22), (25), which obtain their steam through two super-heater pipe coils (20) and (23) laid in the heat-exchanger (5) swept by the combustion gases of turbine (4).

The gases flowing from the heat exchanger (5) have a relatively high pressure but a very low temperature. In this state, so long as any reaction drive persists, it is conveyed through the opened valve (32) to the reaction nozzle (33). In some circumstances the gases when they leave the outflow and (33) are even super-cooled, the propulsion jet thus removes no heat uselessly.

If the speed of travel drops below a certain value, as for example in the case of aircraft when they fly in air layers of greater density, the reaction propulsion system becomes uneconomical and will be substituted to better advantage by airscrew propulsion. In the case under consideration a permanent current turbine (34) is provided, which through a reduction gear drives a screw propeller after the valve (32) has been closed and the valve (37) opened.

R. H. Goddard, the American physicist, famed for his experiments with rocket propulsion systems and his book on this subject,(5) has described a thermal air jet-propulsion system (combustion chamber with constant volume) in the American Patent Specification 1980266 (applied for February 7, 1931) (Figs. 41 to 46). Air entry and gas exit are automatically controlled by the pressures produced, by means of a spring (36) Fig. 45, in the following manner:

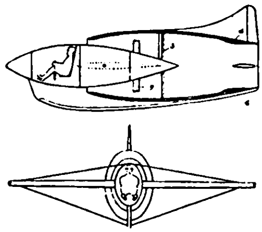
Immediately ignition has taken place in the chamber (21) (Fig. 41) with the stopper cone (26) open and flaps (31) closed (Fig. 42) and the gas escaping through the diffusor (22), owing to its inertia, has produced a negative pressure in the chamber, the latter and the air (relative wind) caught up by the cone (24) will open the flaps (31), simultaneously bringing the cone into the closed position, and the air enriched by the fuel jets at (30) (Figs. 45 and 46) will be impelled into the after end of the chamber. The fuel delivery lessens in measure with the closing of the flaps with increasing pressure equalization, so that in the neigborhood of the cone (26) and of the spark plugs (40) there is a richer, more readily ignitable mixture than in the neighborhood of the flaps (31). Such a mixture is produced also in "auxiliary containers" (45) (these are perforated cylinders surrounded by a perforated cylinder capable of axial displacement), a large number of injection nozzles being arranged at those positions of the fuel-conveying walls (30) which lie in line with the containers (45) (Fig. 46); controlled by the rod (34), the cylinder orifices allow a complete passage for the rich mixture contained in the containers (45) when the flaps are closed; then ignition contact is produced by the contact of (38) and (42) (Fig. 45), the contents of the chamber are ignited and the combustion gas flows away into the diffusor. The working cycle thus described is repeated. The quantity of fuel distributed per cycle is regulated automatic-



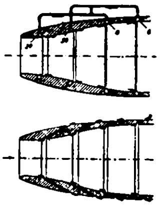
Figs. 45 and 46. *Goddard, 1931. Air inlet flaps with fuel injection*

ally by the impact on of a governor surface (72) (Fig. 44) in the funnel (24) according to the velocity and density of the inflowing air; an auxiliary carbuerettor for starting is indicated at (78) (Fig. 41). In reply to the objection that the efficiency of this power system would only be small, because the compression in the chamber with cone (26) could not be high, Goddard alleges that the pressure drop in the interior of the chamber in relation to the dynamic pressure would be unimportant owing to the small cross-section of the neck of the diffusor at (26) and the rapid sequence of the processes.

The French Patent Specifications 770326 and 779,655 applied for by R. Leduc on June 7, 1933 and January 2, 1934 respectively, deal with the method, already known from earlier publications, of converting heat into kinetic energy without the assistance of mechanical compressors. The form of construction of the aircraft (Figs. 47 and 48) resembles that suggested by Campini (Fig. 31) apart from the centrifugal compressor which appears there. The guide surfaces, intended to guide the flow at the inside wall of the pipe are indicated by (9); (3) indicates burners, (4) fuel pre-heaters. As it is more difficult to prevent the fluid medium in widening (compression) funnels from becoming diverted from the wall than in narrowing (expansion) funnels. Leduc's notion is to blow a thin layer of the fluid medium along the wall



FIGS. 47 and 48. *Leduc, 1933. Aeroplane with thermal-air jet-propulsion*



FIGS. 49 and 50. *Leduc 1933. Jet propulsion tube with means for sucking away the boundary layer*

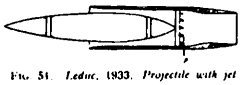


FIG. 51. *Leduc, 1933. Projectile with jet propulsion tube*

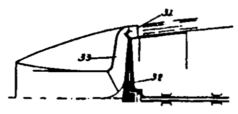


FIG. 52. *Leduc, 1933. Turbine form of propulsion device for aircraft*

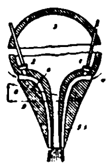


FIG. 54. *N. W. Akimoff, 1934. Additional air over aerofoil profiles: sucking away of boundary layer*

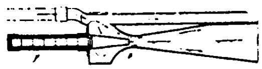
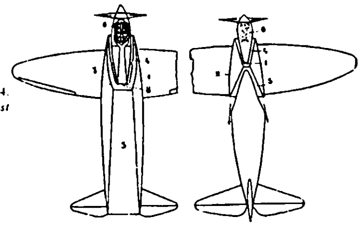


FIG. 53. *Durand-Fontugne, 1933. The starting rocket creates negative pressure behind the engine piston*



FIGS. 56 and 57. *G. Caproni, 1934. Utilization of the engine exhaust for additional propulsion*

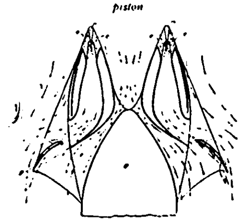


FIG. 55. *H. Coanda, 1922. Reaction and aero foil propulsion*

of the former, cf. Fig. 49, this fluid being led from positions of higher pressure (8) to annular grooves (10). In a similar manner he seeks to prevent the formation of boundary layer on the outside by blowing away (Fig. 50). Further suggestions of Leduc's (cf. e.g. Fig. 51) refer to projectiles, according to which the body of the actual projectile is surrounded by a tubular body "suppressing the impact waves at supersonic speed," with or without a source of heat (2). Fig. 52 represents a sort of turbine jet producer in which the angularly arranged combustion chambers (31) set the wheel (32) in rotation, whereby the air admitted is pre-compressed in the blower (33).

The combination of jet propulsion with the sucking away of the boundary layer has been met with frequently in more recent times; e.g. in the German Patent Specification No. 607894/62b (Maingnet) and in the British patent specification No. 484405 (Bristol).

A peculiar application of a starting rocket was suggested by Durand-Fontugne in the French patent specification No. 770689, (Fig. 53). The blown-out rocket F in an ejector D communicating with the engine exhaust, is intended to increase the engine power on starting by the creation of a sudden low pressure behind the engine piston.

An invention patented in Germany (No. 626326, applied for on June 4,1934) by N. W. Akimoff, is associated with the jet propulsion systems referred to above combining the sucking away of the boundary layer. This at the same time represents a further development of the jet propulsion systems suggested by Melot, Kort and others, in which additional air is aspired into the jet emerging from the combustion chamber over annular aerofoil profiles with chord running outwards (cf. e.g. Figs. 18 to 24). Akimoff again reduces the air resistance of the jet propulsion body Fig. 54) by giving the combustion chamber (3) and the wall of the channel a uniform streamline form; in addition, however, he places the annular inlet opening (4) of the suction channel, starting almost at right angles to the axis of the body, at a position close to and aft of the "mid-ship" section, viz. where otherwise the diversion of the air sweeping past would take place, an arrangement which, at super-sonic flight speeds presents special advantages over acute-angled air inlet. As may be seen from Fig. 54, an aerofoil profile ring (5) is formed by the channel beginning at (4), the convex inner side of which is impinged upon by jets from the combustion chamber through the valve orifices (1) and (2) which here, in spite of the aspired air, produce a flow of higher velocity than that of the outer air at the flat or concave profile wall. Owing to the circulation flow round the profile ring, transverse forces (6) are produced, the radial components (9) of which cancel each other out whilst the axial components (8) combine to form together a propulsive force which supplements the reaction force produced at the mouth. Control effects are obtained by partial closing of valves 1, 2, etc. The patent specifications contain numerous examples of realizations of the invention.

A similar though less convincing thermal jet propulsion system had been previously patented by H. Coanda in France (Patent No. 762688, applied for on November 23, 1932—cf. also Austrian Patent No. 150009 and British Patent No. 431646). Here also, as may be seen from Fig. 55, a fuel gas jet intermixed with air (c are the burners and e the air admissions) is led over aerofoil or "stream-line" profiled rings (g) so that the transverse forces ("lifts") produced here are caused to become added to the sum of their axial components and perform additional reaction. The body (o) can be a fuselage or a wing.

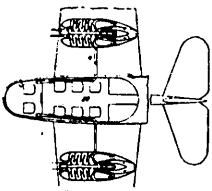
In the jet propulsion system patented in France by G. Caproni (No. 767816, applied for on January 30, 1934,) the exhaust gases of the air-screw plant (engine or gas turbine) are made to contribute to the propulsion. In one form of realization (Fig. 56), the engine gases enter at point (8) into a Venturi tube (5) shortly in front of its narrowest point, where an annular channel (4) conducting airscrew air also opens. Along this channel the radiators (7) of the combustion engine (6) are arranged. In the second form of realization (Fig. 57) the Venturi tube through the whole fuselage, but is shorter and ends in the form of a conical ring on the circumference of the fuselage. In both cases, additional burners can be fitted at point 1 in order to increase the thermal energy of the power jet.

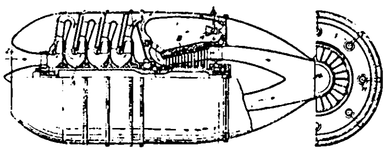
To the series of thermal air jet propulsion systems of constant volume, consisting of compressor plus combustion chamber plus exhaust gas turbine plus diffusor with or without airscrew, already mentioned, must be added, the numerous, noteworthy designs of the Milo Aktie-Colegat, Stockholm, some of which are reproduced here in Figs. 5861. (These drawings have been taken from the comprehensive American Patent Specification 2085761 (applied for February 15, 1933—inventor A. Lysholm). Fig. 58 shows that the jet propulsion systems mounted on the wings of the aircraft can supply compressed air tapped at (4) and at the same time heat, which can be regulated, to the high-altitude cabin (20). Fig. 59 shows the construction of the power unit more clearly. The relative wind entering forward at (2) is compressed in a multi-stage system A and led in an annular channel (8) along the wall to burner nozzles (14) and enters as combustion gas behind the expanding combustion chamber (3) into an axial turbine B, where part of the energy is utilized for driving the compressor and eventually also an airscrew (cf. Fig. 60). With still continuously higher tension and speed, the driving medium emerging from a large turbine section (6) enters an outlet channel, the flow cross-section of which diminishes towards the end (10) where the "recoil" is produced.

In the form represented in Fig. 61, use is made of a radial exhaust gas turbine (4) which is interposed between two compressor stages (15) and (16) running in opposite directions. After the air has passed through the low pressure stage (15) it washes round the turbine aggregate before entering the high pressure stage (16) and then, heated, flows again along the wall and reverses through the burner nozzle (14) almost at the end of the stream-lined housing in the combustion chamber (3). The combustion gas is led through channels (17) into the radial turbine (14) with opposing vanes and from there radially to the circumference of the body. Aft of the maximum diameter the jet, producing reaction effect (recoil) emerges out of outlet connexions (7) at the circumference.

Reference should further be made to the Swiss Patent Specifications (in German text) Nos. 174257 and 170667, the first of which corresponds to Figs. 58 and 59, the second applying more to airscrew propulsion systems, to Figs. 60 and 61, and also to the British Patent Specification 472850 (applied for April 21, 1936) of the Aktiebolaget Ljungstroms Angturbin, Stockholm, in which similar kinds of constructions are described.

F. Whittle, Cambridge, to whom reference has already been made in connexion with his patented principle for a thermal jet system (Fig. (14), submitted specifications for types of construction on May 16, 1935 and March 4, 1936 (Swiss Patent Specifications 188758 and 195823). The former (Figs. 62 to 65) deals chiefly with the development of the centrifugal compressor which is driven by a turbo-rotor (17) inside a housing open forward. The vane wheel (10) of the compressor allows the air to enter at (25) on both sides of its axis of symmetry, accelerates it at its circumference to super-sonic speed and sends it by way of a diffusor (27) into the helical guide (28), from which it proceeds into a spiral combustion chamber (30) of increasing cross-section and through a nozzle into the annular nozzle box (19) of the turbine (19) surrounded partially by a cooling jacket (52), after it has been enriched with fuel in an ignition pipe (7) shown in Fig. 64, and a combustible mixture has been formed. The inner wall of the ignition pipe (7) is covered with a wire mesh in order to produce a boundary layer of smaller velocity.





Figs. 58, 59. *Milo, 1933. Thermal-air jet-propulsion with axial turbine*

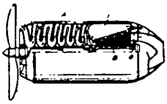


Fig. 60. *Milo, 1933. As Figs. 58, 59, but with airscrew propulsion*

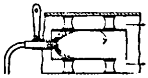


Fig. 64

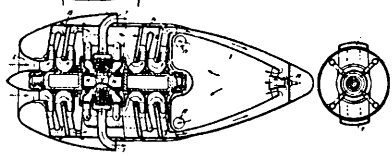
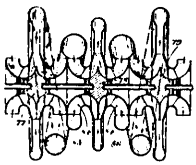


Fig. 61. *Milo, 1933. Thermal-air jet-propulsion with radial turbine*



Figs. 62-65. *Whittle, 1935. Thermal-air jet-propulsion with axial turbine*

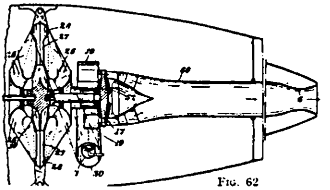


Fig. 62

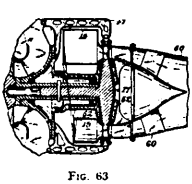


Fig. 63

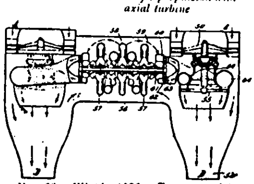


Fig. 66. *Whittle, 1936. Twin propulsion system*

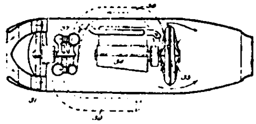


Fig. 67. *Whittle, 1936. Thermal jet propulsion with piston engine and turbine*

A part of the compressed air (delivery $3\frac{1}{2}$ times in excess) flows round the ignition pipe (7). After the combustion gas has given up part of its energy to the turbo-rotor (7) it proceeds by way of the channel and emerges, producing recoil, out ot the nozzle (6). Fig. 63 shows, among other things, the structure of the connexion of the compressor and turbine in the form of bracket arms (47); Fig. 65 shows the construction of a two-stage compressor, in which the two outer vane wheels (77), (79) deliver by way of spiral guide channels 85, 86 to the double inlets (84) of the central high-pressure vane wheel (78).

The second of Whittle's patent specification is concerned with a twin propulsion system, Fig. 66. The relative wind entering each of the two nozzle bodies at E is taken up by an axial compressor (50), which is driven by a combustion motor system, a piston motor or, as represented, a gas turbine (55), over a step-up gear (54). The compressed air travels in part, down through the reaction nozzles D into a central chamber (56) connecting the two nozzle bodies, where they are still further compressed by a two-stage compressor (57), (58) of the kind already described and conducted through channels (59) into admission chambers (60) is rendered combustible by action turbines (62) which drive the compressor aggregate off a common shaft (61). The exhaust gases of these turbines are conducted through channels (63), (64) to the combustion motors already referred to and, on emerging from these combine with the air mass flowing directly through the hollow body to form the propulsion jet.

In a further form, described in the same Swiss Patent Specification No. 195823 (Fig. 67), the gas turbine (37) driving the pre-compressor (31) derives its driving medium partly from a centrifugal compressor (35) through pipe (36), partly from the motor (34) driving and charged by the compressor, in that its exhaust gases are also conducted to the pipe (36). The turbine exhaust gases give up the remainder of their energy in the reaction pipe (38).

The invention, published a few weeks ago in the German patent No. 669687/46b (applied for May 14, 1937) by the Erla Maschinenwerk G.m.b.H., Leipzig, (inventor: Dr. E. Mumder), seeks to eliminate the drawbacks of the heat-consuming dissociation to which the gases are subjected at the high temperatures in the combustion chamber and which deprives them of chemical-technical energy, causing the dissociation of the gas mixture to take place already on entry into the "furnace" in the ante-chamber by means of a special source of heat, so that, "as a result of the association of the atoms to molecules taking place in the outlet part of the furnace, in addition to the heat of the exothermic oxidation of the molecules, the heat of dissociation again liberated, also is utilized for the production of the gas pressure." As the source of heat, use is made of an electric arc, formed between obliquely set wolfram electrodes, with the admission of hydrogen and oxygen to the arc through the tubes.

Ever since the earliest days, the principle of jet propulsion has been visualized as the future method of aircraft propulsion; it remains to be seen how long it will be before this ideal means becomes a practical possibility.

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