

May 2, 1961

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2,982,093

COMPOUND RAM JET TURBO-ROCKET ENGINES

Filed Aug. 26, 1958

7 Sheets-Sheet 1

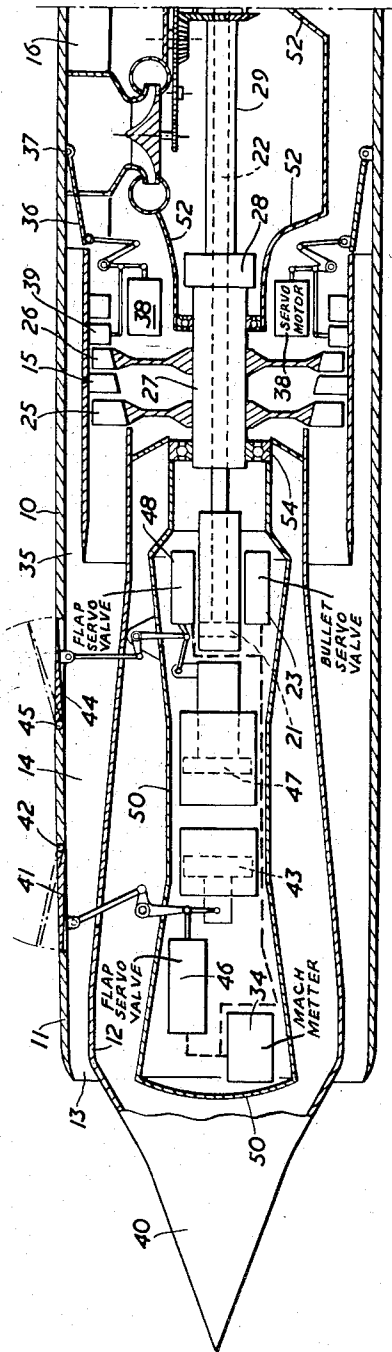


FIG. 1A.

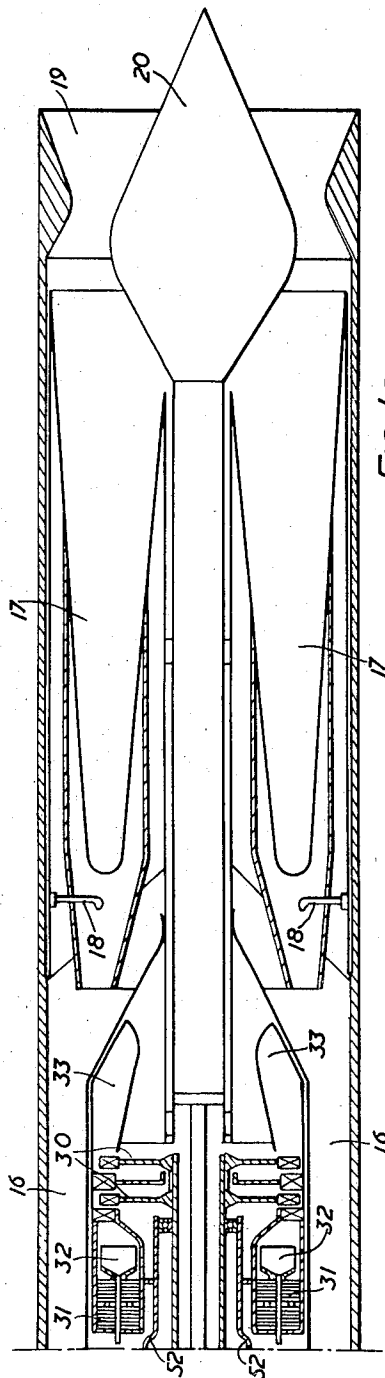


FIG. 1B.

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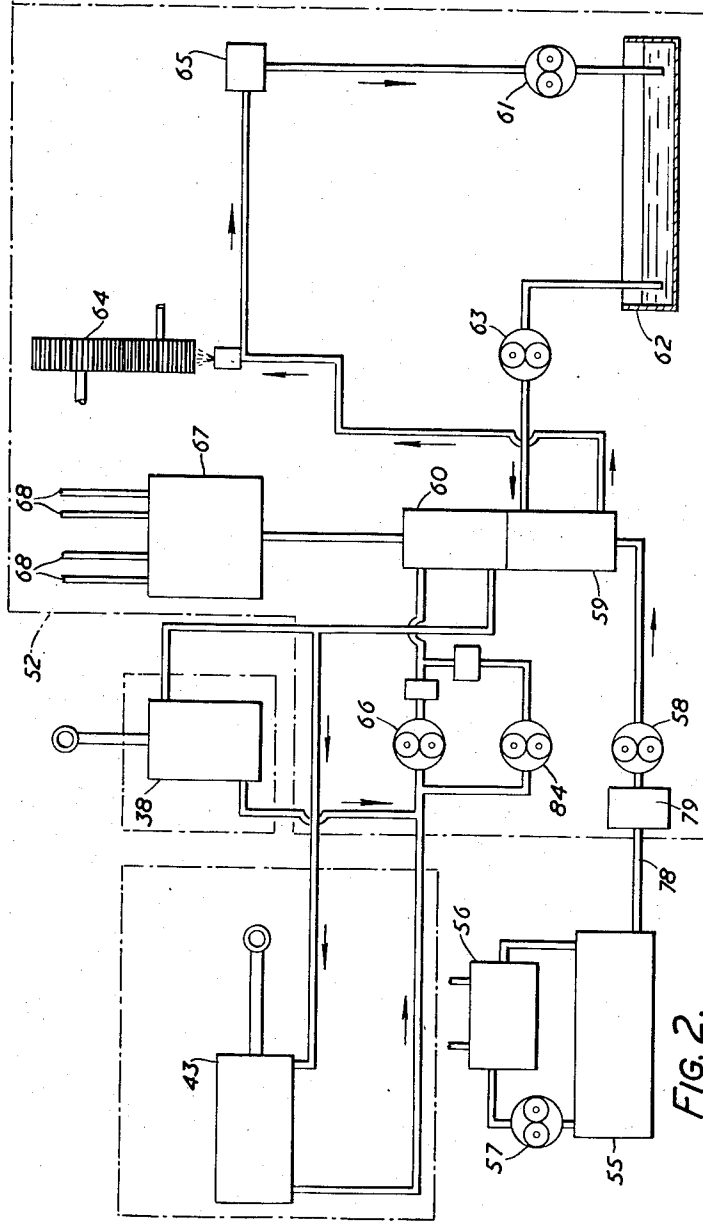


FIG. 2.

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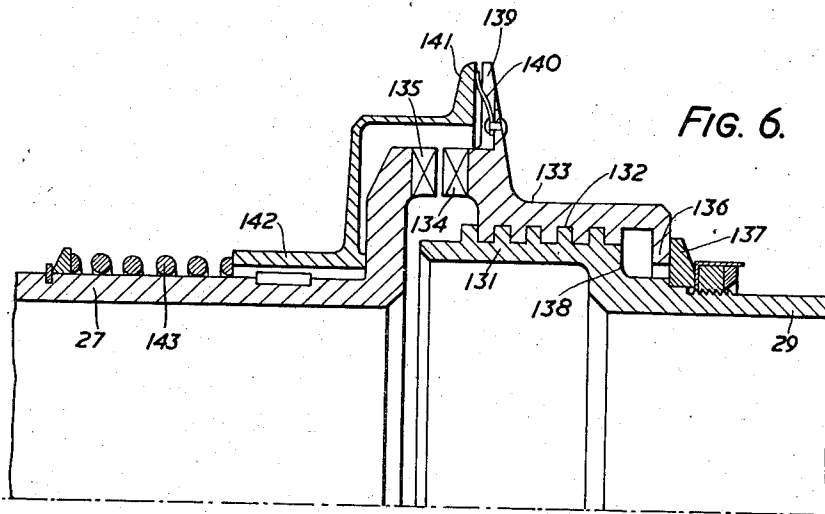
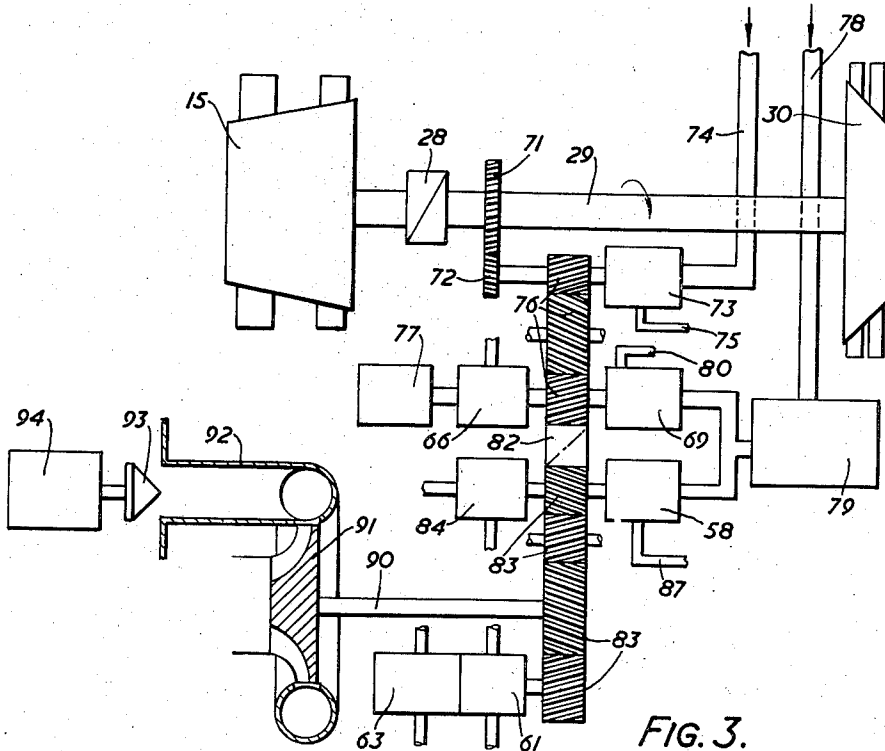
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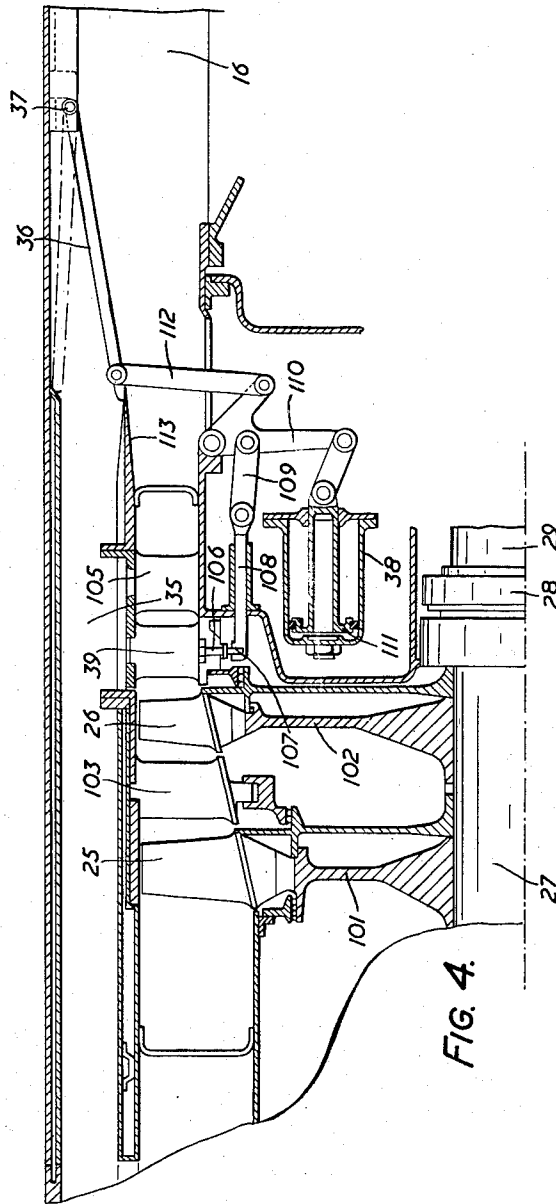


FIG. 4.

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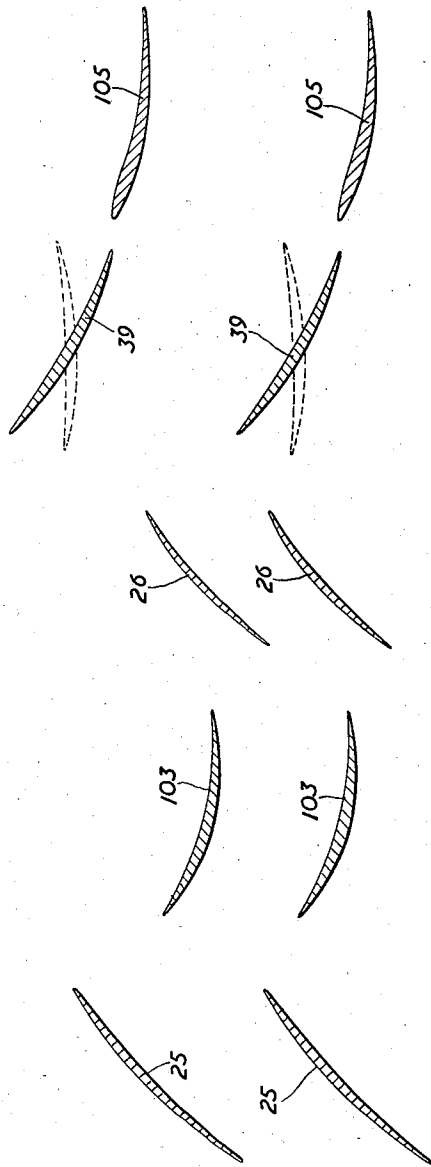
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FIG. 5.



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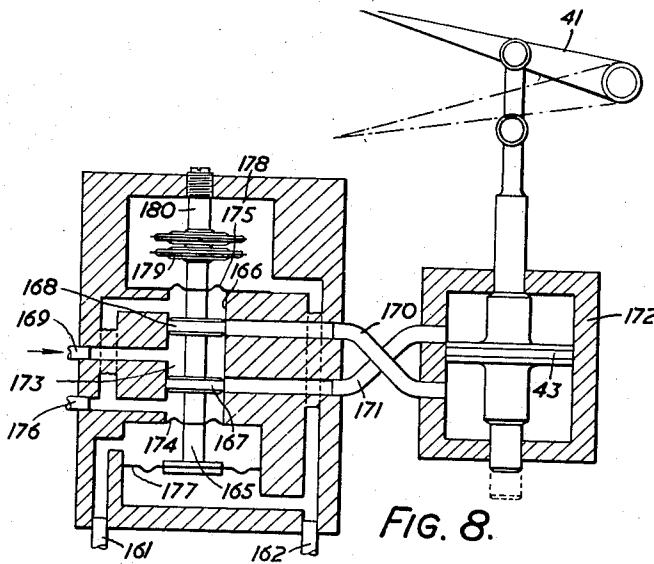


FIG. 8.

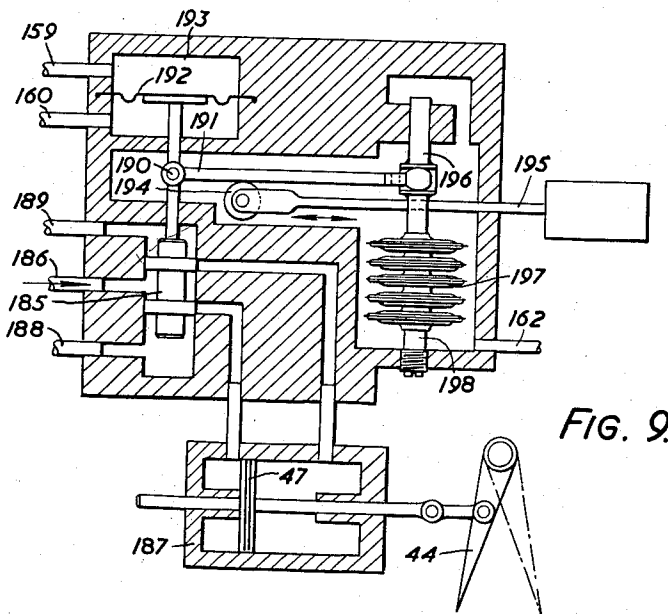


FIG. 9.

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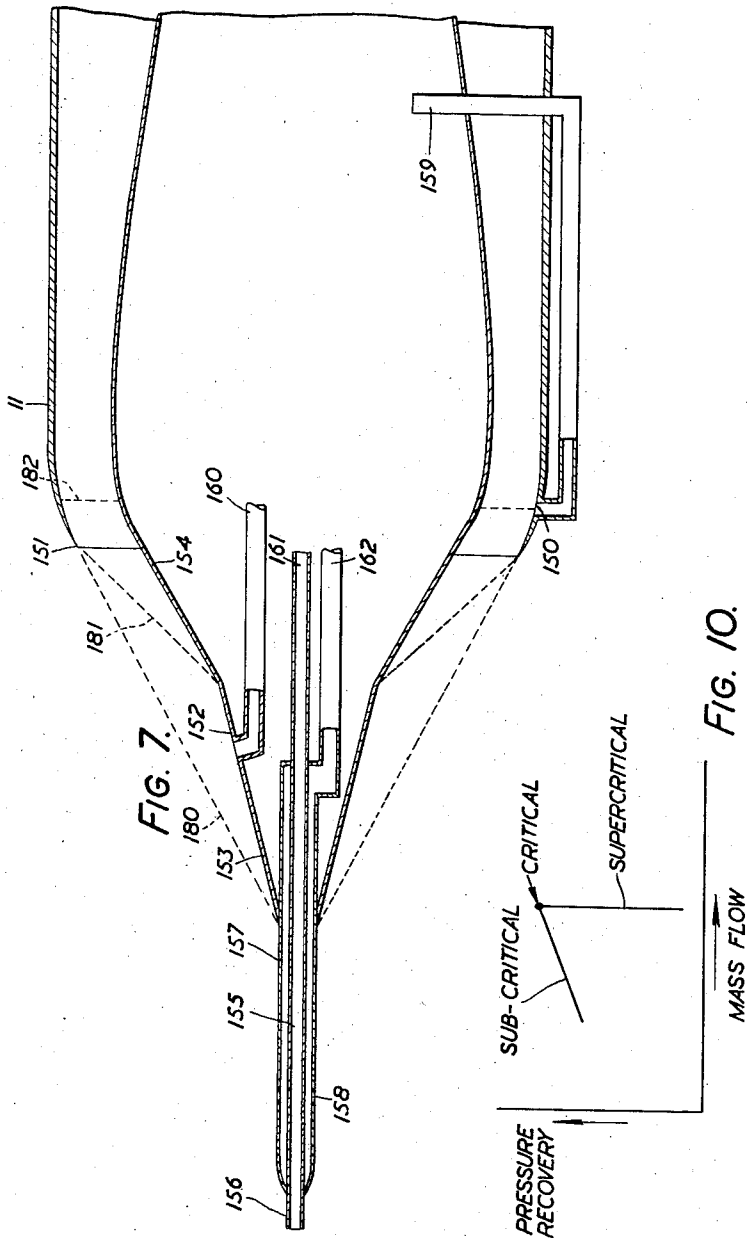
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COMPOUND RAM JET TURBO-ROCKET ENGINES

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Claims priority, application Great Britain Aug. 30, 1957

5 Claims. (Cl. 60—35.6)

This invention relates to compound ram jet turbo-rocket engines of the type including an air intake at the forward end of the engine, a main combustion chamber to which fuel is supplied and an exhaust passage terminating in a propulsion nozzle, and a rocket type gas generator arranged to drive a turbine which is in turn coupled to a compressor, the compressor being arranged to receive air from the air intake and to deliver it to the main combustion chamber.

Such engines operate under two different regimes. In the ram jet regime air is admitted to the engine through the air intake at the forward end and is compressed by the ram effect and supplied under pressure to the main combustion chamber where the fuel is burnt. In the rocket regime the rocket drives the turbine which in turn drives the compressor and the air supplied to the main combustion chamber is pressurised by the compressor. Thus the rocket regime is particularly adaptable to operations at forward flight velocities which are insufficient to provide the necessary ram effect. In some operating conditions it may be desirable to operate the engine on both systems simultaneously. In any case it will be seen that the internal operating conditions of the engine are subject to wide fluctuations due to the wide range in forward flight velocities and also to the various different regimes in which the engine operates. In particular the operating conditions, such as pressure, velocity and temperature of the air passing through the air intake to the main combustion chamber, are liable to fluctuate considerably. It is an object of the present invention to provide an engine of the kind referred to which will be capable of efficient operation over the different conditions that may be expected.

According to the present invention, therefore, a compound ram jet turbo-rocket engine of the kind referred to includes a by-pass passage between the air intake and the main combustion chamber by-passing the working passages of the compressor.

The engine also preferably includes valve mechanism arranged to control the flow of air through the by-pass passage.

According to a preferred feature of the invention the compressor includes at least two rings of rotor blades and at least two rings of stator blades downstream thereof, the downstream ring of stator blades being adjustable, each blade on a pivotal axis which is substantially radial to the axis of rotation of the compressor, and including adjusting mechanism arranged to pivot each blade of this downstream ring into one or other of two operating positions, in one of which the blade ring operates at maximum efficiency as a normal stator blade ring, while in the other position the blades are positioned to give the maximum effective throat area between blades.

In such case according to another preferred feature of the invention the valve mechanism controlling the air flow through the by-pass passage is preferably associated with and arranged to act simultaneously with the

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mechanism adjusting the position of the stator blades of the compressor.

According to yet another preferred feature of the invention the air intake comprises two series of circumferentially spaced flaps arranged to open or close apertures in the outer wall thereof, the first upstream series of flaps being pivotally mounted at their rear ends while the second downstream series are pivotally mounted at their forward ends, both series of flaps being arranged to open outwards.

It will be understood that to obtain the maximum rate of air flow through the air intake to the combustion chamber it is desirable that air should pass through the compressor in addition to passing through the by-pass passage. Thus according to another preferred feature of the invention the compressor rotor and the turbine rotor are coupled to one another through a unidirectional clutch arranged to enable the compressor to over-run the turbine or to free-wheel or windmill when the turbine is stationary.

The exhaust nozzle assembly of the engine must also be capable of efficient operation over the full range of flight conditions, and according to yet another preferred feature of the invention the exhaust nozzle assembly comprises an outer venturi shaped wall and an inner double-tapered central bullet (that is to say tapered in both directions from the centre), the outer wall or the central bullet being movable in a longitudinal direction relative to one another between two main positions in one of which the maximum diameter of the bullet is adjacent the point of minimum diameter of the venturi throat, while in the other main position the maximum diameter of the bullet is adjacent the rear end of the outer wall.

The fuel supply system for the engine preferably comprises a rocket fuel pump driven by the rocket turbine, and supplying fuel to the rocket gas generator, and a separate main fuel pump capable of being driven alternatively by the rocket turbine or by an independent motor and supplying fuel to the main combustion chamber.

In such an engine including component or auxiliary mechanisms such as lubrication or hydraulic servo systems which necessarily contain a liquid medium such as oil, the fluid circuits of the mechanisms are preferably arranged in at least two separate closed circuits each incorporating a separate heat exchanger, the main liquid fuel supply to the engine being passed in series through these heat exchangers to maintain the liquid in one of the circuits at the minimum temperature attainable by the cooling effect of the fuel at its delivery temperature to the engine.

The invention may be performed in various different ways, but one specific embodiment will now be described by way of example as applied to an aircraft propulsion engine which is illustrated in sectional elevation in Figures 1A and 1B of the accompanying drawings, of which:

Figure 2 is a diagrammatic illustration of the fuel lubrication and hydraulic servo systems;

Figure 3 is a diagrammatic illustration of the driving mechanism for the pumps;

Figure 4 is a sectional side elevation on an enlarged scale of the compressor;

Figure 5 is a diagrammatic developed sectional view of the compressor blading;

Figure 6 is a sectional elevation on an enlarged scale through the freewheel mechanism 28 between the turbine and compressor;

Figure 7 is a diagrammatic sectional elevation on a slightly reduced scale of the air intake of the engine showing the pressure sensing heads;

Figure 8 is a diagrammatic illustration of the automatic servo control mechanism controlling the air intake flaps;

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Figure 9 is a diagrammatic illustration of the automatic control mechanism for the spill flaps; and

Figure 10 is a graph illustrating various conditions which occur in the air flow entering the air intake.

This engine is a compounded ram jet-turbo rocket engine. It includes an outer generally cylindrical casing 10, the front end 11 of which forms with a conical centre body 12 an annular air intake 13 leading to an axial diffuser passage 14 and then to an axial flow compressor 15 from which the air passes rearwardly through an annular air duct 16 into an annular combustion chamber 17 to which a hydrocarbon fuel such as kerosene is supplied through burners 18. The hot products of combustion issue through a nozzle 19 at the rear of the engine as a high speed propulsion jet. A bullet 20 is provided for adjusting the area of the nozzle, this bullet being axially movable by a hydraulic ram 21 disposed in the front part of the engine and connected to the bullet by a long shaft 22 extending rearwardly through the centre of the engine. The ram 21 is controlled by a follow-up servo valve 23.

The compressor comprises two rotor blade rings 25, 26 mounted on a hollow shaft 27 which is connected by freewheel mechanism 28 to another hollow shaft 29 at the downstream end of which is mounted a two stage axial flow turbine 30. This turbine is driven by a rocket system including catalytic decomposition chambers 31 to which hydrogen peroxide is supplied and decomposed to form oxygen-rich steam, and rocket combustion chambers 32 into which some paraffin is then introduced for combustion with some of the oxygen. The combustion products, which are still rich in oxygen, are expanded in the turbine 30, and then pass through ducts 33 to enter the main combustion chamber 17 along with the air from the said annular duct 16, to contribute to the propulsive effect of the jet. Also, the residual oxygen content of the turbine effluent assists the main combustion process.

Provision is also made for the engine to operate as a pure ram jet when a sufficiently high speed has been reached. For this purpose an annular by-pass duct 35 is provided around the axial flow compressor 15 and the downstream end of this by-pass duct communicates through flap valves 36, pivoted at 37, with the said annular air duct 16 at the downstream end of the compressor. These flap valves 36 are actuated by hydraulic servo motors 38 which also actuate a ring of adjustable stator blades 39 for the last stage of the compressor, to increase the flow through the compressor and reduce losses therein during ram jet operation. At a predetermined Mach number, when the ram effect alone will provide sufficient compression of the air, and which is sensed by a Mach meter indicated generally at 34, the hydrogen peroxide and paraffin supply to the rocket system is automatically shut off, thus stopping the turbine 30 and removing the power supply for the axial flow compressor 15. At the same time the by-pass flap valves 36 are opened to allow air from the air intake 13 to pass through the annular by-pass duct 35 to the combustion chamber 17. The free wheel mechanism 28 between the turbine 30 and the axial flow compressor 15 permits the latter to "wind-mill" during ram jet operation.

The centre body 12 has a conical nose tip 40, and cooperates with the outer cowl 11 to provide shock compression during ram jet operation. Behind the lip of the cowl at the beginning of the diffuser section 14 there is an annular port providing communication between the outside of the engine and the diffuser section. During ram jet operation this port is closed by a series of petal type flaps 41 pivotally attached to the outer shell of the engine at their rear ends 42. During turbo rocket operation these flaps are swung outwards as shown in chain lines by a hydraulic servo motor 43 controlled by a follow-up servo valve 46, so as to provide an additional annular air intake of larger diameter surrounding the main air intake 13.

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Towards the rear end of the diffuser section 14 and upstream of the axial flow compressor 15 there is arranged another series of similar pivoted flaps 44 controlling another annular port in the outer shell 11 which constitutes a controllable spill port which is opened during ram jet operation to the extent required to maintain the desired shock pattern at the intake. These flaps 44 are pivotally connected to the shell at their upstream ends 45 and are opened outwards by a hydraulic servo motor 47 controlled by a follow-up servo valve 48.

Thermally insulated compartments are provided in the engine within the annular air duct through the engine. There is a front compartment 50 lying mainly within the diffuser section 14 and terminating adjacent the forward end of the compressor 15. This compartment houses the hydraulic servomotors 43, 47 which are connected through mechanical linkages with the said two series of flaps 41 and 44, and their control valves 46, 48. It also houses the Mach meter 34 and the shock sensing system, a forward bearing 51 for the axial flow compressor 15, and the hydraulic ram 21 for adjusting the position of the nozzle bullet 20.

A second insulated compartment 52 surrounds the shaft 29 connecting the turbine to the compressor and encloses the freewheel mechanism 28, pumps for lubricant, servo motor fluid, paraffin and hydrogen peroxide, gearing for driving these pumps and other auxiliaries. This compartment also contains a sump of lubricating oil, two heat exchangers through which paraffin fuel is pumped in succession as a coolant and a metering unit for the paraffin.

The fuel supply system and lubricating and hydraulic servo supply circuits are illustrated in Figure 2.

Paraffin is supplied from a tank 55 mounted outside the engine, for example in an aircraft or missile to which the engine is attached. The fuel in this tank is used as a coolant or heat sink for parts of the aircraft and a heat exchanger 56 and fuel circulating pump 57 are provided for the purpose. The fuel in the tank 55 may thus be at a relatively high temperature possibly close to the vaporisation point. In order to permit the fuel to be further heated, and used as a coolant in the process, it is admitted to the engine through a pressurising pump 58 which raises its pressure substantially. The fuel then passes in succession through two heat exchangers 59, 60.

In the first heat exchanger 59 the paraffin takes up heat from lubricating oil which is delivered by a pump 63 from a sump 62, through the heat exchanger, to the gearing for the pumps and auxiliaries indicated diagrammatically at 64 and to the turbine and compressor bearings indicated at 65 all these parts being within the said insulated compartments 52 and therefore receiving little heat. In the second heat exchanger 60 the paraffin takes up heat from the actuating fluid of the several hydraulic servomotors such as 43, 47, 21 and 38. The paraffin then passes to a metering unit 67 and on to the burners 18 via ducts 68.

The hydraulic servo circuit includes a pressurising pump 66 which impels the servo fluid through the heat exchanger 60, and thence in parallel to the servo rams two of which are indicated diagrammatically at 38 and 43.

The heat exchanger 59 being upstream of heat exchanger 60 in the fuel supply line, will have a lower temperature datum, and this is desirable since the lubricating oil may tend to carbonise if heated excessively with risk of damage to bearings and other high speed parts. The hydraulic servo liquid on the other hand can safely be allowed to reach higher temperatures, since the servo mechanisms are relatively slow moving. In the present example the paraffin will enter the engine at pump 58 at a temperature not exceeding 150° C. and in passing through the two heat exchangers its temperature may be raised 30° C. It then passes to a fuel metering unit 67, and thence to delivery liners 68 leading to burners 18 in the main combustion chamber 17. The lubricating oil

entering the first heat exchanger 59 may be at a temperature of about 250° C. while the servo liquid entering the second heat exchanger may be at a temperature of about 300° C.

The gearing and drive for the hydrogen peroxide, paraffin fuel, lubricating oil, hydraulic servo and other pumps is illustrated diagrammatically in Figure 3. The shaft 29 on which is mounted the rocket turbine 30 is connected through gearing 71, 72 to drive a pump 73 which receives hydrogen peroxide from a main supply conduit 74 and delivers it under pressure to the catalytic decomposition chambers 31 via a conduit 75. The turbine shaft 29 is also arranged to drive through the gearing 71, 72 and further gearing 76, three units 77, 66 and 69. Unit 77 is a hydraulic r.p.m. signal generator which provides a fluid pressure proportional to the speed of rotation of the turbine, and is used for automatic control purposes. Servo pump 66 is arranged to provide servo fluid under pressure to operate the servos 43, 47, 38 etc. when the rocket turbine 30 is in operation. Pump 69 is arranged to receive paraffin fuel from the main aircraft fuel tank 55 through duct 78 via a filter 79 and to deliver the fuel under increased pressure to the rocket combustion chambers 32 via a conduit 80.

The gearing 76 is connected through a free wheel device 82 to another gear train indicated at 83, this gearing being arranged to drive the second servo pump 84, as illustrated in Figure 2, and the ramjet paraffin pump 58, which delivers paraffin at high pressure through duct 87 to the heat exchangers 59, 60, and thence to the main burners 18. This gear train 83 also drives pumps 63, and 61, the pressure and scavenge pumps in the circuit illustrated in Figure 2.

The gearing 83 is also connected by a shaft 90 to a radial flow turbine 91 to which air is supplied under pressure from the annular air duct 16. The exhaust of this turbine is allowed to escape to a low pressure region such as atmosphere through a duct 92 in which is arranged an adjustable throttle valve 93 under the control of a servo control device 94.

Thus in operation when the engine is first started by an external booster pump or starter motor, the rocket turbine 30 will be driven by the rocket exhaust and this will drive both the main compressor 15 through the free wheel 28, and also all units driven by gearing 76, and in addition will drive through the free wheel 82 and gearing 83 all the units connected to this gearing 83. When the engine has achieved a forward flight speed sufficient for ram jet operation the rocket section will be shut down and the turbine 30 will stop. The main compressor 15 can then windmill overrunning the turbine shaft by means of the free wheel 28, but the gearing 76 will not be driven by the turbine and the units 73, 77, 66 and 69 will be out of operation. The air turbine 91 however will then be driven by the relatively high pressure in the annular air duct 16 and through the shaft 90 and gearing 83 all units associated therewith will be driven. In particular pump 58 supplying fuel to the main burners 18, servo pump 84 and lubrication pumps 61 and 63 will then continue to be driven by the air turbine.

The compressor 15 itself is of the two stage type including the two rotor blade rings 25, 26 mounted on rotor discs 101, 102, attached to the compressor shaft 27. Between the rotor blade rings there is mounted a ring of stator blades 103 which are angularly fixed and non-adjustable. Downstream of the second rotor blade ring 26 there is mounted a second ring of stator blades 39 which are each angularly adjustable about axes through each blade which are radial to the main axis of the compressor. A further series of fixed straightener vanes 105 is provided downstream of the second adjustable stator blade ring 39.

The blades 39 are each connected rigidly to a pin 106 capable of rotating in a bushing carried by a fixed part

of the engine and the inner end of this pin is connected to an off-set crank 107 which is in turn connected through pivoted links 108 and 109 to a point on a bell crank lever 110 which is angularly adjustable by means of the double acting servo ram 38. The ram comprises a ram piston 111 connected to a piston rod passing through a gland at one end of the ram cylinder and means are also provided for admitting pressure fluid to either end of the ram cylinder as required under the control of an automatic servo valve. The servo valve itself forms no part of the present invention and will not therefore be described in detail. The hydraulic servo ram 38 is also arranged to actuate the flap valves 36. To this end the bell crank lever 110 is connected through a pivoted link 112 to a point at the upstream end of each flap valve. In the position illustrated in the upstream end of the flap valve abuts against a cylindrical shield 113 which separates the by-pass passage 35 from the outlet passage of the compressor, both these passages communicating at their downstream ends with the annular air passage 16. In this position the flap valve 36 closes the by-pass passage 35 and air can only pass into the passage 16 via the compressor. In the other operative position of the flap valve 36 as illustrated in chain lines the by-pass passage 35 is opened to the passage 16 and air can then flow both through the compressor and through the by-pass passage.

In operation when the rocket turbine 30 is driving the compressor 15 the servo ram piston 111 is in the position illustrated and the flap valve 36 is closed preventing air flow through the by-pass passage, and the second row of stator blades 39 are in the position indicated in full lines in Figure 5. The compressor thus delivers air to the main combustion chamber 17 and operates normally at full efficiency.

When the engine has attained a forward flight velocity at which the ram pressure is sufficient to support combustion the supply of fuel to the rocket engine driving the turbine is shut off automatically or by the pilot selection and the turbine stops. At the same time the servo valve automatically reverses the high pressure connections to the ram cylinder 38 and the ram piston is moved to the right in Figure 2 thus opening the flap valves 36 so that the by-pass passage 35 allows air to flow around the compressor into the air passage 16, and at the same time the adjustable stator blades 39 are rotated into their second operative positions as indicated in chain lines in Figure 5. In this position of the blades the maximum throat area is achieved with the minimum resistance to flow and the turbine rotor blade rings 25, 26 will windmill under the air flowing through the compressor thus augmenting the total air flow into the main combustion chambers 17.

The servo valve controlling actuation of the ram 38 may be arranged to be responsive to the speed of rotation of the turbine. Thus at all turbine speeds above a predetermined figure the servo valve will be arranged to hold the ram piston 111 in the position illustrated, while when the turbine speed falls below this valve as a result of the fuel supply being shut off to this rocket combustion chambers the ram piston will move into its alternative operative position.

The freewheel mechanism 28 is illustrated in detail in Figure 6. The turbine shaft 29 is formed with a hollow cylindrical extension 131 at its end adjacent the compressor shaft 27 and the external surface of this extension piece is provided with a quick pitch helical screwthread 132. Cooperating with this screwthread is an internal screwthread sleeve 133 which constitutes a movable clutch member and which is formed with a ring of dogs 134 which can be engaged with a corresponding ring of dogs 135 formed on a flange secured to the compressor shaft 27. The sleeve 133 is also provided with an inwardly projecting radial flange 136 which in the position shown abuts against a locking ring 137 while in the other limiting position of the sleeve this flange

abuts against a shoulder 138 formed on the turbine shaft. The sleeve 133 is also formed with an outwardly projecting radial flange 139 to which are connected a series of resilient friction leads 140 which bear against the face of a flange 141 formed of a sleeve 142 which is splined or keyed to the compressor shaft 27. This sleeve 142 is urged towards the turbine shaft by a compression spring 143.

In the position illustrated in Figure 6 the dogs 134, 135 are out of engagement and the mechanism is in its free wheeling position. The compressor shaft 27 can rotate in a clockwise direction when viewed from the turbine and there will be a slight frictional drag between the friction leads 140 and the flange 141.

If the turbine shaft 29 is driven in this same direction of rotation at a speed faster than the compressor shaft 27 the frictional drag on the leads will cause the sleeve 133 to rotate on the quick pitch screwthread 132 and the sleeve will move axially towards the compressor until the dogs 134, 135 engage and ultimately the flange 136 on the sleeve abuts against the should 138. During this axial movement of the sleeve a spring 143 will be compressed thus increasing the loading pressure between the leads 140 and the flange 141 and so increasing the frictional drag and hence the torque available for rotating the sleeve 133. When the dogs 134, 135 are fully engaged the turbine shaft 29 will then drive the compressor shaft 27.

The two sets of flaps 41 and 44 can be arranged to be controlled automatically by the apparatus illustrated in Figures 7, 8 and 9. The apparatus comprises a series of pressure sensing heads as illustrated diagrammatically in Figure 7. A first pressure head 150 is mounted on the inner surface of the cowl 11 at a point adjacent to but a short distance downstream of the forward lip 151 of this cowl. A second pressure sensing head 152 is positioned on the surface of the conical centre body 40 at a point some distance downstream of the extreme tip or apex of the cone. It will be seen that the cone is in fact of double frusto-conical form and includes a first sharp angled conical section 153 and a rearward frusto-conical section 154, the pressure head 152 being situated somewhat upstream of the junction between these two sections. At the extreme forward end or point of the conical centre body there is provided a pivot head on a forwardly facing probe comprising an inner tube 155 with a sharp intake lip 156 at its forward end, and a surrounding hollow tube 157 provided with side apertures 158. The pressure sensing heads 150, 152, 156 and 158 are connected respectively to pressure conduits 159, 160, 161 and 162.

At low flight speeds below Mach .95 the spill flaps 44 remain closed. Within the range of flight speeds the intake flaps 41 are under the control of the valve apparatus 46 which is illustrated in detail in Figure 8. This valve is influenced by the pressures in the conduits 161 and 162, that is to say by the total pressure at the pitot head 156 and the ambient air pressure as sensed by the side orifices 158. The apparatus comprises a piston type control valve 165 arranged in a valve cylinder 166 and provided with lands 167, 168 which control the flow of a high pressure servo fluid from an inlet aperture 169 selectively to one or other of the delivery passages 170 and 171. These delivery passages are connected to opposite ends of the ram cylinder 172 which houses the reciprocating ram 43, this ram being connected by a mechanical linkage to the intake flaps 41 (one flap only being illustrated in Figure 8). The opposite ends of the valve chamber 173 are closed by flexible diaphragms 174 and 175 and these two ends of the chamber are connected to a low pressure fluid line 176. It will be seen that when one end of the ram cylinder 172 is connected to the high pressure fluid line 169 the opposite end of the ram cylinder is connected to the low pressure line 176 and vice versa.

The valve apparatus also includes chambers lying on

the remote sides of the diaphragms 174 and 175. One of these chambers is itself sub-divided by a flexible diaphragm 177 the centre part of which is rigidly connected to the valve stem 165. The upper part of this sub-divided chamber is connected to the pressure conduit 161 which leads to the forward facing orifice 156 of the pitot tube, while the lower part of this chamber is connected to the conduit 162 which leads to the side orifices 158 on the pitot head. The chamber 178 at the opposite end of the valve is also connected to the conduit 162 and this chamber contains an evacuated flexible capsule 179, one end of which is rigidly connected by a bolt 180 to the end of the valve chamber, while the other end of the diaphragm is rigidly connected to the valve stem 165.

It will be seen that the servo fluid pressure acting on the valve stem is substantially balanced and the total force exerted on the valve stem is determined by the resilience of the bellows and the pressures in the conduits 161 and 162 and by the effective area of the capsule 179 and of the diaphragms 175 and 177. In practice these areas and the spring rate of the diaphragm are so selected that the valve stem will move to cause the ram 43 to be urged downwards to hold the intake flap 41 in its open position, until the total pressure in the conduit 161 exceeds that in the conduit 162 by a predetermined value. This value, which is derived from the pitot head, is in effect the Rayleigh number of the air flow conditions due to the forward flight velocity and the dimensions of the various parts are so selected that the valve will operate in this manner when the forward flight speed reaches a value of Mach 0.95. At this flight speed the further automatic Mach No. control 34 comes into operation to cut off the supply of fuel to the rocket engine and at all flight speeds above this figure the engine then operates as a ram jet. At all such higher flight speeds the intake flaps 41 remain fully closed under the influence of the valve 46.

At higher supersonic flight speeds a shock wave pattern exists in the neighbourhood of the air intake which varies at different speeds but which adopts a pattern as illustrated in chain lines in Figure 7 when the engine is operating at the design point at approximately "critical" conditions. This pattern comprises a first oblique shock wave 180 extending rearwardly from the forward end of the cone 40 to a point adjacent the lip 151 of the cowl. A second oblique shock wave 181 originates at the junction between the forward cone 153 and the rear cone 154 and this shock wave also extends to a point adjacent the lip 151 of the cowl. A third normal shock wave 182 occurs within the air intake itself at a point somewhat downstream of the lip 151. Referring to Figure 10 it will be seen that the critical condition corresponds to the maximum pressure recovery or intake efficiency while the sub-critical condition occurs when the mass flow is below the critical value. The critical mass flow represents the maximum mass air flow that will pass through the intake and at supercritical conditions the pressure recovery or intake efficiency is progressively reduced. When related to the shock wave pattern illustrated in Figure 7 the main noticeable change in the shock pattern as conditions changed from sub-critical to super-critical is the movement of the normal third shock wave 182 forwardly or rearwardly. At sub-critical conditions this normal shock wave 182 tends to move forward and vice versa.

It will be seen that the first pressure head 150 is situated at or closely adjacent to the position of the third shock wave 182 during critical operation. Any movement of this shock wave upstream or downstream will thus provide a significant change in the pressure in the conduit 159 and this pressure is used to control the attitude of the spill flaps 44 through the valve mechanism 48 which is illustrated in detail in Figure 9.

This valve mechanism comprises a piston type servo control valve 185 controlling the supply of servo pressure fluid from a high pressure source 186 selectively to

either end of a ram cylinder 187 containing the ram piston 47. The opposite end of the ram cylinder is similarly connected to one or other of the low pressure lines 188, 189. The ram piston 47 is connected by a mechanical linkage to the spill flaps 44 (one only being illustrated in its closed position in Figure 9).

The valve stem 185 extends through one end of the valve chamber and is connected at pivotal joint 190 to one end of a floating beam 191, this pivotal joint 190 also being connected to the mid-point of a flexible diaphragm 192 which sub-divides a chamber 193, the upper end of this chamber being connected to the conduit 159 while the lower part is connected to the conduit 160. The beam 191 bears at an intermediate point in its length on a roller 194 which constitutes a movable fulcrum and is adjustable longitudinally by a rod 195 under the control of the pilot or automatically by sensing of Mach No. The opposite end of the beam 191 is connected to a vertical plunger 196 the upper end of which is carried in a sliding bearing in the valve chamber, while the lower end is connected to an evacuated flexible capsule or bellows 197. The lower end of this bellows is connected by a bolt 198 to the lower end of the surrounding valve chamber. The interior of this valve chamber is connected to conduit 162 and is thus subject to ambient static pressure which provides through the capsule a corresponding vertical force on the plunger 196. The diaphragm 192 is subjected on opposite sides, to the pressures in conduits 159 and 160 and is thus sensitive to changes in the position of the normal shock wave 182 and also to changes in the pressure behind the first oblique shock wave 180. The resulting force acts on the pivotal connection 190 at the opposite end of the beam 191 and the differential resultant is transmitted to the valve piston 185, the actual value of this differential resultant being adjustable by means of the movable fulcrum 194.

In operation it will be seen that if the third shock wave 182 moves forwards as a result of the conditions becoming sub-critical the pressure in conduit 159 will be increased, which results in the valve piston 185 moving downwardly and so causing the ram 47 to move to the right in Figure 9 to move the spill flaps 44 towards their open position as indicated in chain lines. Conversely a rearward movement of the shock wave 182 will cause a decrease in the pressure in conduit 159 and the valve 185 will move upwardly causing the flaps 44 to move towards their closed position. In practice some instability of the shock wave is bound to occur and the spill flaps 44 will be continuously in movement, due to the pressure changes or flutters in the moving shock pattern, tending at all times to maintain critical conditions in the air intake.

What we claim as our invention and desire to secure by Letters Patent is:

1. A compound ram jet turbo-rocket engine including an air intake at the forward end of the engine, a main combustion chamber to which fuel is supplied and an ex-

haust passage communicating with said combustion chamber and terminating in a propulsion nozzle, a rocket type gas generator, a turbine arranged to be driven by the gas generated, and a compressor coupled to the turbine, the compressor being arranged to receive air from the air intake and to deliver it to the main combustion chamber, and including a by-pass passage between the air intake and the main combustion chamber by-passing the working passages of the compressor and a valve mechanism arranged to control the flow of air through the by-pass passage independently of the air flow through the compressor.

2. A compound engine as claimed in claim 1, in which the compressor includes at least two rings of rotor blades and at least two rings of stator blades each downstream of one of the rotor blade rings, the downstream ring of stator blades being adjustable, each blade on a pivotal axis which is substantially radial to the axis of rotation of the compressor, and including adjusting mechanism arranged to pivot each blade of this downstream ring into one or the other of two operating positions, in one of which the blade ring operates at maximum efficiency as a normal stator blade ring, while in the other position the blades are positioned to give the maximum effective throat area between blades.

3. A compound engine as claimed in claim 1, in which the air intake comprises two series of circumferentially spaced flaps arranged to open or close apertures in the outer wall thereof, the first upstream series of flaps being pivotally mounted at their rear ends while the second downstream series are pivotally mounted at their forward ends, both series of flaps being arranged to open outwards.

4. A compound engine as claimed in claim 1, in which the compressor rotor and the turbine rotor are coupled to one another through a unidirectional clutch arranged to enable the compressor to free-wheel or windmill when the turbine is stationary.

5. A compound engine as claimed in claim 2, including a coupling interconnecting the said valve mechanism and the said blade adjusting mechanism to cause said adjusting mechanism to place the stator blades in the position of maximum effective throat area when the by-pass passage is opened by said valve mechanism.

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