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Design, Development, and History of The Oxygen/Hydrogen Engine RD-0120

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Abstract

The designers and manufacturers of launch vehicles in the United States are in search of new options in booster propulsion for easily maintained reusable launch systems. The RD-0120, designed by the Chemical Automatics Design Bureau (CADB) of Voronezh, Russia, is a high performance LH_2/LO_2 booster designed for the Energia family of Russian launch vehicles. The robust, low cost RD-0120 is an excellent choice for such reusable launch systems.

This discussion will cover engine system design and operating characteristics as well as component design and operating characteristics of the RD-0120. The scope of testing performed to qualify this engine for flight is included. Key manufacturing processes and production capabilities are also described herein.

Introduction

The RD-0120 is a modern, flight qualified propulsion system. Using the high energy liquid hydrogen and liquid oxygen propellants, at 106% of nominal thrust this engine develops 200 metric tons of thrust in vacuum with a specific impulse of 455.5 seconds. The RD-0120 is an operationally efficient engine, which does not require excessive time or manpower to prepare it for operation, whether before the first use or in between repeated uses. Producibility is a fundamental concern in this engine which is truly configured for serial production. Four engines each have operated flawlessly on the flights of two Energia launch vehicles.

The established industry team which can deliver the RD-0120 is Aerojet of Sacramento, California and the Chemical Automatics Design Bureau (CADB) of Voronezh, Russia. Aerojet and CADB have established a teaming agreement to cooperate in providing the RD-0120 to American launch vehicle manufacturers. At present, technology development is underway to support production of a version of the RD-0120 for the Reusable Launch Vehicle program. For this application an inventory of engines is available for timely use in an unmodified condition, or in a modified condition using the output of our technology development program.

Chemical Automatics Design Bureau

The Chemical Automatics Design Bureau (CADB) was formed in 1941, and is one of the leading enterprises in the Russian Federation in the field of liquid rocket engines, providing propulsion for rocket and aerospace systems. The leaders of the enterprise were: 1941-1965 Doctor of Technical Sciences S.A. Kosberg; 1965-1993 Academician A.D. Konopotov; 1993-present Doctor of Technical Sciences V.S. Rachuk. CADB has a highly qualified staff of scientists, designers, manufacturing personnel, technicians, and investigators. The enterprise consists of a designing organization, pilot production facility, hydraulic and gas dynamic laboratories, vibration stands, and 6 stands for engine hot fire tests. CADB has an excellent relationship with the Voronezh Mechanical Plant, leading scientific research institutes, and enterprises of rocket design.

Until 1954 CADB developed systems for the aircraft industry. Since 1954 CADB has developed more than 60 rocket engines and power systems for different applications, 30 of which have been put into serial production.

Range of parameters of engines

Thrust, metric tons	0.15-200
Specific impulse, seconds	up to 455
Combustion chamber pressure, kg/cm^2	up to 325
Pump discharge pressure, kg/cm^2	up to 900
Turbopump assembly rotational speed, rpm	up to 70,000
Preburner gas temperature, °K	up to 1100
Turbine power, hp	up to 126,000

Propellant combinations used in liquid rocket engines

Kerosene + Oxygen
Hydrogen + Oxygen
Nonsymetrical Dimethyl Hydrazine + Nitrogen Tetroxide

Liquid rocket engines developed by CADB are produced at six manufacturing plants. A special role is played by Voronezh Mechanical Plant (VMP), which is co-located with CADB in Voronezh. VMP develops manufacturing processes and is responsible for the production of liquid rocket engines according to the technical documentation of CADB. During the experimental testing stage VMP works together with CADB production, and then performs serial production itself thereafter.

RD-0120 Development

A recent success for CADB was the significant and complex task of developing the oxygen-hydrogen liquid rocket engine RD-0120, developed from 1976 to 1990. Some of the challenges resolved in this engine were multiple-use engine testing, multiple-use ignition systems, new manufacturing techniques, creation of an engine safety system, development of new measurement devices, and new techniques of measurement, inspection, and diagnostics of the engine.

The RD-0120 development history has demonstrated the robustness and reliability of this engine. Total engine firing duration of approximately 163,000 seconds has been accumulated while performing 793 engine ground tests. The engine qualification program utilized three engines which were tested up to thrust levels of 114% of nominal. A 14 engine reliability program was performed, with engines tested at thrust levels up to 109% of nominal. Of the engines tested, 39 engines had over 2000 seconds of duration accumulated, and one engine accumulated over 4000 seconds duration. This extensive testing has resulted in a demonstrated reliability for the RD-0120 of 0.992 with 90 % confidence. During the course of this comprehensive test program all development failures were successfully eliminated.

Energia Launch Vehicle

The RD-0120 is used in the second stage of the universal launch system 'Energia', which can launch the reusable orbital vehicle Buran and other space vehicles with a mass of approximately 100 metric tons. The requirements for operational life and reusability of the engine are a function of the peculiarities of the rocket configuration, where the engines are installed in the central core (see Figure 1), not on the orbital vehicle. Although the engine is expendable, the operational life requirement for the engine is 4 cycles and the demonstrated life is 6 cycles. This type of configuration allows the rocket to be universally capable of a payload up to 100 tons or an orbital spacecraft, both of which have been successfully demonstrated by flights of Energia on May 15, 1987 and November 15, 1988.

Engine Pneumohydraulic Scheme

During the design stage special attention was given to the choice of the basic engine scheme. To provide specific impulse in the required range it was accepted as necessary to utilize staged combustion, with the gas from the turbine outlet flowing to the main combustion chamber. The staged combustion scheme widely used in modern engines allows the potential for a specific impulse of 10-15 seconds higher than an open scheme.

The different variants of a basic staged combustion scheme investigated were:

- with two preburners supplying separate oxidizer and fuel turbopump assemblies;
- with one preburner supplying parallel turbines of separate oxidizer and fuel turbopump assemblies;
- with one preburner and series supply to the turbines of separate oxidizer and fuel turbopump assemblies;
- with one preburner supplying an inline turbopump assembly with back-to-back pumps.

In the scheme of an inline turbopump assembly, although the pump efficiency of the propellant supply system is lower than the other schemes, it is less difficult to conduct startup and to control the engine because the main turbopumps are directly linked. Additionally, the engine has a lower overall weight. With this simpler system cost is reduced and reliability is improved. Based on these factors, the scheme of an inline turbopump assembly was selected for the RD-0120 .

In order to prevent cavitation in the main turbopump assembly (TPA), the propellant pressures at the pump inlets were elevated over the saturated vapor pressure by incorporating into the engine scheme boost pump assemblies (BPA) which provide an inlet pressure of 24 kg/cm^2 to the main hydrogen pump and 44 kg/cm^2 to the main oxygen pump. The high pressures at the outlet of the boost pump assemblies allow the use of a coaxial shaft TPA with a high rotational speed which is traditional in liquid rocket engine design in Russia. Thus the turbine efficiency is increased, the design of a separating cavity between the oxidizer and the fuel is significantly simplified, and the helium flowrate for the separating cavity purging is decreased.

The pneumohydraulic system of the engine includes the following main assemblies and systems:

- propellant supply system
- combustion chamber
- preburner
- control system
- regulating system
- purging system
- ignition system
- tank pressurization systems
- gimbal
- flexible elements allowing gimballing

The RD-0120 schematic has the following unique features (see Figure 2);

- three stage hydrogen pump and two parallel stages of the oxygen pump to supply oxygen to the preburner and combustion chamber,
- chamber cooling uses approximately 22% of the hydrogen coming from the pump third stage outlet,
- hydraulic regulator controlling oxidizer flowrate to the preburner with electromechanical actuation for engine thrust level adjustments,
- hydraulic throttle on the oxygen chamber line is electromechanically actuated for engine mixture ratio adjustments,
- automatic hydraulic startup throttle on the chamber oxidizer line to insure the required mixture ratio change in the combustion chamber during startup.

The propellant supply system includes TPA, fuel BPA, and oxidizer BPA. The centrifugal fuel and oxidizer pumps' impellers of the TPA are located coaxially on a coupled shaft. The shaft is driven by an axial flow turbine. The turbine of the TPA is driven with gas from the preburner. The oxygen BPA has two stages with different rotational speed actuated by a hydraulic turbine. The hydraulic turbine used significantly simplifies the design compared to a gas driven turbine. The fuel BPA has one shaft actuated by a gas turbine which is operated by hydrogen that has cooled the combustion chamber.

The control system includes pneumatic valves, tanks for compressed helium storage, and electropneumatic valves (EPV). Pneumatic (main) valves allow the engine to startup and shutdown. These valves are controlled by supplying a voltage to the corresponding EPV. Helium from the tanks through the EPV is provided to the pneumatic valve controlling cavity, causing the pneumatic valve to open.

The regulation system includes regulator, throttle, and startup throttle. The regulator is responsible for the thrust regulation and ensures a controlled engine start in accordance with the vehicle control system commands. The throttle regulates propellant mixture ratio. The startup throttle ensures the proper mixture ratio change in combustion chamber during the engine start. With only two electromechanically actuated control valves the control of the engine is simplified, cost is reduced, and reliability is improved.

The purging system prevents the accumulation of a combustible mixture and displaces propellant from the internal engine cavities.

The ignition system includes electroplasma igniters and serves to ignite propellants in both the combustion chamber and the preburner.

Despite onetime usage in flight, the engine is designed for reusability. This reusability, as compared with past engines, is possible because of electropneumatic actuation of the fuel and oxidizer valves and the multi-use ignition system.

Helium for the oxidizer tank pressurization is heated in heat exchangers. Gaseous hydrogen for the fuel tank pressurization, hydraulic pump drive, and for the electrical power generating system is taken from the combustion chamber cooling system outlet.

The engine has the capability of a thrust component normal to the vehicle's axis by a ±11 degree angular displacement of the engine .

Engine Safety System

The engine has a system of safety diagnostic sensors. This safety system monitors the following operating parameters: gas temperature at the main turbine inlet, TPA, fuel & oxidizer BPAs rotational speed, combustion chamber ignition system gas temperature, oxidizer pump rotor axial displacement, pressure drop at the drainage cavities of the seal joint between the fuel and oxidizer pumps, and helium pressure in the preburner fuel valve control cavity. These parameters are used by the safety system in accordance with specially developed algorithms that enable effective monitoring not only of anomalies of these parameters, but also monitoring for anomalies of some of their rates of change with respect to time (see Figure 3). The relatively limited number of sensors being monitored by the safety system' allows the use of sophisticated algorithms which have resulted in a low number of falsely triggered engine shutdowns, yet protects the engine against true anomalies.

Main Engine Parameters for Nominal Mode (100% Thrust)

sea-level thrust, metric tons	147.6
vacuum thrust, metric tons	
100% thrust	190
106% thrust	200
thrust specific impulse, seconds	
sea-level	353.8±3
vacuum	455.5±3
propellant flowrate, kg/s	418
oxidizer flowrate, kg/s	358
hydrogen flow rate, kg/s	60
propellant mixture ratio	6±0.6
propellant temperature at the engine inlet during startup, K°	
oxidizer	80 -85
fuel	16 -20
propellant pressure at the engine inlet during startup, kg/cm^2	
oxidizer	8.3±0.5
fuel	3.1±0.4
combustion chamber pressure, kg/cm^2	210
nozzle area ratio	85.7
preburner pressure, kg/cm^2	408

Engine layout

The engine layout (see Figure 4 and 5) is designed in such a way that the combustion chamber is used as a platform for the other assemblies.

The TPA is connected with the combustion chamber head by a pair of gas supply lines that also contain helium heat exchangers. The preburner is mounted on the turbine housing. The BPAs are attached with brackets welded to the chamber, which has a system of stiffeners at the throat. A pair of brackets is welded to the chamber stiffeners for attachment of the engine gimballing actuators. Igniters are located on the combustion chamber and preburner heads.

A spherical gimbal bearing located at the combustion chamber head, together with the engine supply line flexible elements, enable the gimballing of the engine. The flexible elements of the supply lines are located upstream from the BPAs.

The lines and assemblies have universal separable/welded joints that can be assembled with flanges and conical seals or can be welded. During the early development stage the joints were primarily separable in order to disassemble the engine during defect detection and maintenance operations. Further development allowed a decrease in the number of separable joints which improved reliability and reduced the overall weight of the engine.

Cold assemblies have a polyurethane foam insulation coating with a thickness of 20 mm. The hot assemblies have specialized insulating cases.

Currently the "dry" weight of the engine is 3450 kg. However, an advanced approach has now been developed allowing a reduction in weight of approximately 150 kg.

Operational Cyclogram

See Figure 6 for the engine operational cyclogram.

Prior to startup the engine is chilled down. The engine chill down includes the following stages:

- Filling the engine while fueling the tanks;
- Chilling the engine is done by recirculation that results from difference of densities between the inlet lines and the recirculation lines. The flowrate at this time is:

fuel	0.16 - 0.35 kg/sec
oxidizer	0.5 - 0.9 kg/sec

- Helium introduced into the propellants raises the velocity of fluid in the recirculation line. The flowrate at this time is:

fuel	0.44 - 0.56 kg/sec
oxidizer	1.7 - 2.65 kg/sec

- The duration of fuel BPA slow spinning is approximately 30 seconds, using approximately 300 grams/sec helium. The fuel flowrate here is 2-2.5 kg/sec.

At ground conditions the chilling duration normally is:

for the fuel	approx. 30 minutes
for the oxidizer	approx. 40 minutes

Filling and chilling down the engine is accompanied by purging of the combustion chamber, oxidizer passages, and TPA interpropellant cavity.

Prior to startup the slow purging of the oxidizer passages is replaced by intense purging.

Engine startup begins with the fuel BPA high speed spinning and ignition system start. The ignition system start is monitored by the safety system which verifies normal operation before going to the next operation. Then the combustion chamber fuel valve opens and 0.6 sec later the oxidizer and fuel preburner valves and combustion chamber oxidizer valve open. This is followed by the ignition of propellants in the combustion chamber and the preburner. The engine requires approximately 0.6 sec to reach 25% of nominal thrust. When this low thrust level is reached the ignition system shuts down and intense purging of the ignition system oxidizer line starts. Regulator actuation causes the engine to increase thrust to the preliminary thrust level of approximately 50% of nominal. Then the intense spinning of fuel BPA is terminated. Simultaneous actuator and throttle re-adjustment insures the values of mixture ratio and chamber pressure are attained for full thrust (106%). After full thrust is reached and at the beginning of the vehicle ascent the engine is throttled down to as low as the 25% thrust level and this low thrust operation is maintained until the booster engines shut down. After the booster engines shut down the thrust is increased back to 106%. When operating at 106% thrust level, the vehicle control system may command adjustments of mixture ratio through the throttle.

Prior to shutdown the engine is re-adjusted to the final thrust of 50% for Energia or as low as 25% for other applications. During the engine shutdown the preburner oxidizer valve is closed first and the purging of combustion chamber and preburner starts. Then, the rest of the valves in the combustion chamber and preburner feed lines close in a predetermined sequence. The RD-0120 operates in flight for approximately 460 seconds.

Turbopump Assembly

The turbopump assembly (TPA) consists of the oxygen pump , hydrogen pump, and the turbine (see Figure 7). The hydrogen pump and the turbine share a single rotor and housing. The oxygen pump is a separate subassembly and is connected with the hydrogen pump shaft by a splined coupling.

Oxygen pump

The oxygen pump incorporates an integrated combustion chamber supply stage and a high pressure preburner stage operating in parallel. The oxygen pump rotor is subcritical. The double suction combustion chamber stage impeller is cast with an integral shaft. The preburner stage impeller is cast, with the five-bladed inducer welded to it.

Both stages use the same inlet manifold. Oxygen for the second side of the double suction impeller of the combustion chamber stage as well as for the preburner stage is supplied by four passages through each of the respective discharge volutes. These supply passages are fabricated by casting and are welded to the discharge volutes

On the end of the preburner stage is a rotor axial thrust balancing device to balance the axial forces of the rotor. The design of this thrust balancing device is traditional for CADB. Around the impeller disk is located a clearance type seal and beneath this seal is a regulating passage. Flow of oxygen through this regulating passage creates a differential pressure, thus balancing the axial loads on the rotor .

The impellers are sealed using shroud seals. The oxygen pump and housing external joints incorporate metallic seals of a small cross section. The sealing surfaces of these seals have a fluorocarbon coating.

Hydrogen pump

The three stage hydrogen pump consists of three impellers with identical hydraulic profiles, two crossovers with identical flowpaths placed after the first and the second stage impellers, and a double discharge volute third stage. The hydrogen pump/turbine rotor is supercritical, operating at nominal conditions between the second and third critical speeds.

The three identical impellers of the hydrogen pump are manufactured using a HIP (hot isostatic pressure) process to consolidate granules of titanium alloy.

The seals between stages and the seals of the impeller inlets utilize floating ring shroud seals. The impeller disks have clearance type seals.

Axial force is balanced by a rotor axial thrust balancing device, which is located on the back side of the third stage impeller disk.

Turbine

The two-stage turbine consists of a turbine housing with an inlet manifold, an outlet spherical manifold with two outlet ducts, first and second stage nozzles, and first and second stage turbine rotors. The gas path of the turbine is separated from the pump by a flow guide welded to the double discharge volute of the housing.

The turbine blades are manufactured from a solid blank integral with the turbine disk. The blades are shrouded to minimize gas leakage past the turbine and to increase the blade dynamic strength. The turbine rotor is fabricated from a blank formed from high strength nickel based alloy granules using the process of hot isostatic pressure. The blades are formed by electrical discharge machining

The first stage nozzle is welded to the inlet manifold housing. To enable assembly, the second stage nozzle is fabricated in twq parts and attached to the housing with screws.

Turbine rotor seals and the seals between stages are of the labyrinth type with metalloceramic inserts in the housing.

The turbine rotors are connected to the shaft by radial pins, providing radial and axial alignment and torque transmission.

The inlet manifold housing and the outlet spherical manifold are welded together and also to the pump outlet. This creates a single housing for the hydrogen pump and the turbine stator. The pump housing is comprised of two sections with internal flange joints and external low pressure actuated flange joint. The seals of the joints are made with multiprofiled metallic seals. This pump and turbine housing configuration enables the TPA to be overhauled separately from the engine. There is no need to disassemble the turbine housing and preburner welded to it, two gas supply lines or hydrogen pump outlet manifold.

During assembly, torquing of the screws attaching the second stage nozzle, the flanged pumps joints, and oxygen pump preburner stage impeller attachment screws are checked ultrasonically.

TPA Bearings

Radial ball bearings support the TPA rotors. The bearings have a DN (peripheral speed) of shaft diameter x speed equal to $1.28 - 1.44 \times 10^6$ mm - rpm. The bearings of the hydrogen pump/turbine rotor are cooled with hydrogen, and the bearings of the oxygen pump are cooled with oxygen. The bearing rings are coated to improve the life of the bearings. In a hydrogen environment lead is typically used, and in an oxygen environment silver is typically used for an added level of protection from ignition. Axial thrust balancing, proper bearing preload during assembly, effective rotor dynamics damping, and high speed rotor balancing insure bearing reliability.

TPA Rotor Dynamics

The TPA rotors are designed to minimize dynamic loads. To further reduce loads, rotor balancing is performed during the assembly of the rotor components. The effectiveness of the rotor balancing is verified at a high speed rotor spin balancing facility. By both designing the rotors for minimum dynamic loads and high speed rotor balancing the reliable operation of the rotor is insured.

The hydrogen pump rotor has low stiffness dampers with a high damping capability that minimizes the loading and rotor displacement for normal operating modes and in cases where the design maximum rotational speed is exceeded.

Fuel Boost Pump Assembly

The fuel boost pump assembly, or fuel BPA, (see figure 8) utilizes a centrifugal inducer consisting of an axial-diagonal mixed flow inducer and a centrifugal impeller disk. Between the inducer and the impeller disk is an alignment device. The two-stage, axial reaction, partial admission turbine is driven by hydrogen gas. The fuel BPA rotor is supported by two radial ball bearings and operates subcritically.

The turbine housing is welded. The gas inlet manifold has 4 inlets (2 for the helium start system supply and 2 for the gaseous hydrogen supply from the combustion chamber), symmetrically located in a circle.

Sealing includes:

- seal cavity separating the turbine gas cavity from the pump cavity
- lift off seal (to allow engine chilldown)
- impeller high pressure cavity seal
- housing joint seal

The seal cavity separating the gas cavity from the pump cavity is supplied with hydrogen from the outlet of the main fuel pump. The seal to the pump side is provided by a floating ring seal, to the turbine side the seal is provided by a clearance type seal.

A lift off seal was incorporated into the fuel BPA to reduce the propellant leakage from the pump cavity to the turbine cavity when the engine is stopped. This lift off seal automatically opens when the fuel BPA rotor begins to rotate and remains open while the rotor is rotating.

The joints between the housing sections utilize metallic ring seals.

A fluid axial thrust balancing device controls end loads.

Oxidizer BPA

The oxidizer BPA (see figure 9) is a two stage axial pump actuated by two coaxial hydraulic turbines. The two pump stages have different rotational speeds. The first is a low speed stage with an inducer actuated by a single stage turbine on the inner rotor, the other is a high speed stage with an impeller actuated by a two stage turbine on the outer rotor.

Each of the two rotors are supported by two radial ball bearings and operate subcritically.

Balancing of axial force in the high speed stage during transient modes is provided by an axial thrust balancing device.

Preburner

The preburner (see figure 10) provides hydrogen-rich gas to the TPA turbine which is then secondarily combusted in the combustion chamber.

The preburner is designed with a single zone of mixing. The majority of propellant is injected from the mixing head. The single zone scheme eliminates a high temperature zone of combustion and therefore the preburner chamber is more easily cooled. The single zone scheme also allows significant design simplification of the preburner.

The mixing head incorporates two types of bipropellant injection elements: shear coax and swirl coax The injectors of the peripheral row are shear coax. The remainder of the injectors are swirl coax with tangential holes. Such an injector arrangement provides uniform combustion within the preburner and reduces the possibility for the oxidizer to come in contact with the preburner wall.

To prevent longitudinal mode instabilities and to provide the required temperature uniformity of the preburner gas, a spherical lattice was incorporated into the design. This lattice is a hemispherical shell with numerous holes, providing a flow resistance and creating turbulence.

A plasma arc ignition system ignites the combustion mixture in the preburner.

Combustion Chamber

The combustion chamber (see Figure 11) is designed as an inseparable welded-brazed assembly. and consists of the following subassemblies: gas manifold, mixing head, chamber housing, upper nozzle, middle nozzle, lower nozzle, stiffeners, propellants supply ducts, and igniter.

The gas manifold includes a housing, bottom, and inlet tubes. The gas manifold has a flange that attaches the chamber to the engine gimballing system. At the bottom of the gas manifold is a boss with a hole in the center to attach the igniter.

The mixing head has 444 injection elements of the shear coax type. The main injector consists of an upper and lower section. The sections are connected by welding. They are attached at the center of the main injector by a tube having steps on its internal surface to center the igniter gas tube.

Based on analytical results the scheme of axial supply of preburner gas and radial supply of oxygen to the mixing head was selected. When compared to the case of radial preburner gas flow and axial oxygen flow, this configuration offers the following advantages:

- the injector elements may be shorter in length, and of equal length, and therefore cost less to manufacture
- better preburner gas mass distribution to the injection elements, leading to better mixture ratio control, and ultimately longer life and higher reliability for combustion chamber components
- smaller and higher strength configuration, therefore lower weight

The chamber housing is a welded/brazed assembly primarily consisting of an external jacket, an internal liner, and a hydrogen outlet manifold The chamber coolant scheme is optimized to achieve the best hydrogen properties for cooling at the chamber throat. Hydrogen coolant enters the upper nozzle, flows upward through the chamber housing, exits near the mixing head, is transferred back to the upper nozzle through external ducts, and flows down through all the nozzle sections before exiting the chamber.

The nozzle of the RD-0120 combustion chamber is of a brazed-milled construction, consisting of three sections (upper, middle, and lower). Each nozzle section has inner and outer shells which are fabricated and inspected separately. The inner shell is slotted to form coolant passages and the outer shell forms the outer wall of the nozzle sections. After the braze alloy is applied the shells are assembled using specialized procedures and then brazed. Following the braze process the sections are inspected and prepared for final assembly to each other by welding. After welding the final inspection of the nozzle is performed. Stiffeners are incorporated into the design of the lower nozzle to insure the required nozzle structural stability. This type of design of the nozzle sections has excellent cooling characteristics while at the same time producing a lightweight, strong structure.

Analysis, cold acoustic tests, and subscale hot fire tests were performed before full scale hot fire tests to insure low frequency and high frequency stability of combustion for the selected design of the combustion chamber and its injection elements. The results of this testing methodology permit the engine to operate in a stable mode without baffles, acoustic cavities, or other similar stability devices in the combustion chamber.

A plasma arc ignition system identical to that in the preburner except for the length of the hot gas tube ignites the combustion mixture in the combustion chamber.

Automatic Control Assemblies

RD-0120 automatic control assemblies form the primary elements of the control system, regulation system, and purging system.

The control system serves to insure propellant supply to the engine's feed lines during chilldown, startup, operation at nominal mode, and termination of supply during shutdown. The control system includes pneumatic valves (see Figure 12), electropneumatic valves, check valves, and containers for compressed gas storage.

The regulation system serves to start the engine, to drive the engine to the required thrust mode, maintain the required mode, and planned engine shutdown.

The regulation system main assemblies are:

- regulator with electrical actuator
- throttle, with electrical actuator
- startup throttle
- automatic nozzle coolant valve

By dividing the requirements for on/off functions and flow regulating functions between separate systems of regulation and control, both systems can be optimized for these very different design requirements. The division of these functions contributes to the high reliability and controllability of the RD-0120.

The purging system displaces propellants from the cavities of the engine and its assemblies during engine chilldown, start, and shutdown. The purging system includes a pressure regulator, electropneumatic valves, check valves, safety valve, and containers for compressed gas storage.

Technical Engine Maintenance

In order to maintain continued operability of the engine during its operation and storage life a group of procedures for technical maintenance was formed, the main element of which is a system of technical diagnostics.

The system of technical diagnostics includes:

- checkout by nondestructive methods of the technical state of engine elements and systems during the stages of fabrication, before and after operation;
- diagnostics of test parameters;
- analysis of technical state in order to determine possibility of further engine use before maintenance or repair is required.

Checkout of the technical state is conducted by specialists on the engine in 4-5 working shifts. The personnel of each shift is composed of an engineer and three technicians.

Engine production

By the middle of 1980 Voronezh Mechanical Plant and CADB had formed the production and testing base for fabrication of the RD-0120 engine, including mechanical workshops for assembling the combustion chambers and propellant supply systems, a workshop of general assembling, facilities for electrochemical processing, electron beam welding of the chamber, perforation of the main mixing head faceplate, dynamic balancing of rotors under conditions similar to those experienced during operation, application of galvanic-chemical heat resistant coatings, casting of heat resistant alloys, and others.

CADB has a serial production base for powder metallurgy to fabricate impeller blanks and turbine disks made of titanium and heat resistant alloys. A facility exists for hydrogasdynamic testing to conduct investigations and tests of assemblies under conditions similar to those experienced during operation.

Advanced manufacturing processes have been developed:

- fabrication of the nozzle shell without weld joints and of large size using an explosive forming method;
- fabrication of the braze-milled nozzles with diameters to 2400mm;
- differential electrochemical processing of the chamber nozzle shells;
- testing of bearings in liquid hydrogen and oxygen;
- ultrasonic inspection of fastener preload for joints using fasteners M10-M18mm.

More than 20 unique manufacturing processes not existing before in the aerospace industry have been developed.

The unique parameters of the operation of the engine required creation and testing of new materials such as new types of stainless steel, heat resistant alloys, composite antifriction materials, thermal insulation materials, and special brazes for joining metal components. Stainless steel sheet with the width of 2800 mm, pipes of heat resistant alloy with internal polished surfaces, and materials for cryogenic thermal insulation were all developed with the help of research-scientific institutes and put into production

During engine development the production capability was established for special assemblies and units, which include special bearings, multilayer bellows of large dimensions (diameters to 360mm), ignition assemblies, valve actuators, sensors for telemetric measurements, and an engine safety system

Procurement of raw materials and purchased parts was performed in cooperation with other enterprises of the former USSR.

In total there are approximately 10300 technological processes of mechanical processing, metallurgy, welding, brazing, assembling, testing and checkout required to produce the RD-0120 . From this amount of processes 100 technological processes are performed by CADB, the remainder being performed by VMP.

Future Applications

While retaining the majority of its components, the RD-0120 can be used as the basis for engines using methane/oxygen or the tripropellant combination of hydrogen/oxygen/kerosene[1,2,3] (see Figure 13). A program to develop critical technology for a tripropellant engine based on the RD-0120 is in progress. The tripropellant engine is a candidate for main propulsion of a Reusable Launch Vehicle (RLV).

A plan and methodology exists for improving the life of the RD-0120[3,4]. Increased life beyond that of modern existing engines is a key requirement for a RLV.

A modification of the RD-0120 is available with increased thrust and specific impulse at sea level of approximately 10%[3]. These increases are attained by use of an expendable nozzle insert which is released at a predetermined height from the rocket.

Concluding Remarks

The RD-0120 was intended for an expendable launch vehicle application, but due to requirement for multiple tests at full thrust before a flight the engine has an effective degree of reusability. This, coupled with the engine's requirement for a minimal amount of maintenance between firings, has resulted in an engine which is a strong baseline for development into an evolutionary engine of enhanced reusability and operability. This flight-proven engine has undergone extensive testing and is a mature, robust design. The experienced team of CADB and Aerojet stands behind the RD-0120 and is prepared to undertake the task of developing an adapted version of the RD-0120 for the Reusable Launch Vehicle (RLV). Personnel, engines, and facilities are available to support a rapid and direct path to a vehicle first flight.

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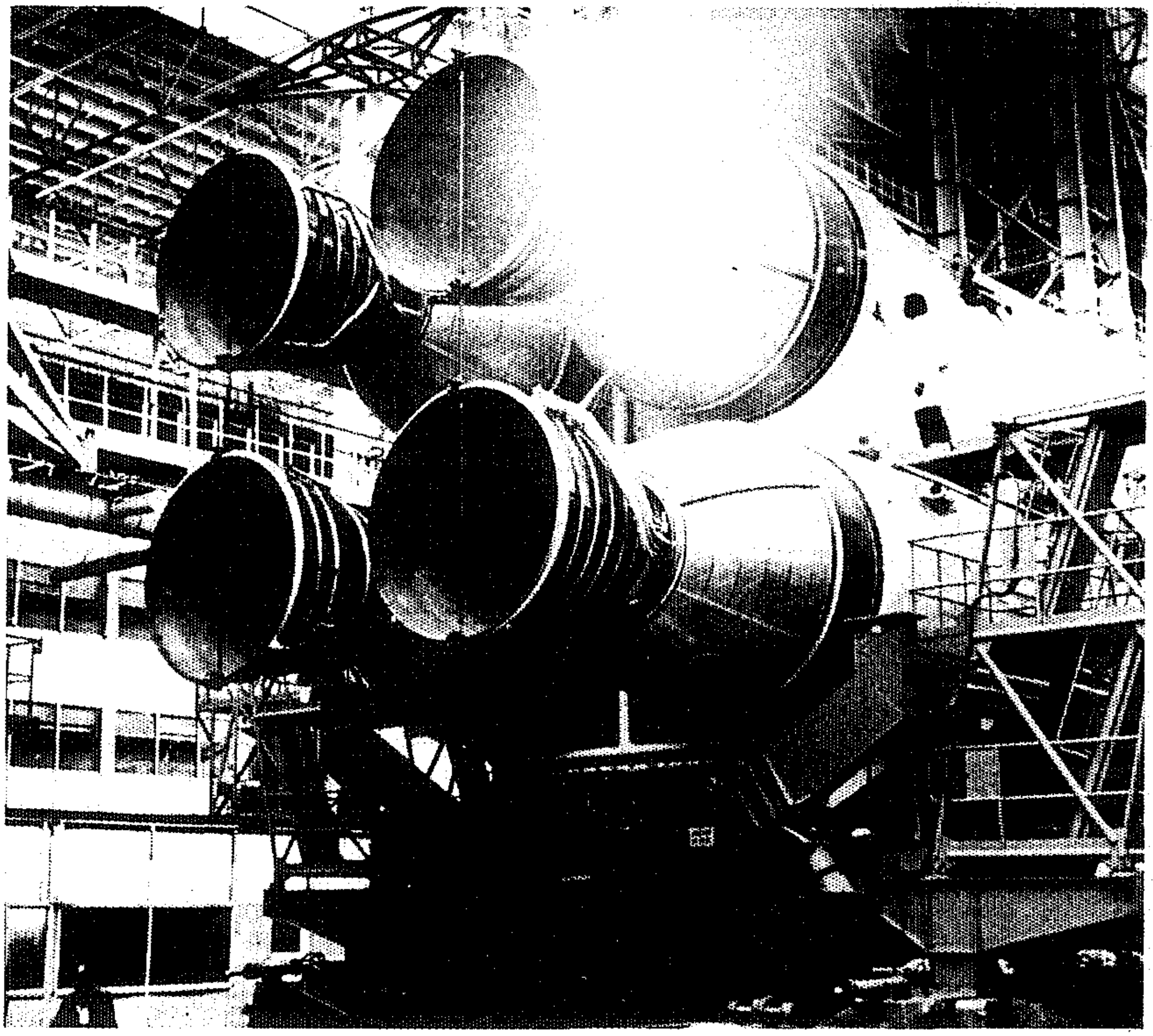

Fig. 1. The RD-0120 Is the Core Propulsion for the Energia Launcher

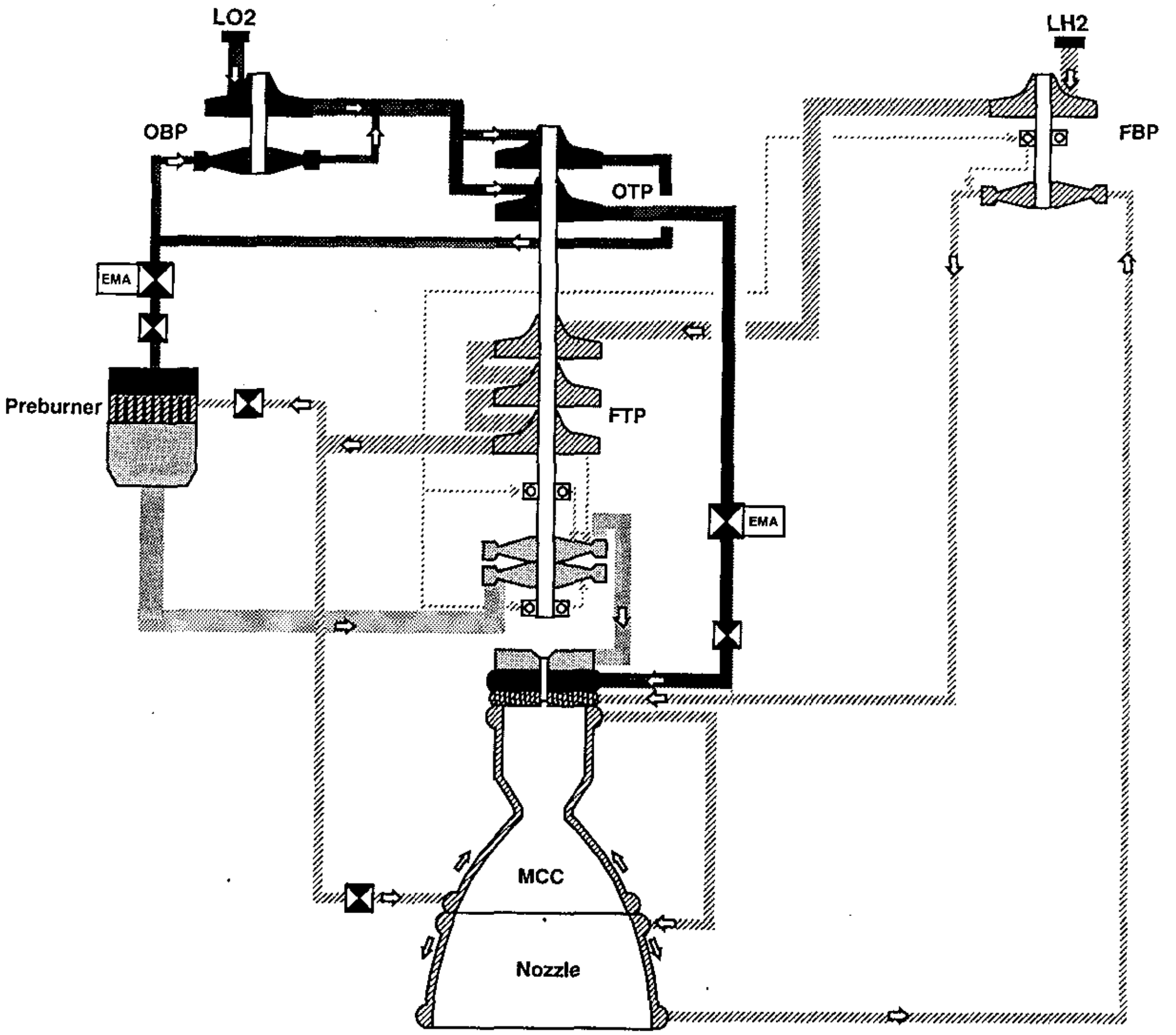

Fig. 2. RD-0120 Engine Schematic

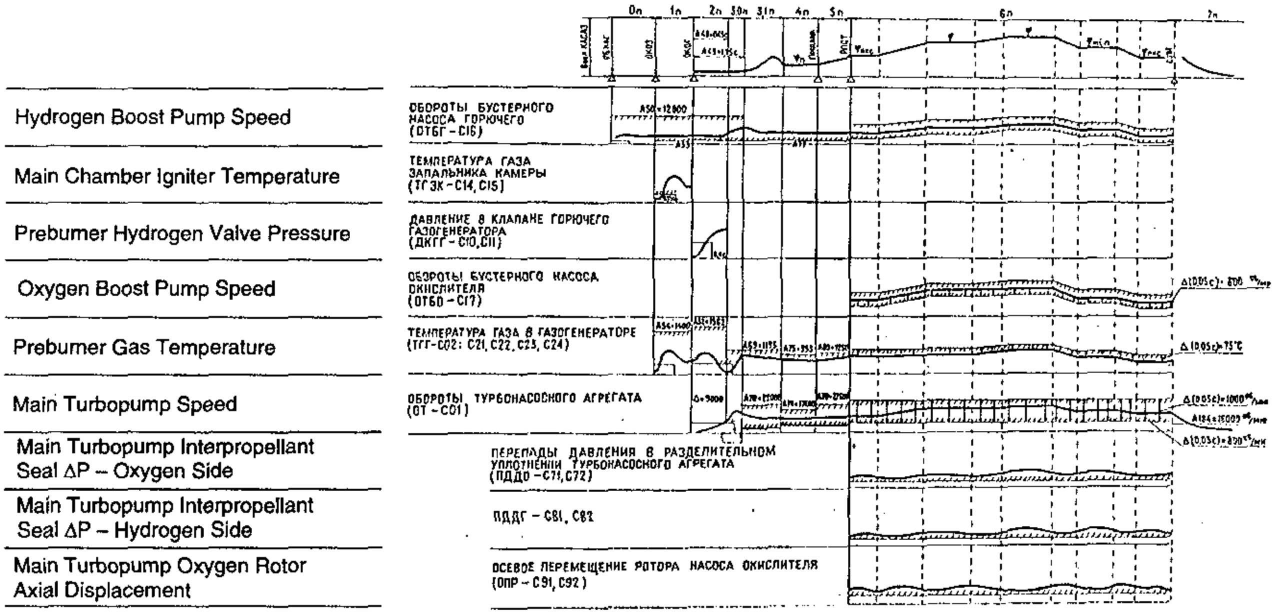

Fig. 3. RD-0120 Protection System Limits

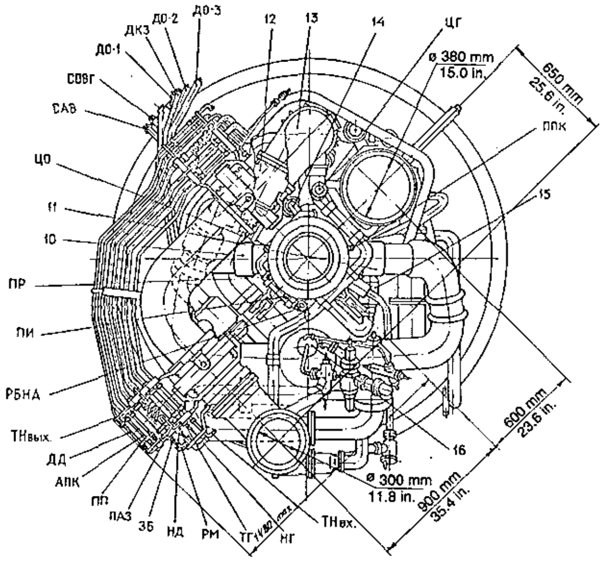

Fig. 4. RD-0120 Envelope and Major Interfaces

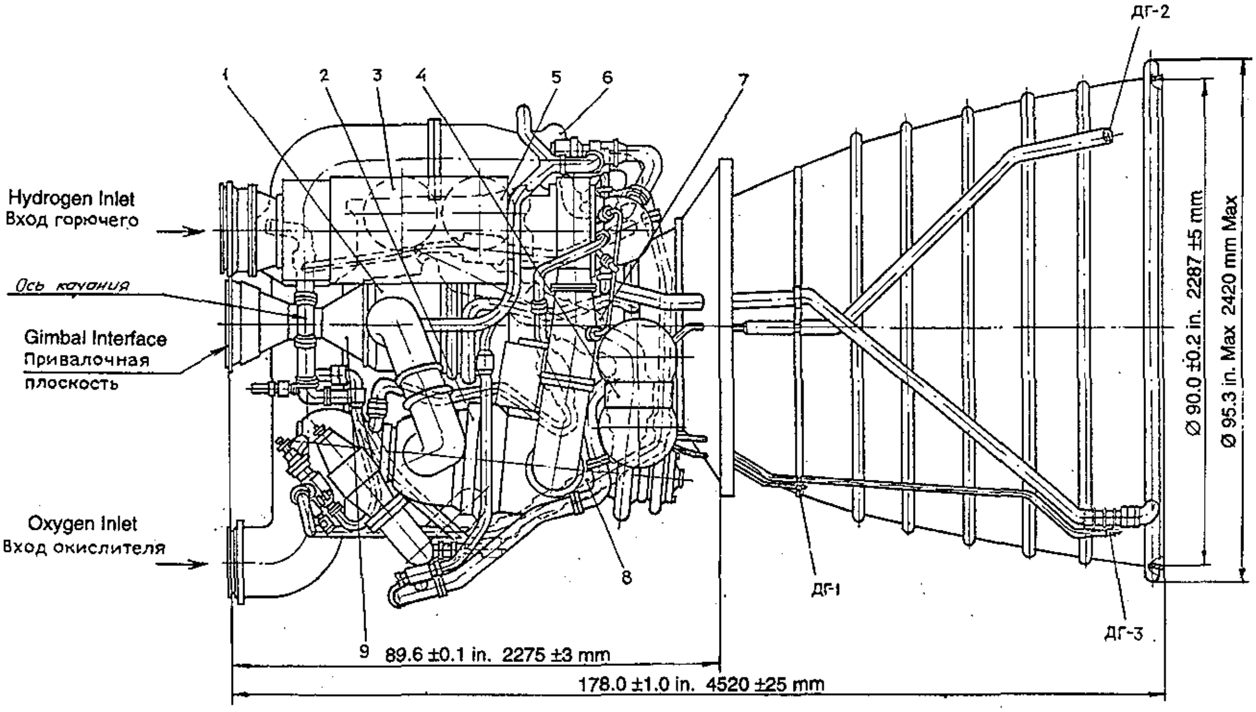

Fig. 5. RD-0120 Envelope and Major Interfaces

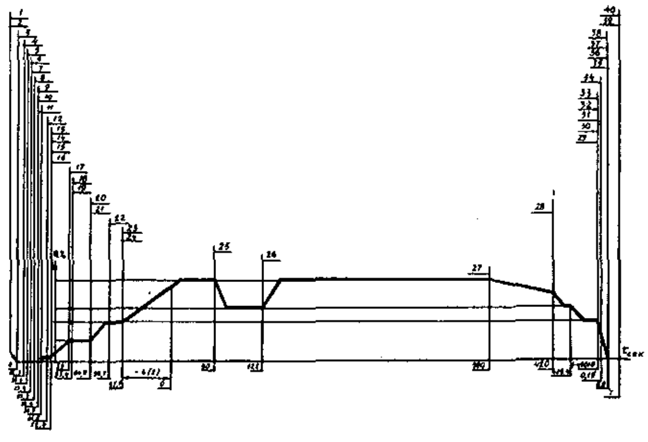

Fig. 6. RD-0120 Engine Operation Sequence

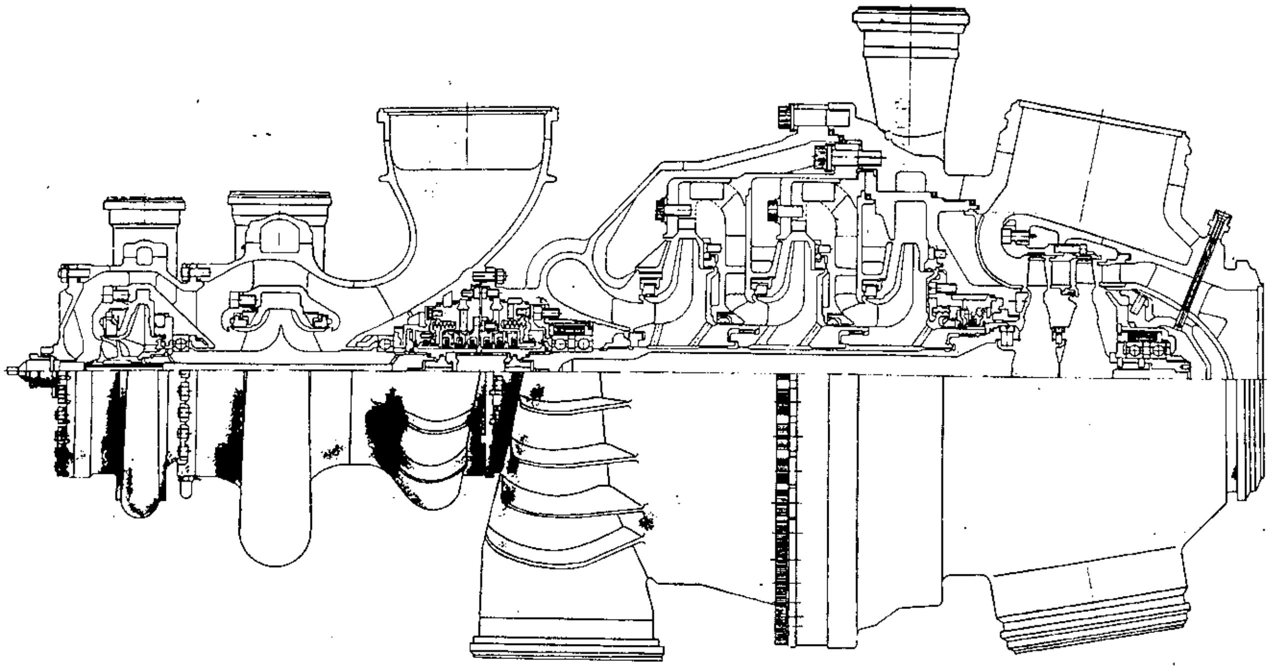

Fig. 7. Turbopump

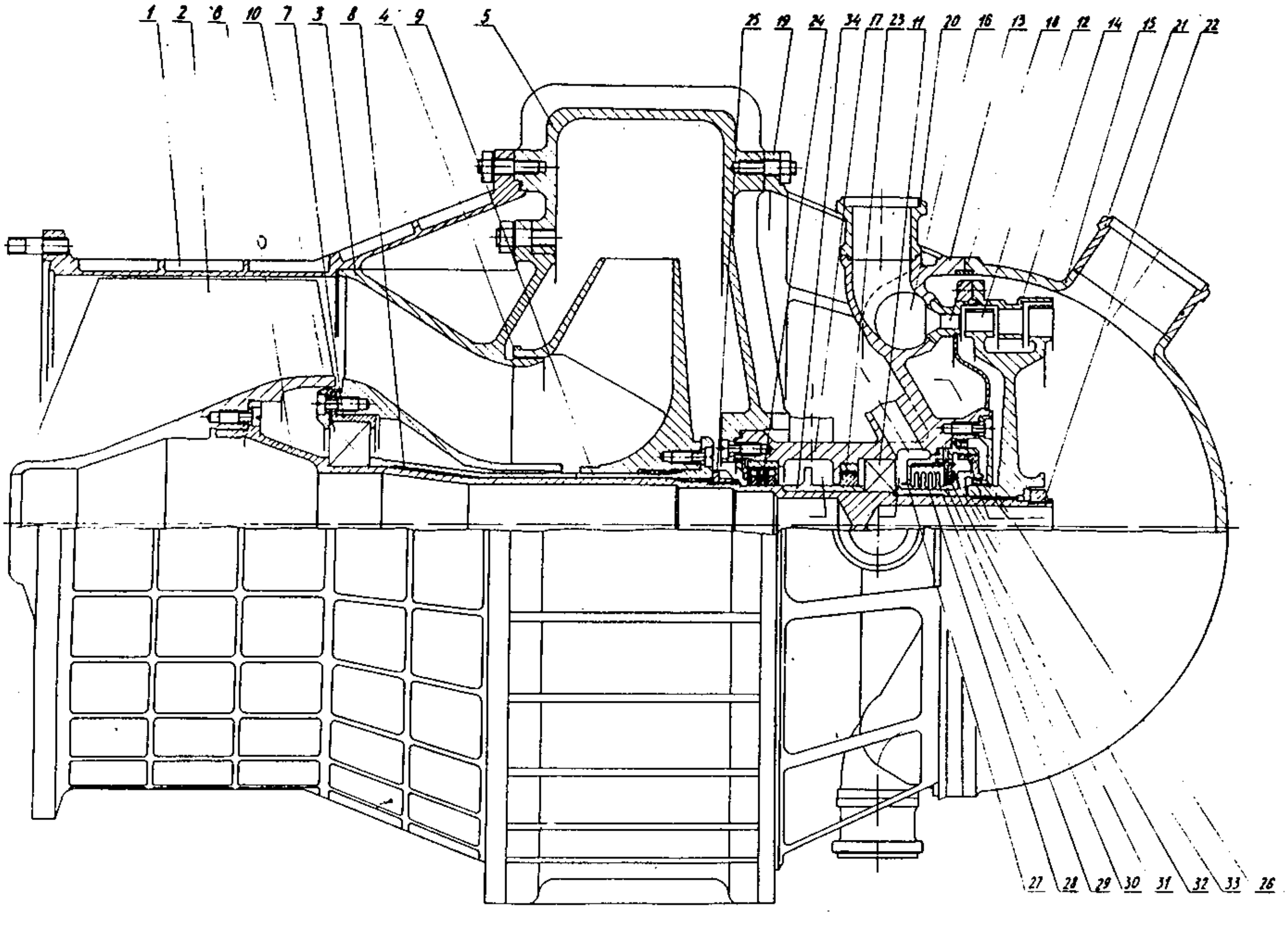

Fig. 8. Hydrogen Boost Pump

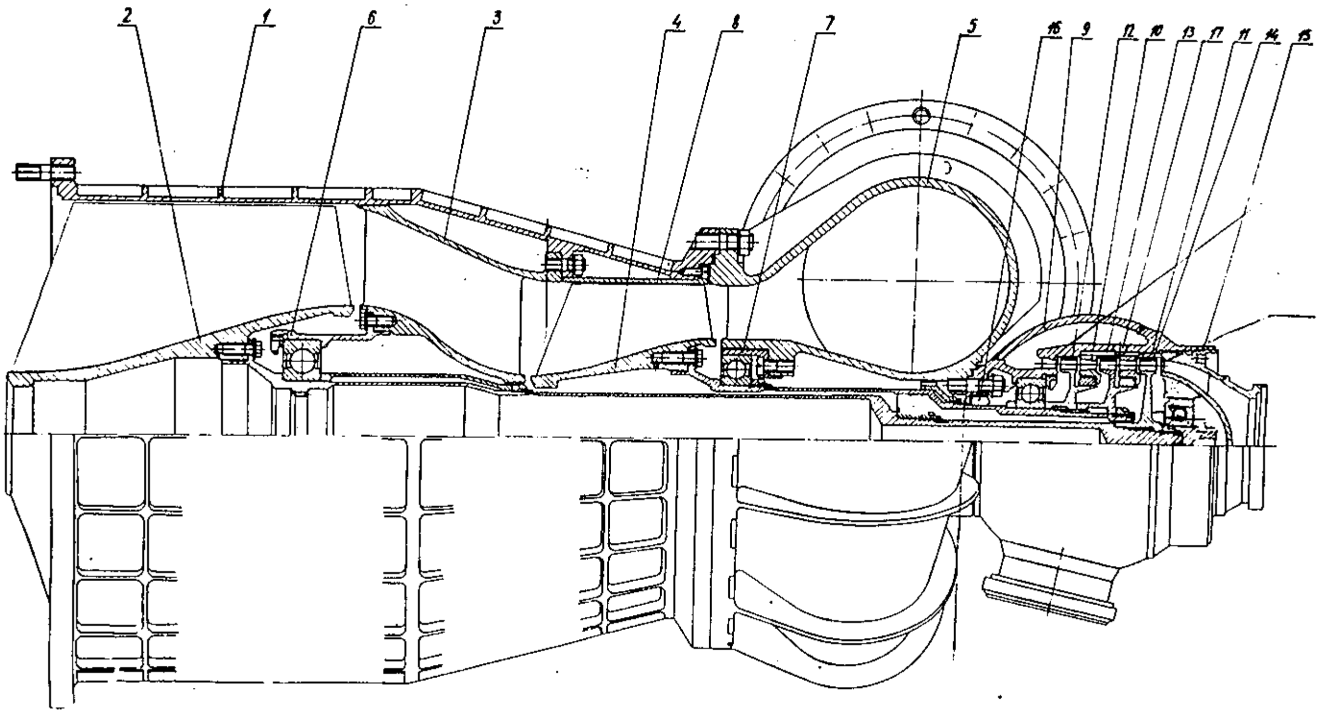

Fig. 9. Oxygen Boost Pump

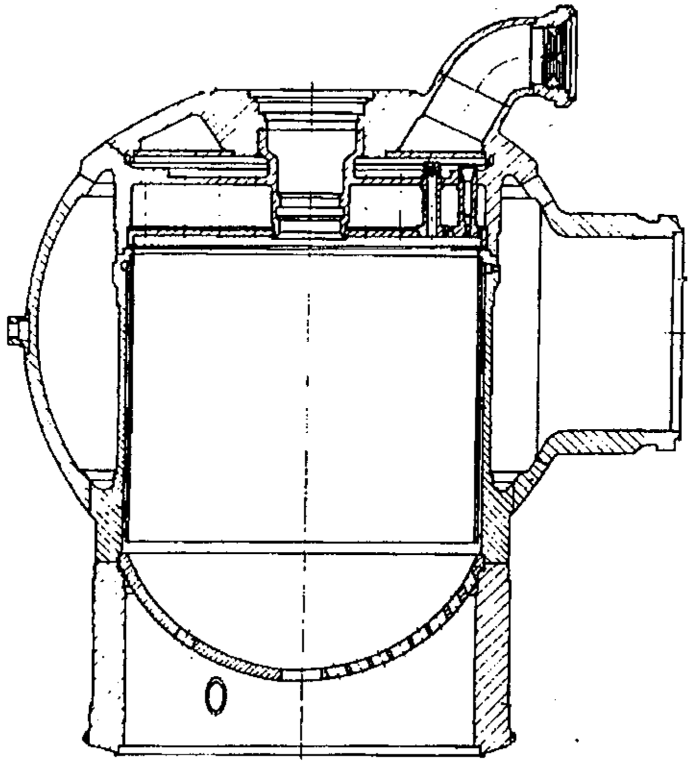

Fig. 10. Preburner Configuration

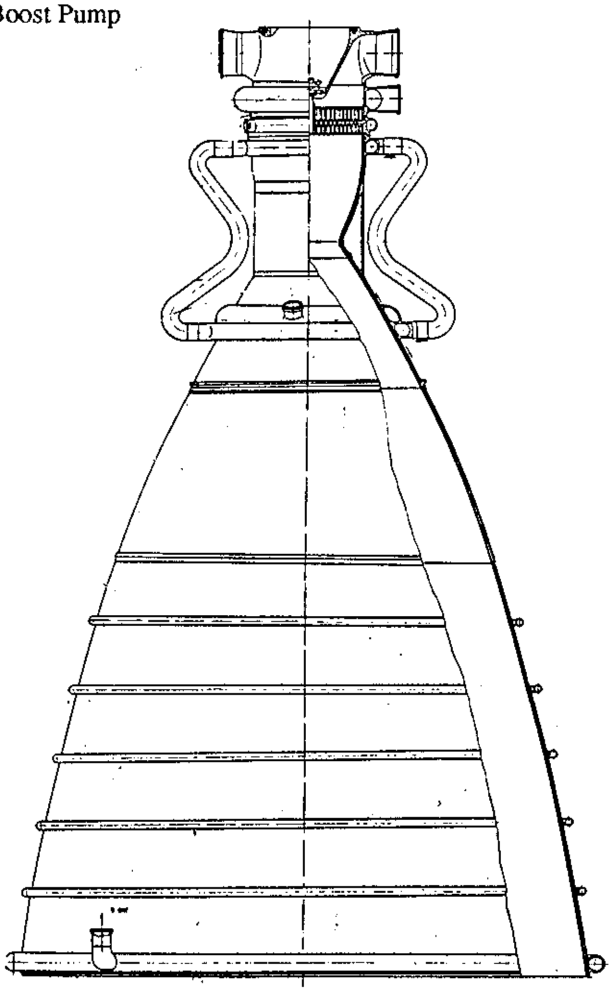

Fig. 11. Thrust Chamber Configuration

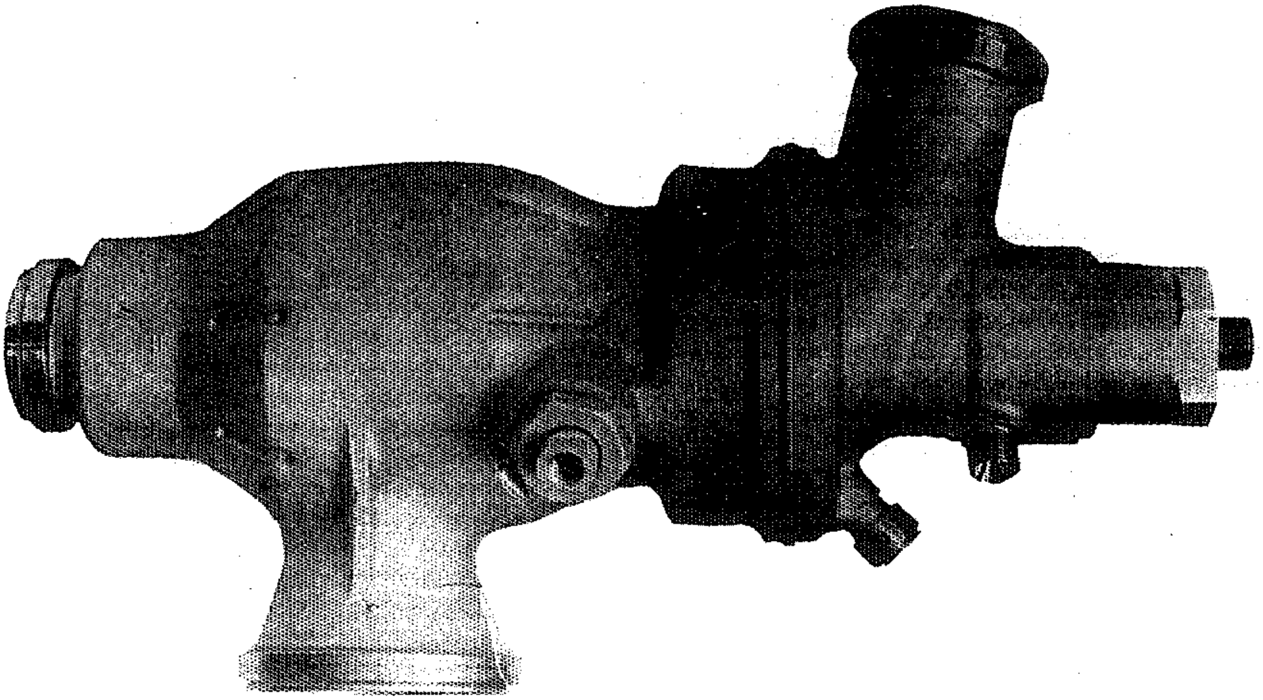

Fig. 12. Preburner Oxygen Valve

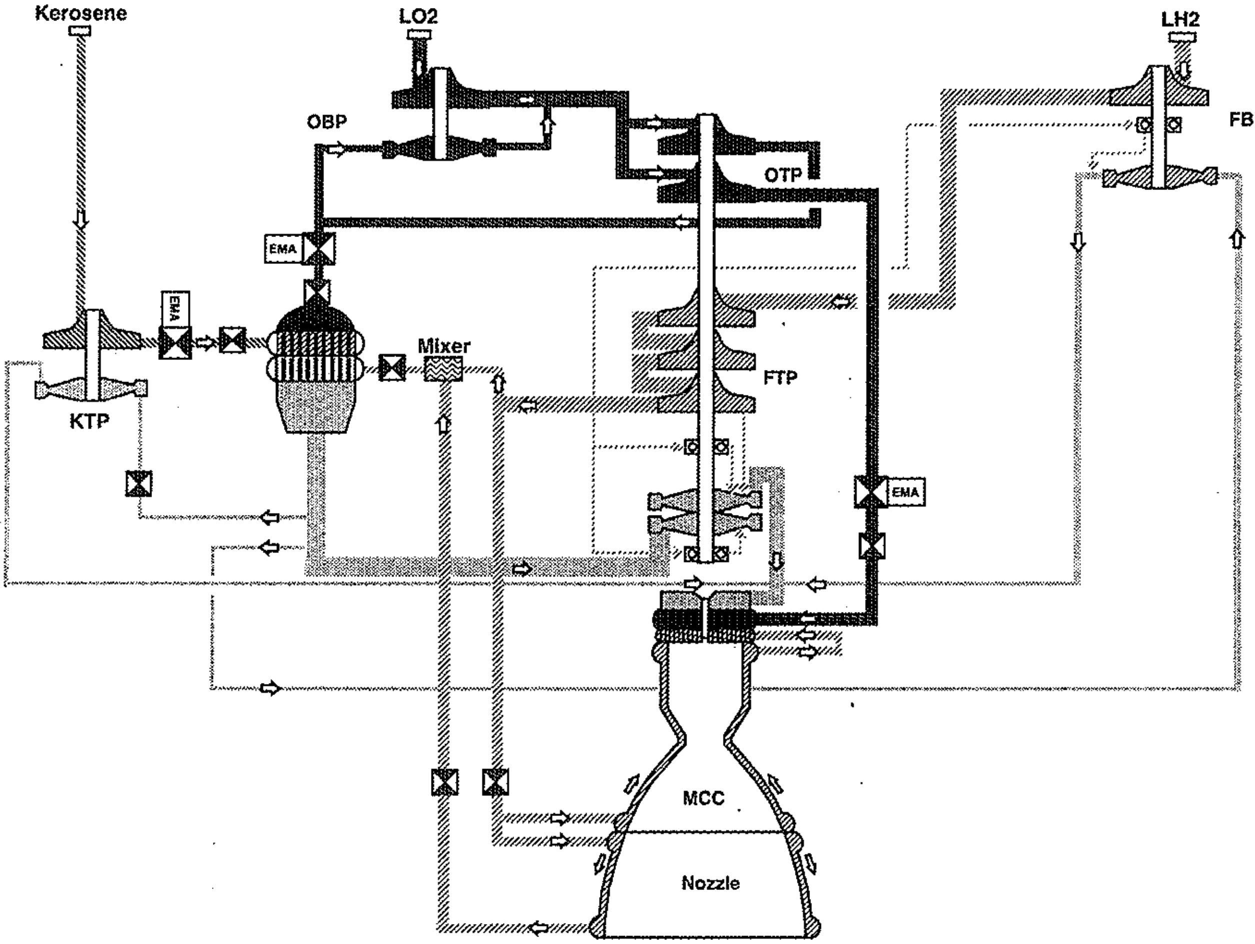

Fig. 13. RD-0120TF Engine Schematic