TECHNOLOGY FOR THE DEVELOPMENT OF A GASEOUS HYDROGEN - GASEOUS OXYGEN APS ENGINE FOR THE SPACE SHUTTLE

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1. Abstract

The Messerschmitt-Bölkow-Blohm Company (MBB) has sufficient technical background for the development of a GH_2/GO_2-APS-engine for the Space-Shuttle program.

MBB has been conducting rocket engine development work with cryogenic propellants since 1959. Since that time essentially the following rocket engines have been developed and/or tested:

66-lb	sea-level-thrust GH_2/LF_2 experimental thrust chambers for establishment of fluorine technology,
1,100-lb	vacuum-thrust LH_2/LF_2 engine (under development since 1968),
66-lb	vacuum-thrust LH_2/LO_2 engine (flight prototype) with restart capability and an effective vacuum specific impulse of 415 sec,
30,000-lb	sea level thrust LH_2/LO_2 extreme high pressure experimental engine (tested at Rocketdyne's Reno facility).

As a result of this work, MBB has the experience and technological capability to produce thrust chambers of various designs, injector heads and engine valves and the capability to test them. This experience can be utilized by MBB for the development of a Space Shuttle APS engine.

The above mentioned 1,100-lb engine falls into the presently discussed performance category for a high pressure Space

Shuttle APS engine. Using the same chamber geometry of the 1,100-lb engine, running it with GH_2/GO_2 at a chamber pressure of 150 psia and at a mixture ratio of 4, it would produce a vacuum thrust of 1,500 lbs with an area-ratio-30 nozzle. With constant engine geometry and varying chamber pressure it can also be adjusted to other thrust levels within a wide range. Currently a sea-level demonstration engine of this type is under development in order to demonstrate its ability of safe ignition, regenerative cooling and high performance. Engine valves shall also be developed.
Testing will be done at MBB's Ottobrunn facilities.

2. Introduction

The Messerschmitt-Bölkow-Blohm Company (MBB) has sufficient technical background for the development of a GH_2/GO_2-APS-engine for the Space Shuttle program. MBB has been conducting rocket engine development work with cryogenic propellants since 1959. Since that time, LOX/Kerosene, H_2/F_2 and H_2/O_2 engines as well as storable propellant engines have been developed and/or tested.
The following discussion will deal to a minor extent with the H_2/F_2-engine work but mainly the H_2/O_2-engine work will be discussed.

3. Test and Propellant Facilities

At first a few words should be said about MBB's test and propellant facilities for cryogenic propellants that were constructed in the early 60's. The first slide (1) shows the complete complex of these facilities at MBB's Ottobrunn plant near Munich. It comprises a double test stand in the foreground with a small scrubbing tower for toxic gases, and a small altitude simulation chamber, a fluorine storage and liquefaction plant in the left background, and a hydrogen liquefaction plant in the right background. The test stands are designed for handling thrusts up to 10,000 lbs. The propellant feed systems presently installed are designed for testing engines up to 2,000 lbs.

All engine test sequences are automatically controlled by a seperate control center.

Data recording is done by analog multi-channel oscillographs and by digital data processing equipment.

4. Small H_2/F_2-Experimental Engines

In the mid 60's, MBB conducted some experimental work with small GH_2/LF_2-engines with a nominal sea-level thrust of 66 lbs. The engines were heat sink and water cooled chambers of different chamber lengths and were run with chamber pressures up to 150 psia and mixture ratios ranging from 5 to 14. On the one hand, this experimental program was aimed to gain the full experience of the safe handling of gaseous and liquid fluorine on rocket test stands.

On the other hand, the program was aimed to give practical experience with the measurement problems in a fluorine system, with the performance behavior of the H_2/F_2-propellant system, and of different propellant injection processes.

Slides 2 and 3 show respectively, a test run of a water cooled GH_2/LF_2-experimental engine, and the coaxial-jet type injector as an example of the injectors tested. The tested injector types were the coaxial-jet injector, a pentad configuration and an unlike impinging jet configuration.

5. The 1,100-lb LH_2/LF_2-Engine

Due to the experience with the small experimental H_2/F_2-engines and with the other cryogenic engines to be described later, MBB was awarded a contract for the development of a LH_2/LF_2 engine with a vacuum thrust of 1,100 lbs. This engine under development since 1968, has a nominal chamber pressure of 107 psia and a nominal mixture ratio of 10.

In the beginning of the development of this engine, sea level tests with heat-sink and water-cooled chambers and with three different types of injectors were performed.

Both chamber types were installed with numerous thermocouples in order to gain the actual values of the combustion gasside film coefficient for the proper design of the regeneratively cooled chamber. The testing of the three different injector configurations with some modifications on each of them and with different chamber lengths, chamber pressures and mixture ratios, was aimed to find the most optimum injector design with respect to performance and chamber wall heat load.

Slides 4 and 5 show respectively, a segmented heat-sink chamber and the water cooled chamber with 7 individual water jackets. Slides 6 through 8 show some test runs of the heat-sink chambers.

The three injectors tested, a coaxial-jet type with solid and porous face plate, a pentad type, and a splash-plate type are shown on slides 9 through 12, respectively.

The best c*-efficiency, being 98 % compared with the equilibrium-c* at design point, was achieved with the coaxial-jet injector at a characteristic chamber length of 0,85 m (33.5 in).

The development of the 1,100-lb H_2/F_2-engine also includes the development of its main propellant valves. As an example of this development work slide 13 shows a test version of the pneumatically operated liquid fluorine valve, whereas slide 14 shows its electromagnetic pilot valve, which needs only a short current-impulse for both opening and closing.

6. The 66-lb LH_2/LO_2-Flight Prototype Engine

The most intensive development work of MBB in the field of cryogenic engines in the 60's was done with H_2/O_2-propellants, both, with very small and relatively large engines.

In the years from 1962 to 1966, MBB under a contract from the German Federal Ministry for Science and Education, developed a flight-prototype LH_2/LO_2-engine with a nominal vacuum thrust of 66 lbs, a nominal chamber pressure of 70 psia, and a nominal mixture ratio of 5.5.

The development program of this engine was, on the one hand, aimed at the establishment of the technologies needed for the handling of liquid hydrogen in rocket test facilities and at learning to overcome the measurement problems of relatively small liquid hydrogen mass flows. On the other hand, the program was also aimed at the demonstration, that even such small LH_2/LO_2-engines can be realized with atleast partial regenerative cooling, with a safe and reliable ignition, and with reasonable high performance in terms of spezific impulse within a certain operating range.

At the start of the development of this engine, practically no concrete experience for the design of such small engines existed. Therefore, testing began with watercooled aluminum chambers of very long chamber lengths and with radial injection of the propellants. With development time proceeding, the chamber length could be made shorter and shorter and propellant injection was accomplished with a star-shaped splash-plate injector. Regenerative cooling was first introduced into the program with copper chambers and was later done with stainless steel chambers. Slide 15 shows the progress from the first sea-level aluminum chamber to the final prototype engine with a vacuum nozzle extension.

The final engine in an all-welded version is shown by slide 16. The engine used regenerative cooling up to an area ratio of 16. The rest of the nozzle was radiation cooled. Since no spezification of the number of required restarts existed, ignition was done chemically by injection of a small amount of triethylaluminum (TEA). The TEA was stored in a small capsule, the volume of it being sufficient for a total of four ignitions. Slide 17 shows a cross section of the engine and slide 18 essentially shows the previonsly mentioned star shaped splash-plate injector.
Slide 19 shows a sea-level flame pattern of this engine.

The final engine version had the following performance data:

vacuum thrust	66 lbs
chamber pressure	71 psia
mixture ratio	5.5
nozzle area ratio	57
characteristic chamber length	15.8 inches
effective vacuum specific impulse	415 sec
chamber pressure range	57 ÷ 114 psia

mixture ratio range	3.5 ÷ 6.5
number of possible starts	4
total burning time	20 min

The final testing of the engine was done in an altitude simulation chamber, with simulated altitudes ranging up to 130,000 feet.

The development of the main propellant valves of the engine, their electrical pilot valves, and the igniter capsule was also required. Both propellant valves were pneumatically operated 3-way valves with the third position of the valves utilized for propellant line and valve precooling. Slides 20 through 23 show such a 3-way valve and the igniter capsule, respectively.

A 20-minutes sound film, synchronized in English, may show some more details of the development of this engine.

7. The 30,000-lb LH_2/LO_2-High Pressure Engine

In the late 50's and early 60's MBB developed a new thrust chamber cooling technique allowing the realization of high chamber pressures with full regenerative cooling. After this technique was first successfully demonstrated in a high pressure LOX/RP1-engine, MBB in cooperation with the Rocketdyne Division of NAR, succeeded in obtaining the interest of the US Air Force and the German DOD in this new chamber technology. As a result, a joint Air Force/German DOD program was established which was aimed at the demonstration of the extreme high pressure regenerative cooling capability of the milled-copper-chamber concept. In this program, MBB designed and fabricated such milled copper chambers with

matching injectors for LH_2 and LO_2 propellants. The testing and evaluation of this engine was done at Rocketdyne's Reno facilities.
This LH_2/LO_2-engine had the following design data:

sea level thrust	30,000 lbs
chamber pressure	≈ 3,000 psia
mixture ratio	≈ 6

During engine testing it was sucessfully demonstrated that the milled copper chamber concept is capable of handling the extreme high heat fluxes experienced at such high chamber pressures. With this engine, the highest chamber pressure ever known up to that time in the free world was achieved. It was shown that considerably less hydrogen was needed for cooling the chamber than was injected into it. In a severe cycling test, the engine experienced no deviation from its normal performance.
Slides 24 through 26 show this high pressure chamber, a total view of Rocketdyne's test stand, and a test run of the engine, respectively.

A short silent film shows the cycling test of the engine.

8. Engine Fabrication Technology

Recently, MBB has developed some modern thrust chamber fabrication techniques, fully or partly based on the application of electroforming. Intensive use of these fabrication techniques has been made on the just described LH_2/LO_2-high pressure engine. Other engines, like the above mentioned 1,100-lb LH_2/LF_2 engine, and small, high-pressure engines for storable propellants, also make use of them, because cooling channels of varying cross sections and thicknesses can be produced with relative ease.

Slides 27 and 28 show examples of such fully electroformed thrust chambers having cooling channels similar to a tubular chamber.

Slide 29 shows a complete small high-pressure chamber for a thrust level of 2,200 lbs and pressures in the range of 3,000psia, which is used for testing the regenerative cooling capability of such chambers with storables. The coolant inlets and outlets are fitted to the chamber and sealed by local electroforming.

9. Possibility of the Development of a Space-Shuttle APS-Engine

Using its experience with small low-pressure and large high-pressure H_2/O_2-engines and using its technological potential, MBB is able to develop, fabricate and test a H_2/O_2-APS-engine for the Space Shuttle program.

The above mentioned 1,100-lb LH_2/LF_2-engine currently under development at MBB falls into the presently discussed thrust category for a high pressure Space Shuttle APS-engine. The engine can be run with H_2/O_2 instead of H_2/F_2 with nearly the same cooling channel geometry but using another chamber material, e. g. copper. The coaxial-jet type injector of the engine can also be used for H_2/O_2 by only changing the sizes of the injector holes and providing for the installation of an igniter.

Using the same inner geometry of the combustion chamber of the 1,100-lb H_2/F_2 engine and running it with GH_2/GO_2 at a chamber pressure of 150 psia and a mixture ratio of 4, it would deliver a vacuum thrust of 1,500 lbs with an area-ratio-30 nozzle. With the same engine geometry and varying chamber pressure, it could also be adjusted to other thrust levels within a wide range, if needed.

Since the design of the thrust chamber is well underway, MBB under a contract of the German Ministry of Science and Education, is currently preparing the demonstration of a sea level GH_2/GO_2-engine in order to show its ability of safe ignition, regenerative cooling and high performance. The testing of such an engine can be done on MBB's Ottobrunn facilities with only minor adjustments for producing the cold H_2- and O_2-gases with which the Space Shuttle APS-engine shall be fed.

In addition a parallel development of main propellant valves for pulse mode operation shall be initiated.
These are the reasons, why MBB thinks, that it can contribute well to the development of a Space Shuttle APS-engine.

10. Conclusions

In the preceeding discussion it was shown that MBB has a lot of experience in the development of H_2/O_2-engines and a broad technological background for fabricating such engines.

The 1,100-lb H_2/F_2-engine presently under development at MBB can be run with H_2/O_2 propellants with only minor modifications. This is the reason, MBB feels it can contribute to the development of a H_2/O_2-APS-engine for the Space Shuttle.

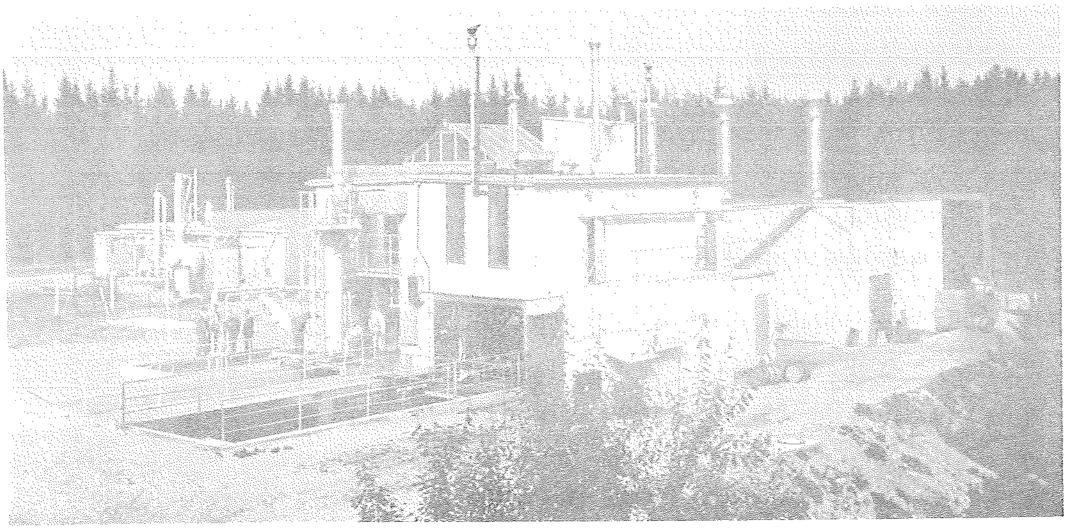

Fig. 1 MBB's test facilities for engines using cryogenic propellants.

Double test stand in the foreground,
fluorine liquefaction and storage plant in left background,
hydrogen liquefaction plant in right background.

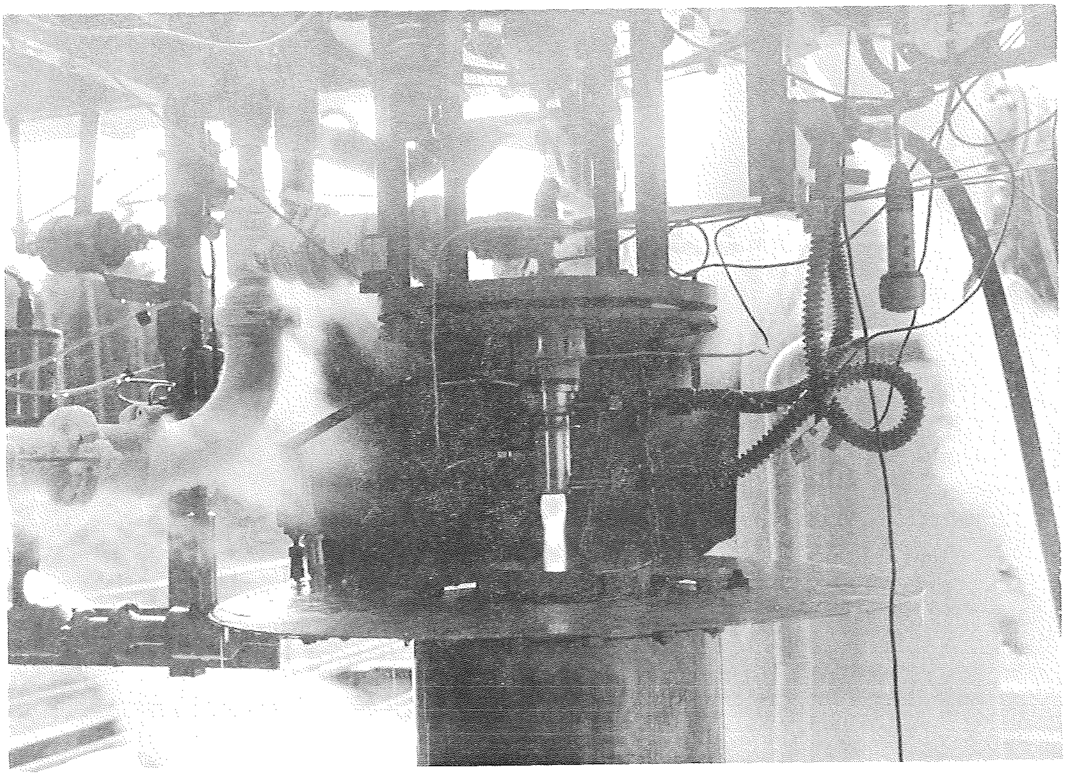

Fig. 2 Test run of a watercooled 66-lb GH_2/LF_2 experimental engine

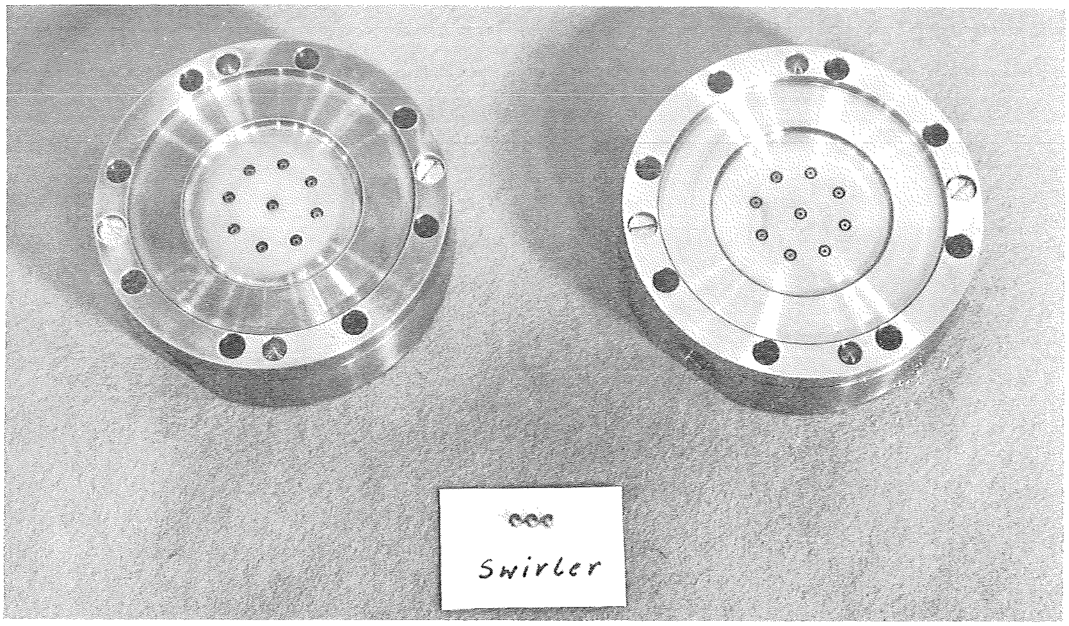

Fig. 3 Coaxial-jet type injector for GH_2/LF_2 experimental engine with copper face plate, left, and nickel-chromium alloy face plate, right

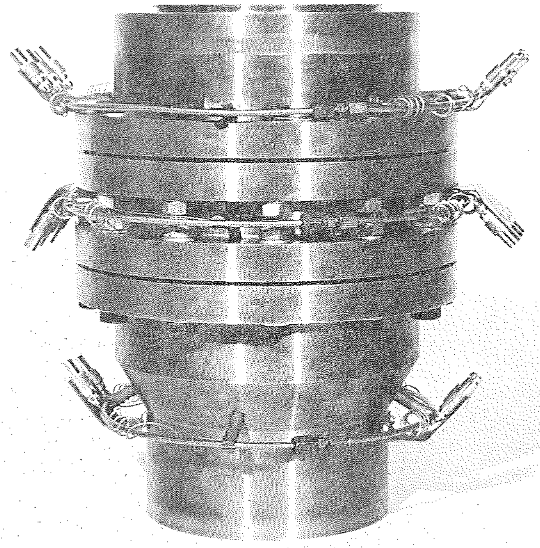

Fig. 4 Segmented heat sink 1,100-lb H_2/F_2 experimental engine for sea level testing with thermocouples installed

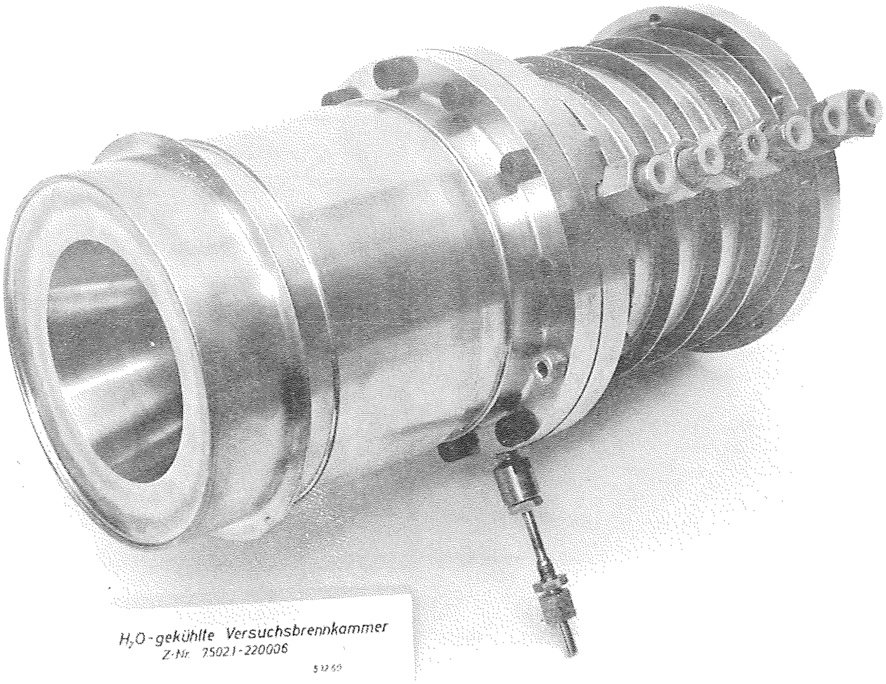

Fig. 5 Watercooled 1,100-lb H_2/F_2 experimental engine for sea level testing with 7 individual water jacket

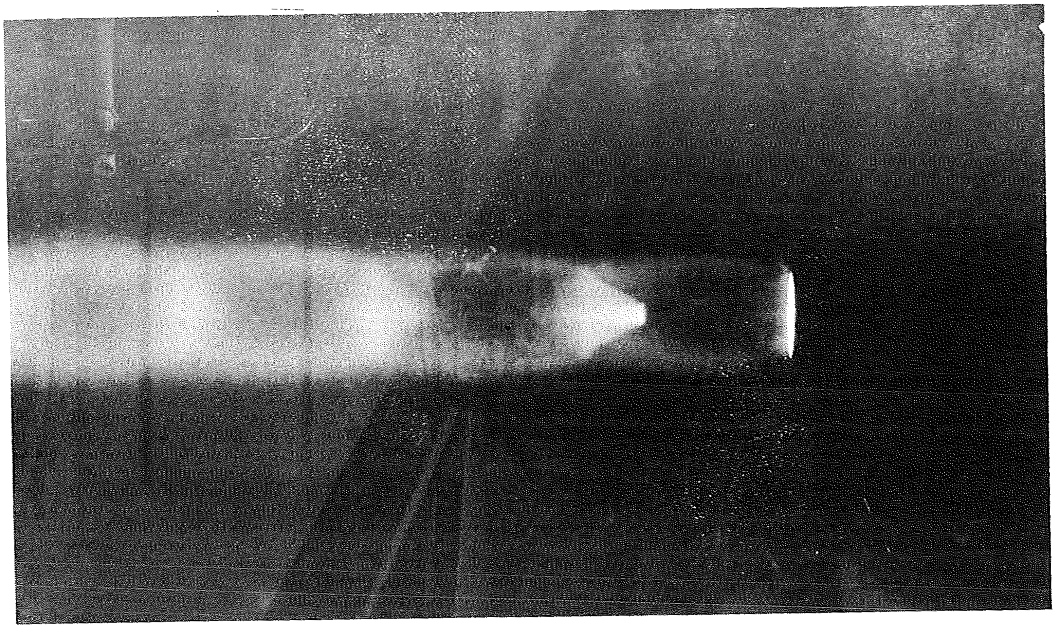

Fig. 6 Sea level flame pattern of the 1,100-lb H_2/F_2-engine; unsegmented heat sink chamber

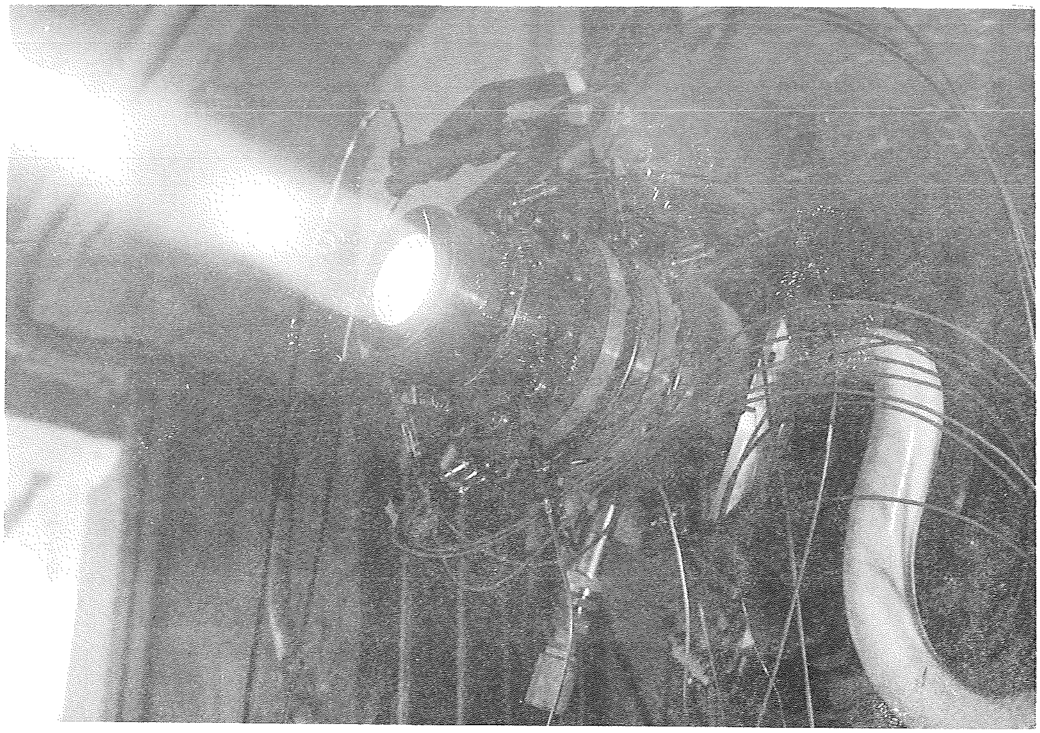

Fig. 7 Sea level flame pattern of the 1,100-lb H_2/F_2-engine; segmented heat sink chamber

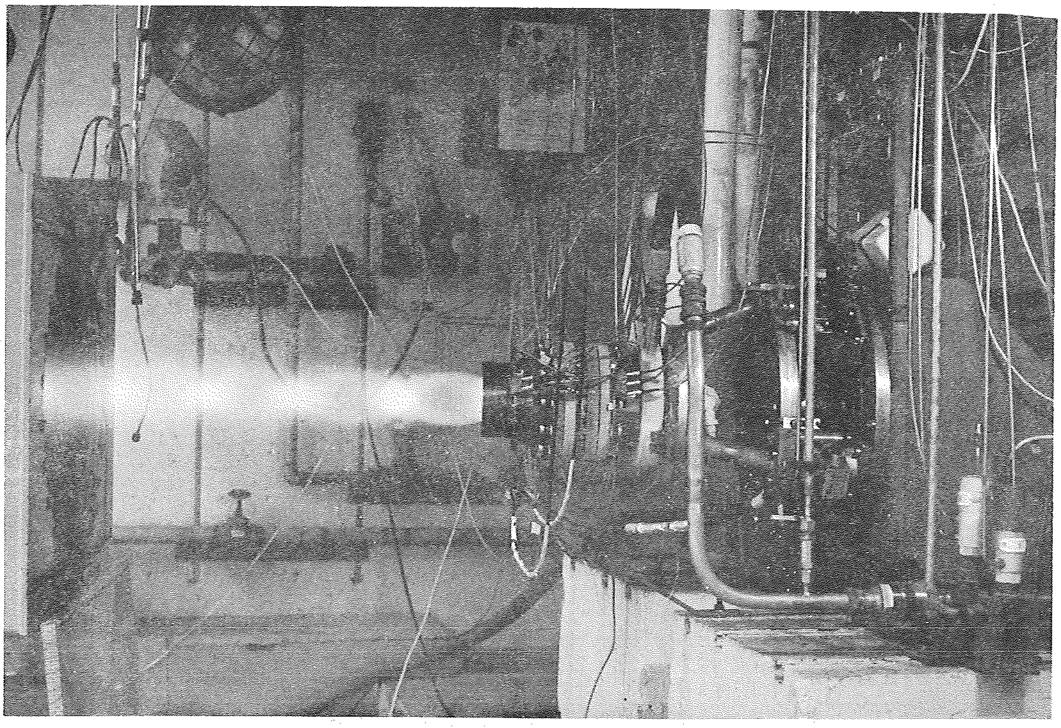

Fig. 8 Sea level flame pattern of the 1,100-lb H_2/F_2-engine; segmented heat sink chamber; details of test stand

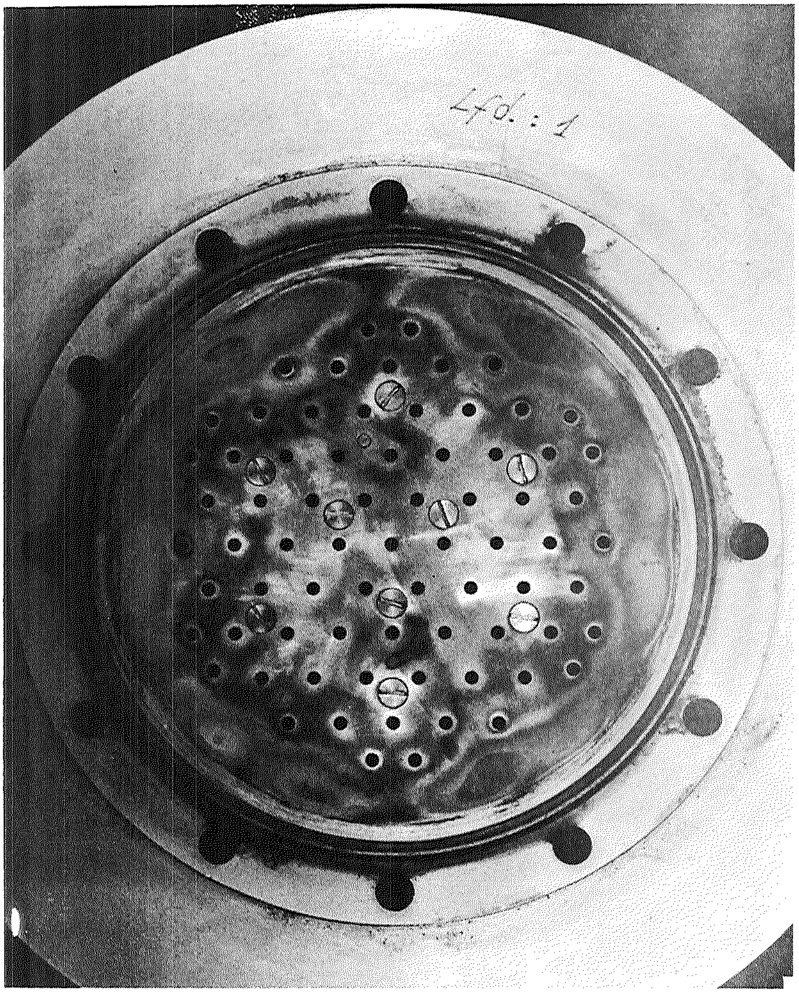

Fig. 9 Coaxial-jet injector with solid faceplate for the 1,100-lb H_2/F_2-engine

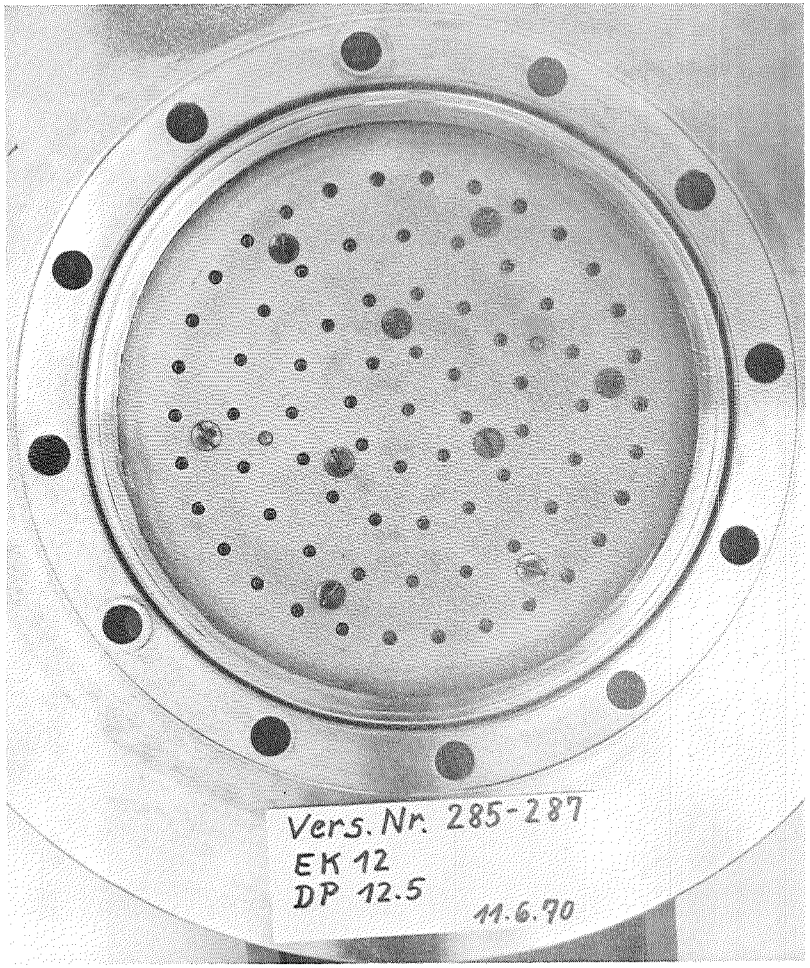

Fig. 10 Coaxial-jet injector with porous faceplate for the 1,100-lb H_2/F_2-engine

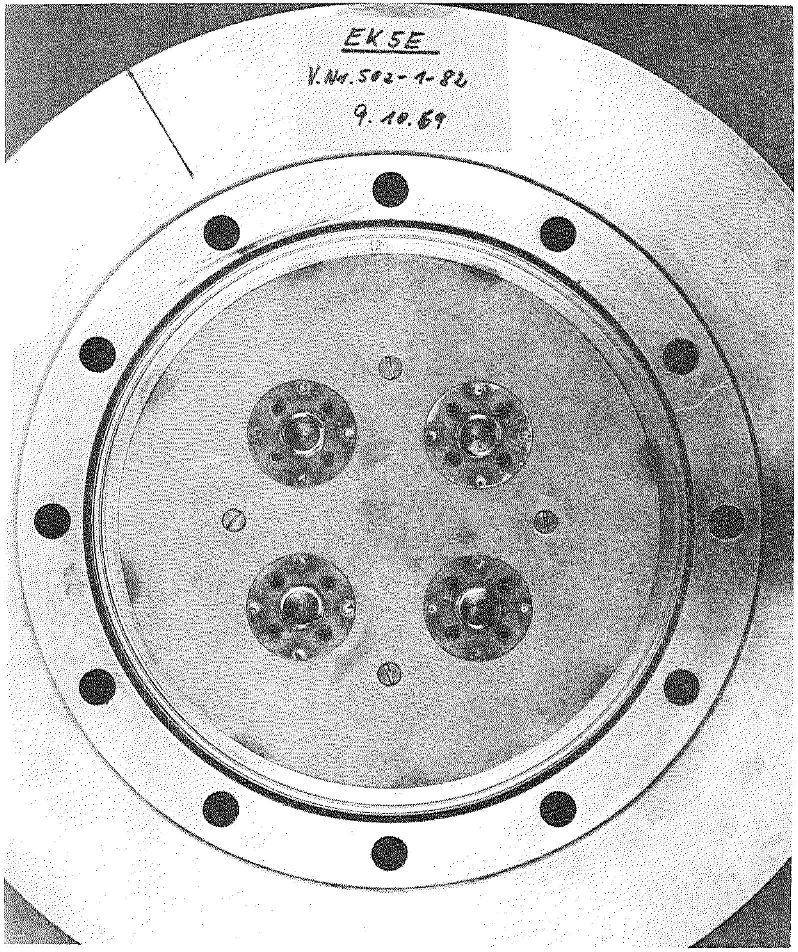

Fig. 11 Pentad injector for the 1,100-lb H_2/F_2-engine

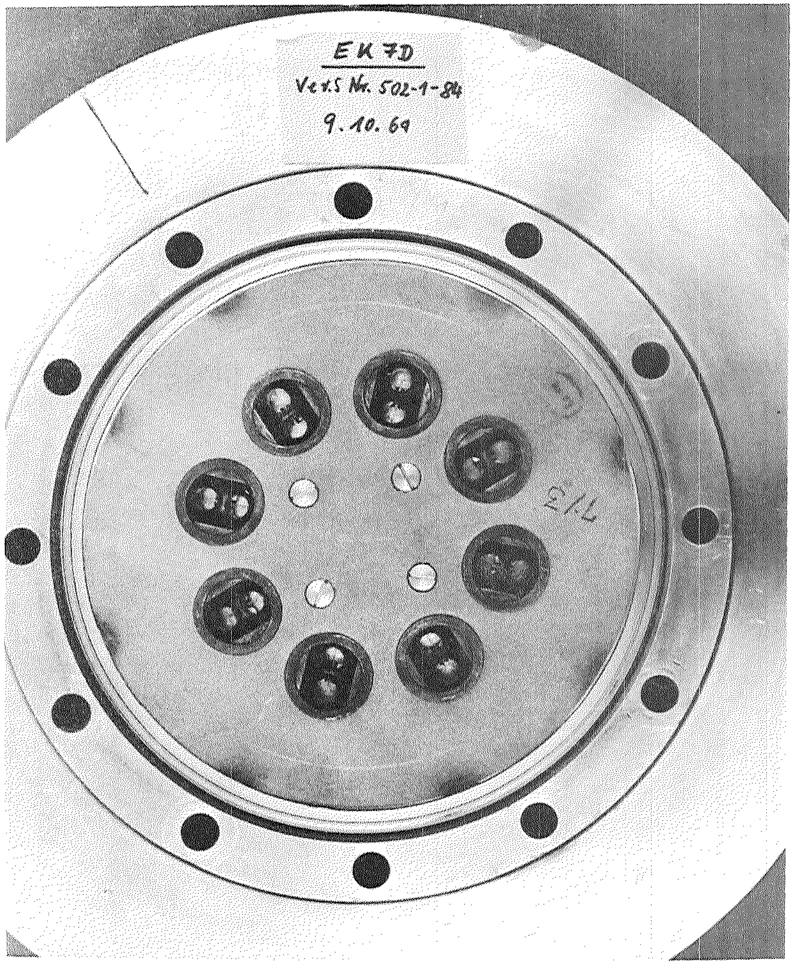

Fig. 12 Splashplate injector for the 1,100-lb H_2/F_2-engine

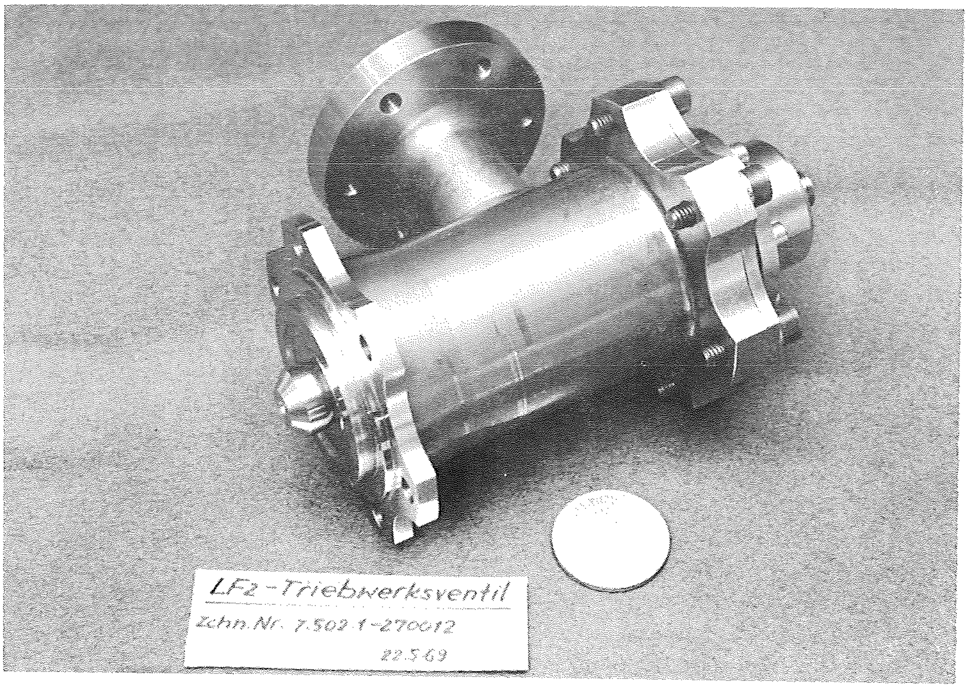

Fig. 13 Test version of a LF_2-main-shutoff valve

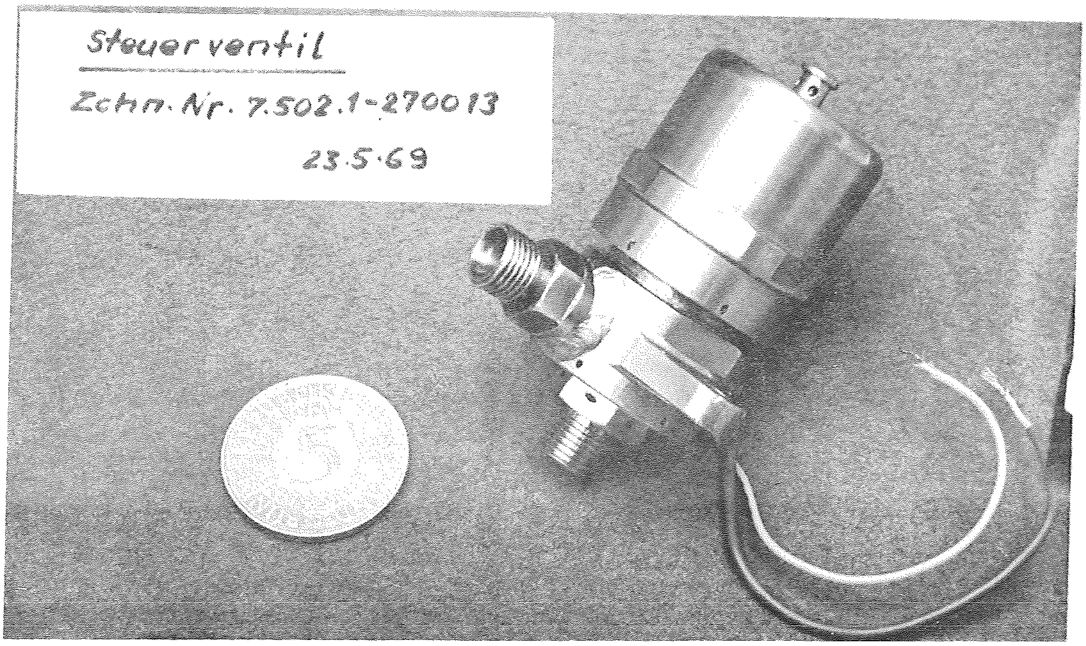

Fig. 14 Electromagnetic pilot valve for the LF_2-main-shutoff valve

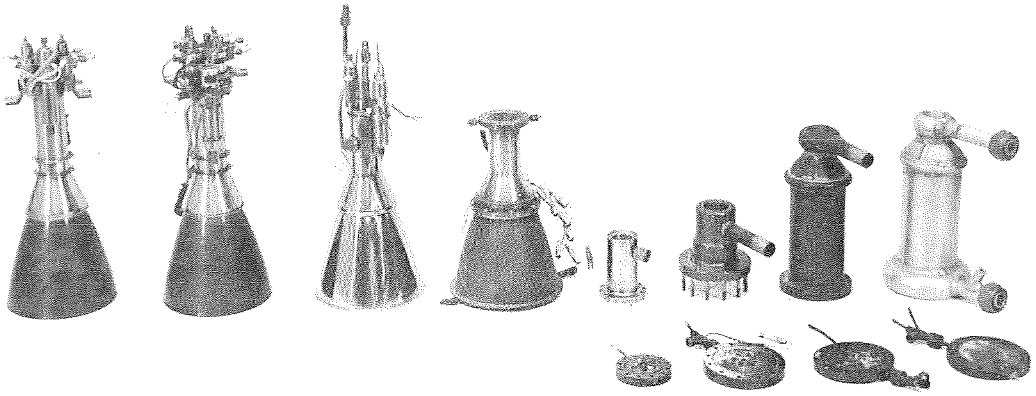

Fig. 15 Development history of the 66-lb LH_2/LO_2-engine

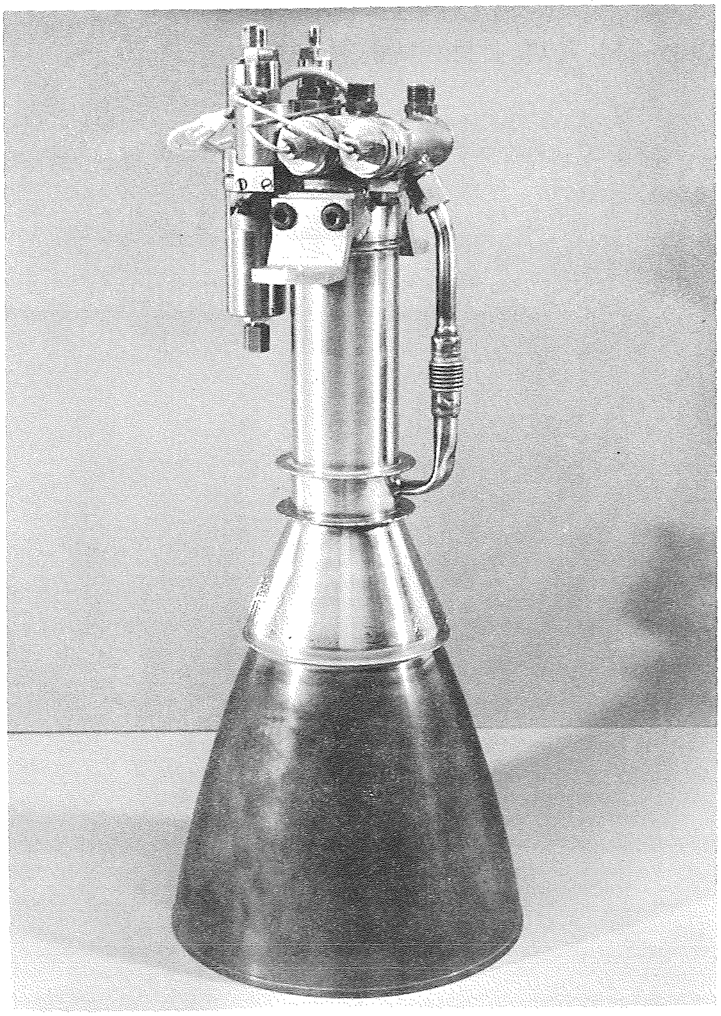

Fig. 16 Final version of the 66-lb LH_2/LO_2-engine with its main propellant valves on top of the chamber and the igniter capsule left of the chamber

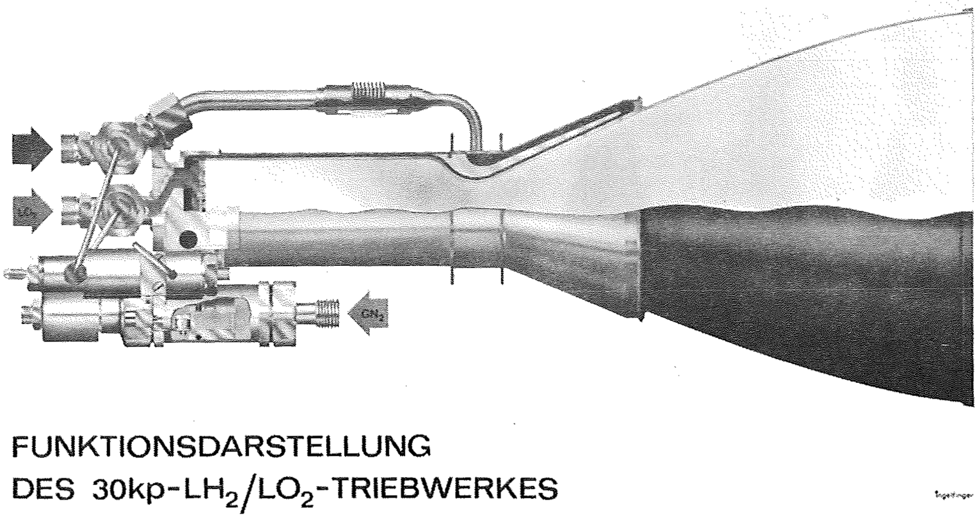

Fig. 17 Function schematic of the 66-lb LH_2/LO_2-engine

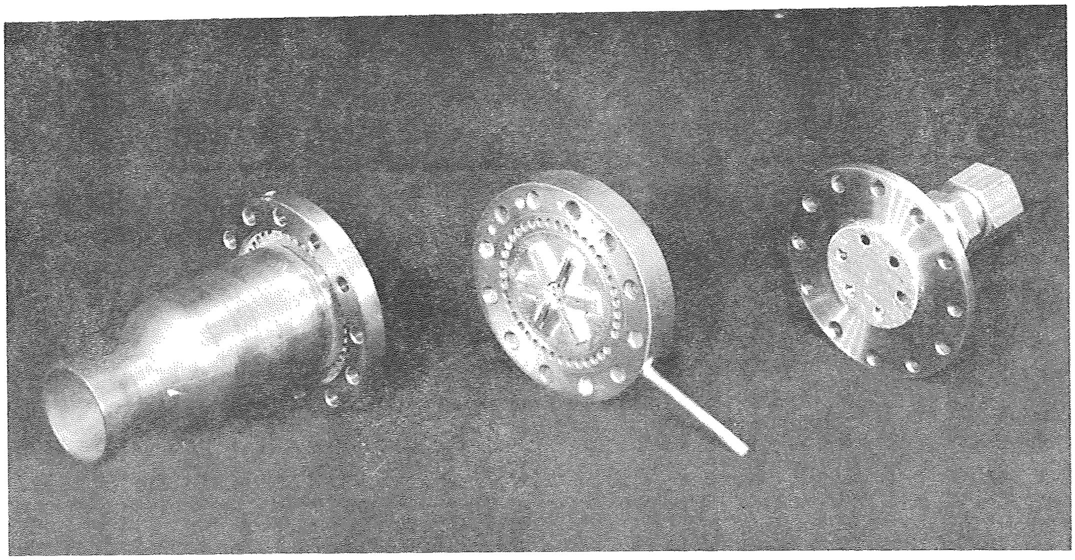

Fig. 18 Star shaped splashplate injector of the 66-lb LH_2/LO_2-engine

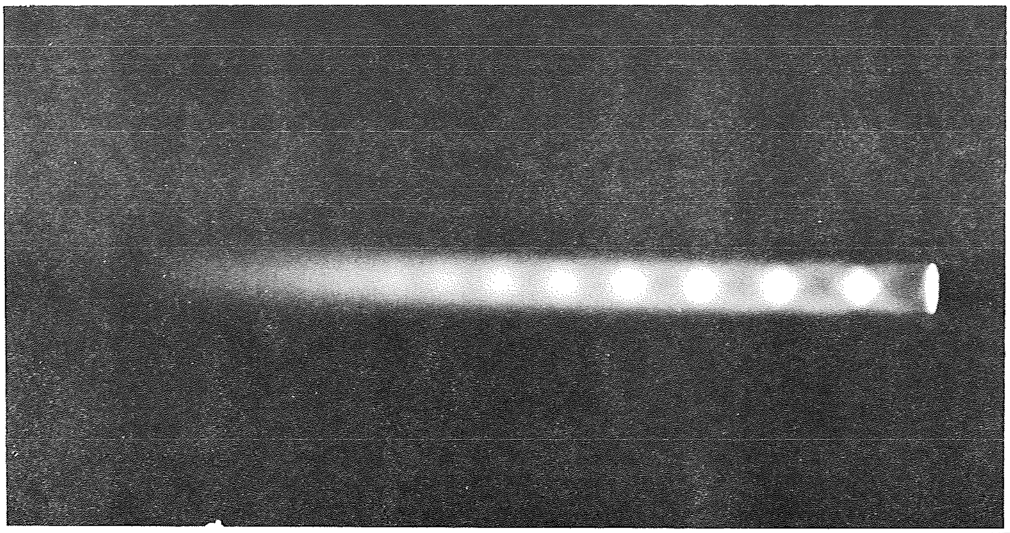

Fig. 19 Sea level flame pattern of the 66-lb LH_2/LO_2-engine

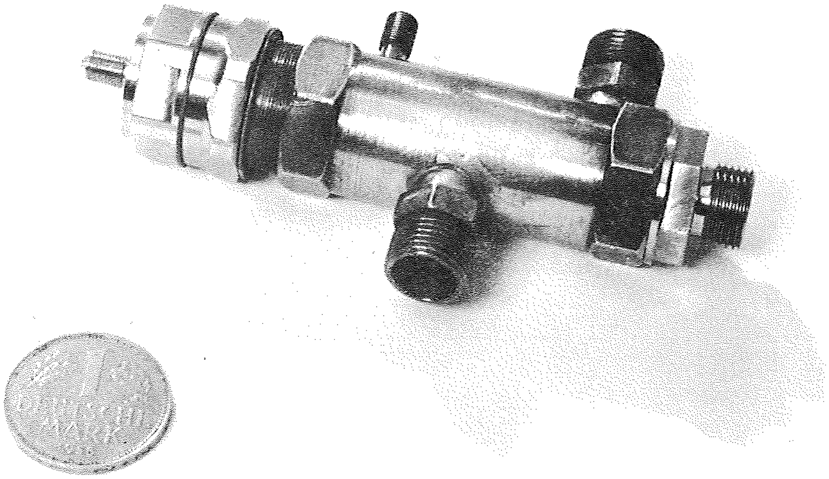

Fig. 20 3-way main propellant valve for the 66-lb LH_2/LO_2-engine

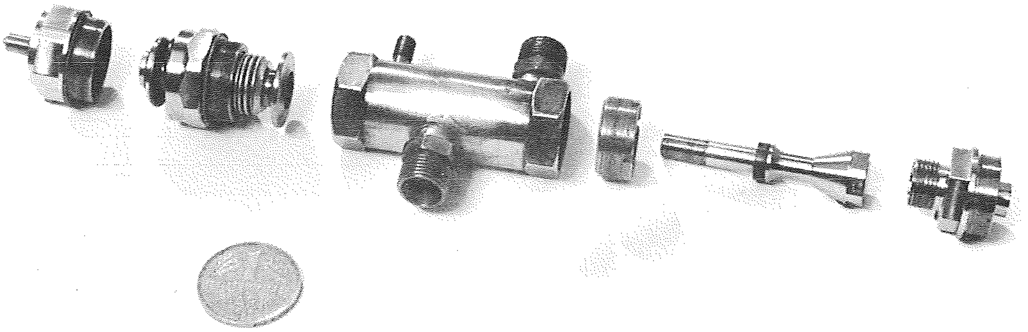

Fig. 21

3-way main propellant valve;
exploded view

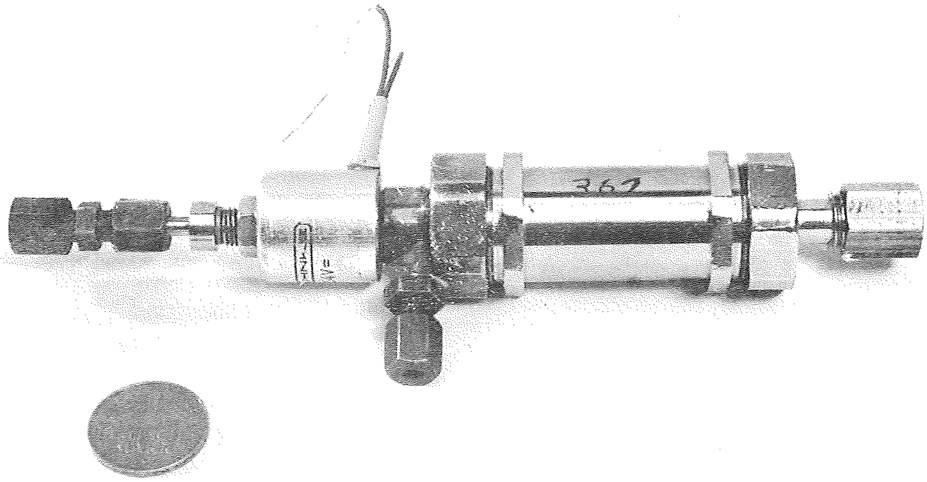

Fig. 22

Igniter capsule for the 66-lb LH_2/LO_2-engine

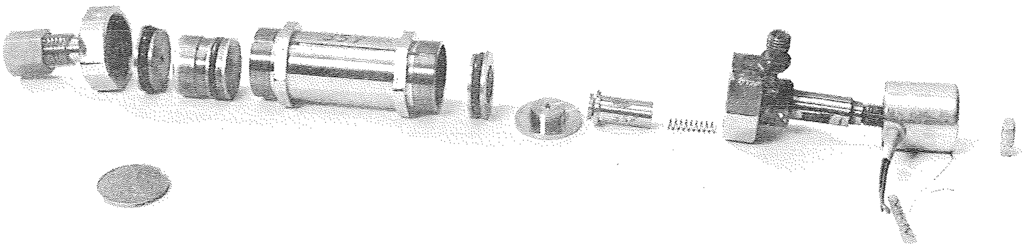

Fig. 23 Igniter capsule; exploded view

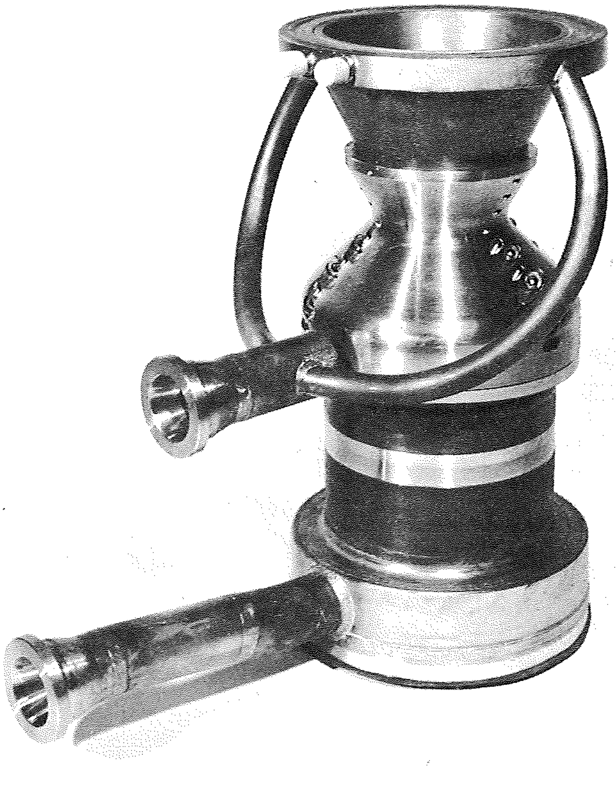

Fig. 24 30,000-lb high pressure LH_2/LO_2-thrust chamber

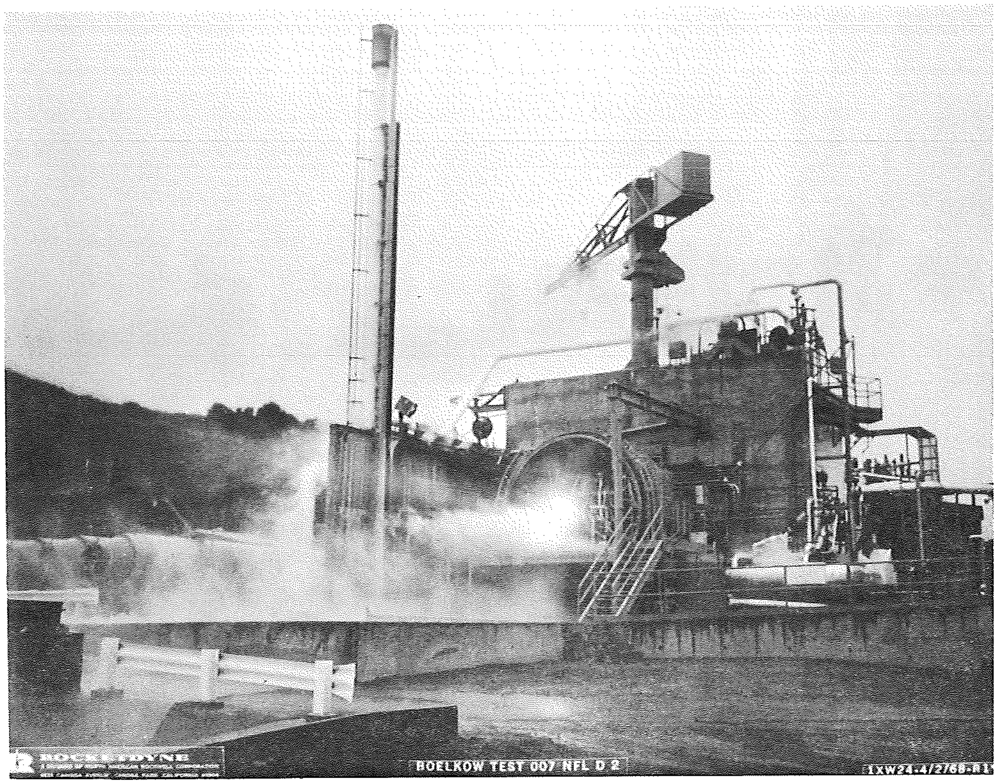

Fig. 25 Total view of the teststand with the 30,000-lb high pressure LH_2/LO_2-engine running

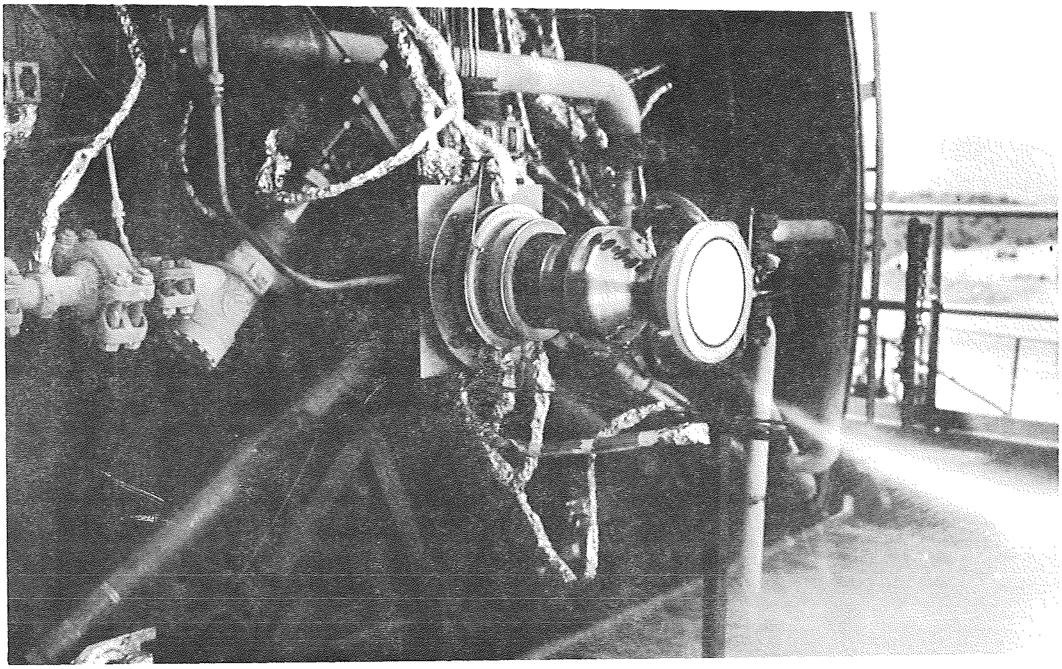

Fig. 26 Test run of the 30,000-lb high pressure LH_2/LO_2-engine

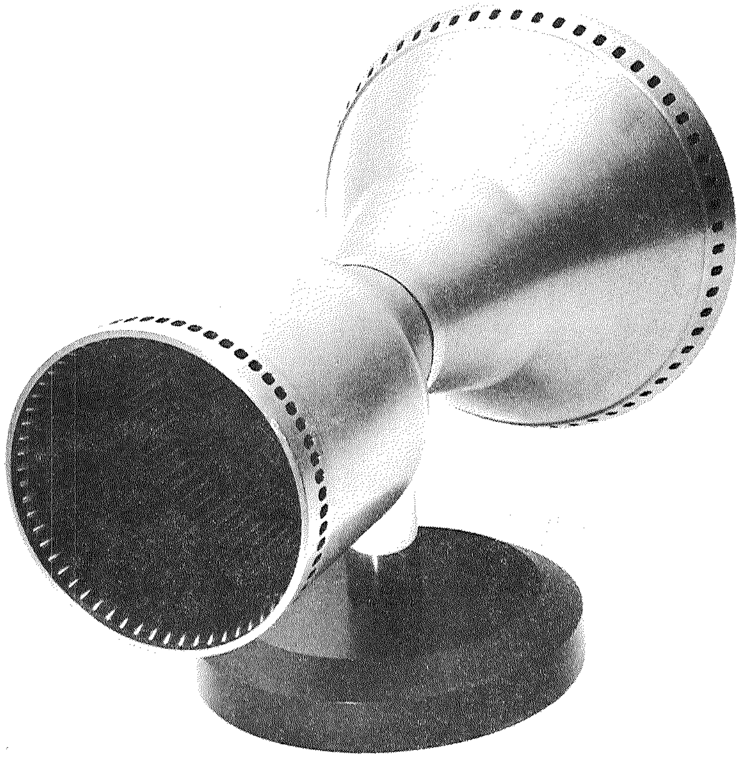

Fig. 27

Completely electroformed copper thrust chamber

Fig. 28

Completely electroformed nickel thrust chamber

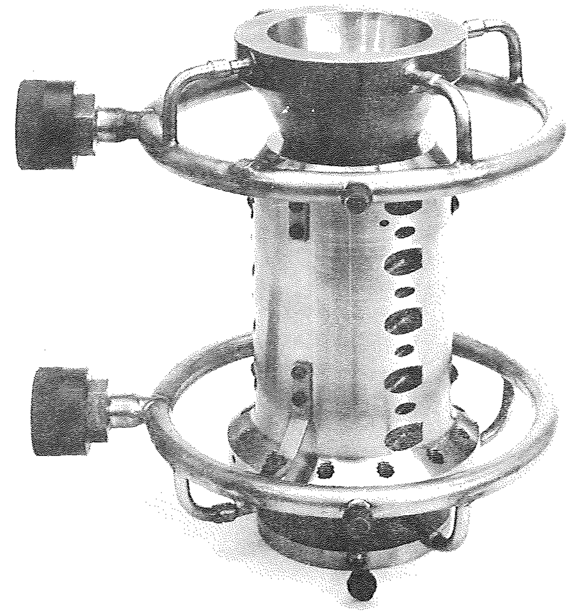

Fig. 29

Completely electroformed 2,200-lb high pressure copper thrust chamber with coolant inlets and outlets