Interesting to read this, though little Technical content.

HISTORY OF GERMAN GUIDED MISSILES DEVELOPMENT

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DEVELOPMENT OF THE V-1 PULSE JET

Fritz Gosslau *

1. TASK

In 1939 the German Air Ministry decided to have jet engines developed. Each of the German aero-engine factories was asked to work on different technical solutions of this task. The Argus Motoren Gesellschaft, Berlin, were asked to develop a pulse jet. Curiously enough, this task was formulated as follows:

"Take a test tube, put in some drops of gasoline, shake the tube and ignite its open end. The mixture will not burn continuously, but in rhythmic pulses."

As an oscillation process of the working gases had evidently to take place, we opposed two oscillation chambers in our first model (Fig. 1).

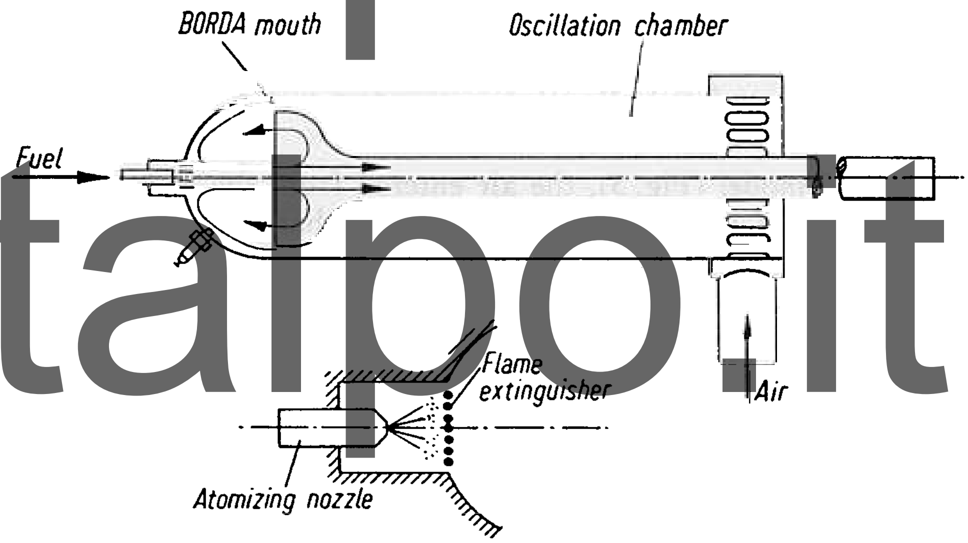

Fig. 1. Pulse jet, first Argus model with oscillation chamber. Borda mouth and flame extinguishing sieve

The pulse jet was intended for flying speeds of at least 700 km/h. We therefore thought that we could supply the air at the corresponding dynamic pressure. We told ourselves: If one of the two components needed for the explosion, i. e. the air, enters intermittently, the other component, i. e. the fuel, can be supplied continuously to the combustion chamber. This analysis facilitated the development of our pulse jet and its control system considerably, and later on contributed to the simplification of the power plant of the flying bomb.

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When pulsation took place, two things had to be prevented:

(i) A return flow of the combustion gases. We had therefore provided a flow-technical valve in the form of a Borda mouth.

(ii) A continuous burning of the fuel. For this purpose the atomizing nozzle was sunk into a small secondary chamber, and this chamber was screened from the combustion chamber by a flame extinction strainer (based on the principle of the well-known miners' lamp).

The apparatus (Fig. 2) was first operated on November 13th, 1939, and immediately we were surprised to observe an intermittent operation with pulsations of high frequency.

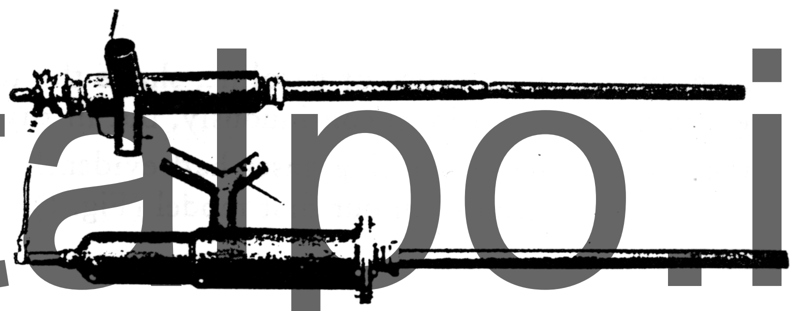


Fig. 2. Models corresponding to Fig. 1

On a second model (Fig. 3), the air entered from the front, under the ram-pressure, and was deflected into the combustion chamber via an annular vortex. We also aimed at achieving an annular vortex in this ball-shaped combustion chamber. The combustion of this model was excellent, and its pulsating operation was steady. We were surprised, however, by the fact that the apparatus continued working satisfactorily after we had switched off the ignition.

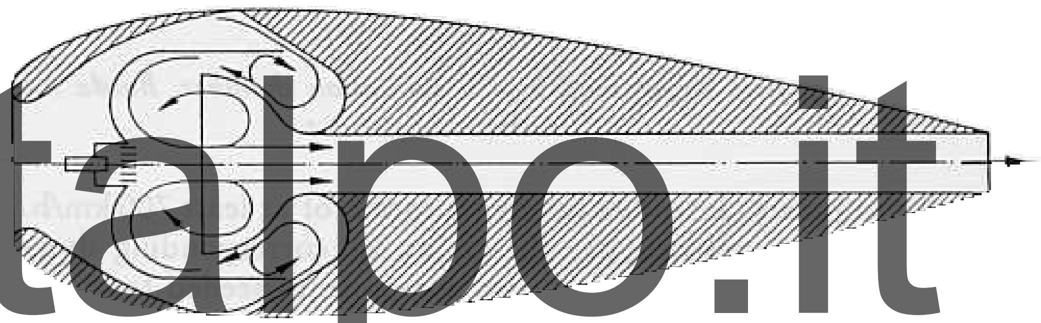


Fig. 3. Second model of the pulse jet with air intake at front

Our third model was equipped with a leaf-spring valve which could be bought as a standard product, i. e. a compressor valve. This pulse jet (Fig. 4) was designed as follows: Fuel and air enter the mixing chamber together, without deflection and in the same direction. The effect of the flame extinction strainer was now achieved by means of a necked portion. The velocity of the mixture became so high, and the pressure in the secondary chamber was balanced in such a way, that a flash back of the flame and a continuous burning

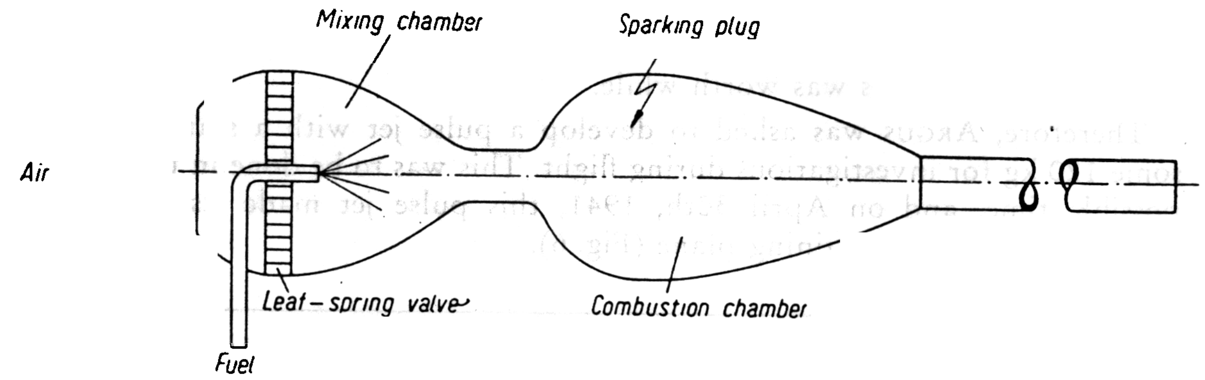


Fig 4. Third Argus pulse jet model. The neck-down in the combustion chamber prevents continuous burning of the fuel at the injection nozzle

of the mixture were prevented under all circumstances. Moreover, this device protected the sensitive valve from being directly touched by the burning gases.

Hence this apparatus already contained all the elements of our nozzle-diaphragm — mixture-formation — process, which will be dealt with later on.

After reaching this state of our experiments, three and a half months after starting them, we were informed by the Ministry that the pulse jet had already been the subject of investigations of another group in Germany for several years. It was the first time that we heard the name of PAUL SCHMIDT, and we were asked to inspect his work at Munich. Herr SCHMIDT demonstrated his big pulse jet (Fig. 5) in March 1940. A big paper bag filled with air and propane gas was suspended in front of the valve apparatus and the pulse-jet unit operated some seconds until the gas was consumed.

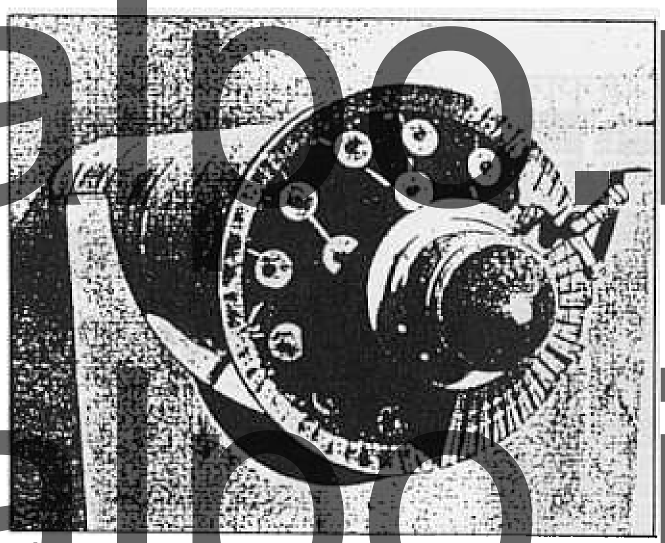


Fig. 5. Conical valve apparatus (see also Fig. 2) of the pulse jet SR 500 built by Paul Schmidt. Destroyed after 13 minutes running time with 450 kg thrust

Herr SCHMIDT had planned to use a small pulse jet for the operation with liquid fuel, but the liquid-fuel system was then obviously in its early state of development.

2. LOW-SPEED FLIGHT TESTS

Up to that time Herr SCHMIDT had only achieved short-time operation on test stands. Nobody knew what thrust could be achieved by means of these pulse jets during flight, or if the further development for the propulsion of high-speed aeroplanes was worth while.

Therefore, Argus was asked to develop a pulse jet with a static thrust of some 120 kg for investigations during flight. This was to be done in the shortest possible time, and on April 30th, 1941, this pulse jet made its first flight suspended beneath a training plane (Fig. 6).

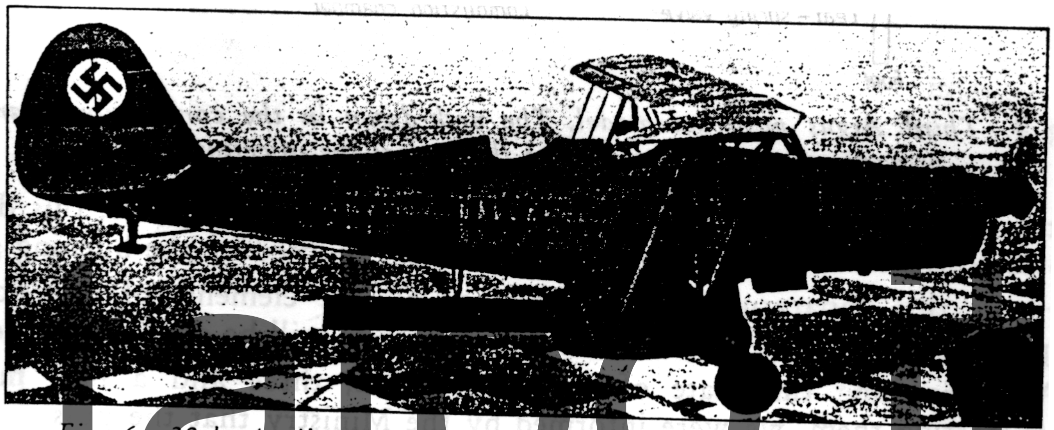
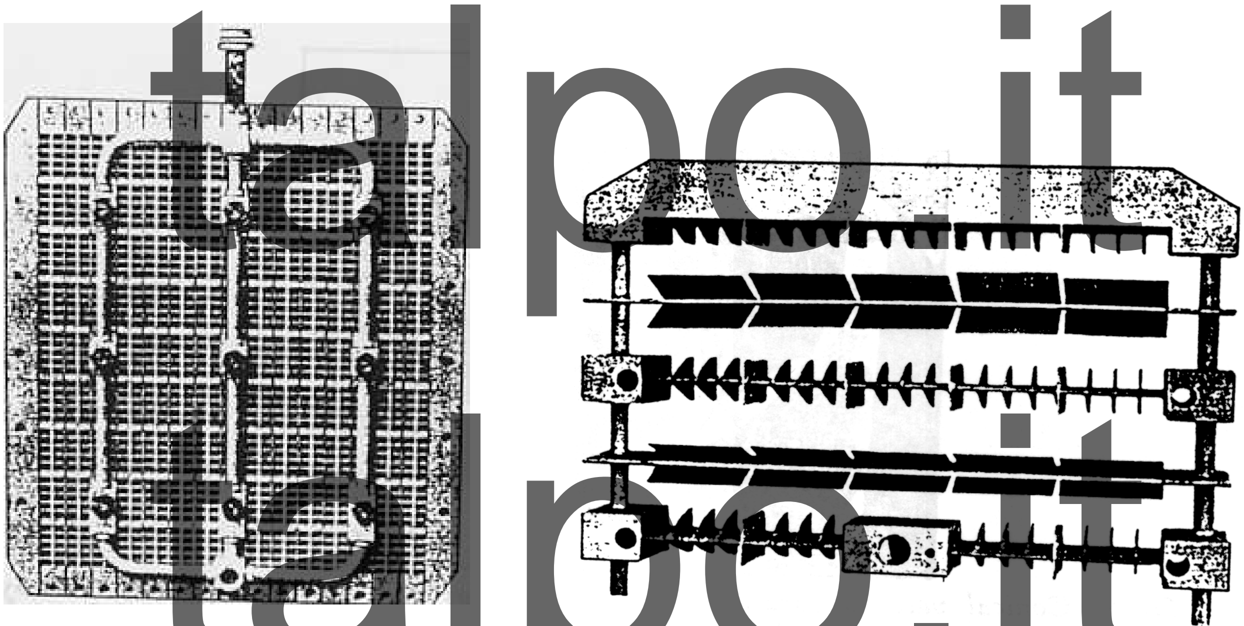


Fig. 6. 30th April 1941: First flight of a pulse jet (Argus design)

The whole valve system, however, was arranged level (Fig. 7), for simplified manufacture, and we adopted from Herr Schmidt the element of the preliminarily bent valve spring flap (Fig. 8). As to the mixture formation we adhered to the method developed by ourselves.



Figs. 7 and 8. The flat valve apparatus of the Argus pulse jet and constructive arrangement with fuel atomizer nozzles and starting air duct

In the summer of 1941 we were asked to motorise cargo gliders. In this connection we arrived at the first aeroplane driven solely by pulse jets.

Towards the end of 1941 the pulse jet had proved to be satisfactory for low-speed aeroplanes, but it was not at all clear if the unit was suitable for higher flying speeds. Doubts were raised in this connection which had to be taken seriously.

At that time my collaborator, Dr. Dietrich, who had earned great merit in initiating the development, separated from Argus, after he had proved, as he thought, in a memorandum, that no useful thrust could be expected from jets at speeds exceeding 600 km/h *.

3. THE V-1 IS ORDERED

Aerial warfare became more and more difficult, and the argument of insufficient accuracy, which had been the reason for the refusal of the long-distance flying bomb at the beginning of the war, became invalid. We therefore decided to submit the project once more and to suggest the pulse jet as its engine.

In view of the fact that, at that time, the performance of the pulse jet at high speeds was completely unknown, it was a bold decision of the German Air Ministry to order a long-distance missile on June 19th, 1942.

The decision to equip an unmanned flying bomb with a pulse-jet engine raised additional problems for Argus. These were:

a) Determination of the thrust of this unit at high flying speeds;
b) Design and construction of a fully automatic fuel-control system;
c) Development of a suitable starting system in order to allow the launching of the projectile by pressing a button.

4 POWER PLANT OF THE V-1

While Argus worked at these tasks, considerable progress was achieved with the design of the airframe. The lay-out of the power plant is shown in Fig. 9.

* In order to set right numerous misunderstandings found in technical literature, I herewith wish to clarify the following points:

1. The pulse jets of Messrs. Argus were not constructed under licence but were an independent development.
2. Argus pulse jets, i. e. including "V-1" propulsion, did not employ the Schmidt patent 523 655 (of 25th April 1931) which was, erroneously, frequently mentioned in this connection.
3. This patent 523 655 does not at all deal with the original idea of the invention of the pulse jet itself, which had been known since 1906, but concerns an additional idea in saying that in "known, approximately pipe-shaped reaction spaces, the one end of which is open" (Karavodine, Marconnet), "a quantity of air, the weight of which is from 10 to 50 times greater than the weight of the inflammable mixture, is immediately accelerated by the force of the excessive pressure of the exploding mixture . . .".
4. The realization of this idea was succesful only in i n d i v i d u a l explosions, however, never, in repeated continuous operation. After years of fruitless test work the inventor (Schmidt) gave up his efforts to achieve continuous explosion, as early as 1938.
5. Laboratory pulse jets, as Herr Schmidt had since operated and demonstrated in March 1940, function in principle in accordance with the ideas, patents, tests and publications by Karavodine, Marconnet and Barbezat (French patents 374 124 and 412 478) which had been known since the beginning of this century. (Literature: "Die Turbine", publishing year 1909, page 305 and subsequent pages, and "Stahl und Eisen", published 1911, No. 42, page 115 and subsequent pages.)
6. Marconnet had even laid down the plate spring valve in his patent specification (French No. 412 478) as the inlet device for the pulse jets: "The mixture enters the combustion chamber through a very light valve . . . This valve consists of a metal plate spring which opens and closes similar to the voice of a clarinet . . . ".
7. However, whilst Marconnet's plate valve was flat when in a closed state, and curved when opened, Herr Schmidt had recommended the reverse. His valves were curved when in a closed state and flat when the valve was open. This "precurved" plate valve was the only device which Argus really took over from Schmidt, whilst the valve apparatus as a whole was completely and basically remodelled by Argus, and with progressing development was more and more simplified to facilitate production.

1 = Air reservoir
2 = Filling valve
3 = Pressure reducing valve
4 = Check valve
5 = Fuel tank
6 = Filter
7 = Governor
8 = Fuel exit
9 = Ram tube
10 = Connecting ring
11 = Switch valve
12 = Starting air nozzles
13 = Compressed air for control equipment
14 = Stop button

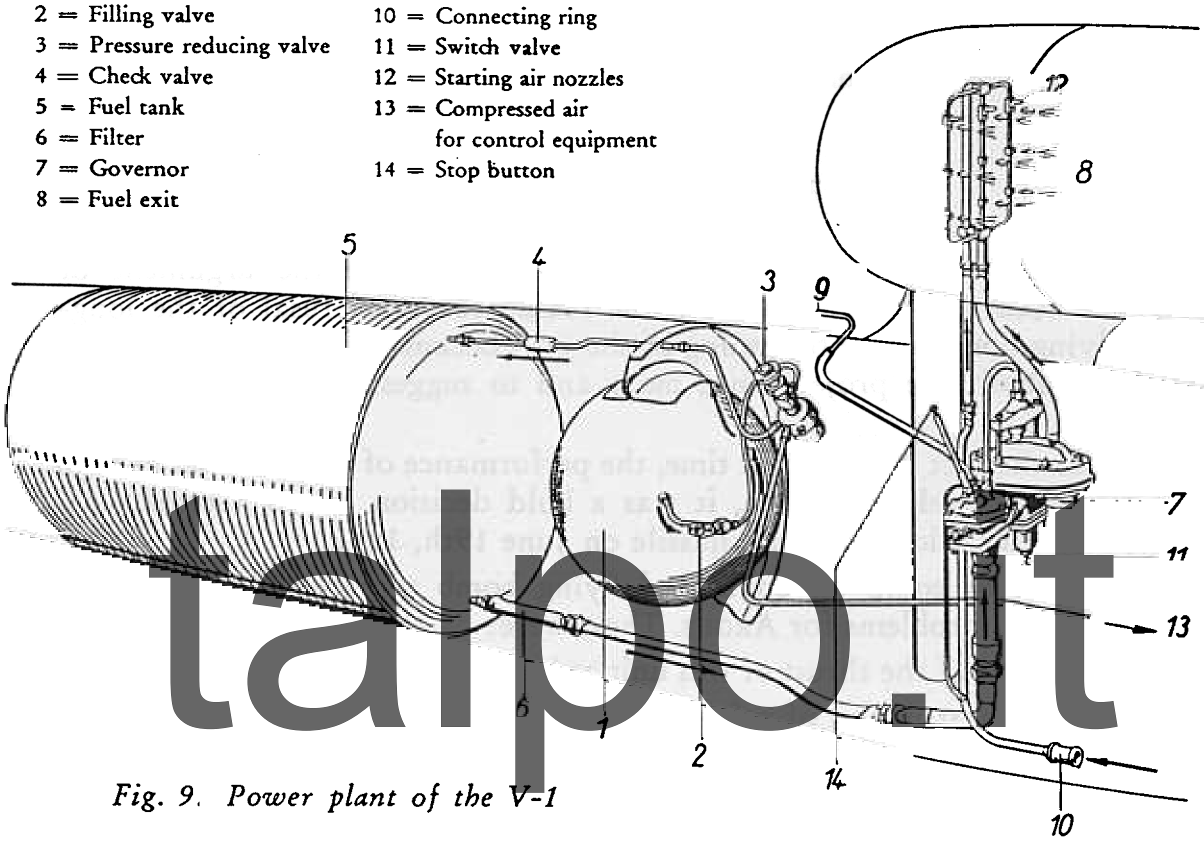


Fig. 9. Power plant of the V-1

4.1 Fue Supply

The fuel in the tank was put under pressure by means of the compressed air which in any case was needed for the control system. The fuel flowed through the filter and control system, was atomized by the injection nozzles, and was continuously supplied to the combustion chamber.

4.2 The Fuel-Contro System

With this unmanned flying body the fuel-control system had to perform complicated tasks, which can be judged from a consideration of the time histories of the fuel tank, and a point just ahead of the injector nozzles (Fig. 10).

Before the take-off the pressure in the fuel tank was 7 atm but for starting the injection pressure at the nozzles had to be reduced to 1.2 atm. Immediately after starting, the injection pressure had to rise to 2.2 atm for static operation, while the pressure in the tank simultaneously decreased to 6.8 atm.

Owing to the inertia effect of the fuel columns, a pressure peak of 9 atm arises when launching, and this pressure peak has to be removed by the control system.

During the launching operation the pressure at the nozzles had to rise simultaneously to 2.6 atm, corresponding to the take-off speed.

The injection pressure then had to drop during climb and rise again with increasing flying speed after changing to horizontal flight. During flight the pressure acting on the fuel tank slowly dropped from 7 to 6 atm.

Fig. 11 shows the design of the fuel-control system. When the stop valve was opened, the fuel flowed to the constant-pressure valve which had to maintain a constant pressure of 4 atm in front of the throttle valve. The throttle valve

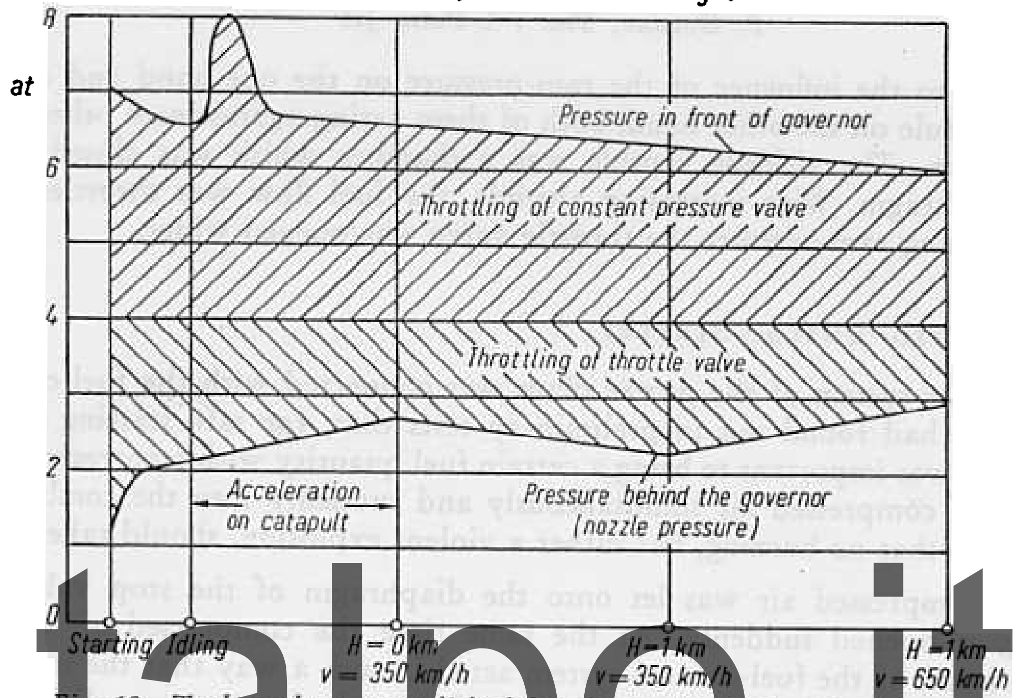


Fig. 10. Task to be accomplished by the engine fuel-control system

Fig. 11. Fuel-control system of the V-1. Filter with locking valve and stop mechanism, balanced-pressure valve and throttle valve, ram-pressure piston and barometer capsule

was subject to the influence of the ram-pressure on the one hand and of the altitude capsule on the other hand, both of them acting against each other on a balance beam. The altitude capsule was a chamber which was closed by a plastic diaphragm. With increasing altitude, the fuel flow was throttled and with increasing ram-pressure the throttle valve was opened wider.

The Push-Button Starter

The starter system of the power plant was connected with the fuel-control system. We had found out in preliminary tests that, for safe starting of the pulse jet, it was important to bring a certain fuel quantity with a corresponding quantity of compressed air simultaneously and suddenly into the combustion chamber, so that no burning, but rather a violent explosion, should take place.

When compressed air was let onto the diaphragm of the stop valve for starting, it opened suddenly. At the same time the compressed air on the balance beam of the fuel-control system acted in such a way that the injection pressure was reduced to 1.2 atm. This starting method was very reliable and enabled us to use the push-button starter.

5. FLIGHT-TESTING OF THE V-1

The First Test Shot

Work on completing the first test V-1 had made extraordinarily quick progress, and the first test shot was fired on December 24th, 1942 — six months after the initial order. At this time no results of the flight measurements on the pulse jet, which would have rendered possible an optimum design of the governing system, were available.

During the flight tests the pulse jet proved to be rather a troublesome power unit. The sensitive carriers could not stand the high pressure fluctuations of the pulsating jet, and long repair work on the frames had to be carried out after each test flight *.

When the fuel-control system had to be supplied in the winter of 1942 we only knew that the pulse jet extinguished easily with too high a rate of fuel flow. In order not to endanger the initial tests of the V-1 the rate of fuel flow was controlled with the greatest precaution, and the flying speed was not at all satisfactory in the first shots. But progress was achieved, and speeds of some 600 km/h were soon reached.

Speed Crisis

It was just at the time of the invasion when a serious reaction set in. Peenemünde announced that the flying speed of the test equipment suddenly

* Practical flight tests carried out by the Argus Flight Department were of decisive importance for the airworthiness development of jet propulsion, and I wish to express in this place my special thanks to our Flugbaumeister Staege and Schenk for their valuable co-operation. In the evaluation of the results, Dr. Zammert and Dr. Flössel, and in the constructive development of the various fuel-control systems which were based on these evaluations, Messrs. Weiche, Belitz and Kreuziger earned special merit.

dropped to 450 km/h. As you can imagine, we were thoroughly upset. We were thinking of the cause day and night and finally found out: the altitude capsule of our fuel-control system had been covered by a plastic diaphragm. Without our being informed, this plastic material had been changed to another material which allowed the fuel to diffuse. Gasoline sometimes flowed over this diaphragm when testing the governing system, and this gradually diffused into the capsule. The altitude cell thus worked incorrectly and hence too much fuel and power were throttled at low altitudes.

A great number of low-speed V-1's were actually launched.

5.3. Increase of the Speed from 600 to 765 km/h.

We, the engineers, did of course not agree with this decision and we were finally permitted to substitute new altitude capsules. The speed was in this way increased to 645 km/h.

The results of our flight department had meanwhile shown that the rate of fuel flow would allow another increase of speed.

That was why, in August 1944, the ram piston in the fuel-control system was enlarged. The speed of the V-1 increased by another 50 km/h, but still higher rates of fuel flow led us to expect further improvements. We now modified the constant-pressure valve so that a higher injection pressure became available at the fuel nozzles. The result of this measure was another 75 km/h increase of the flying speed.

In order to achieve an optimum (Fig. 12), a new very simple fuel-control system was designed in which the constant-pressure valve was omitted and the

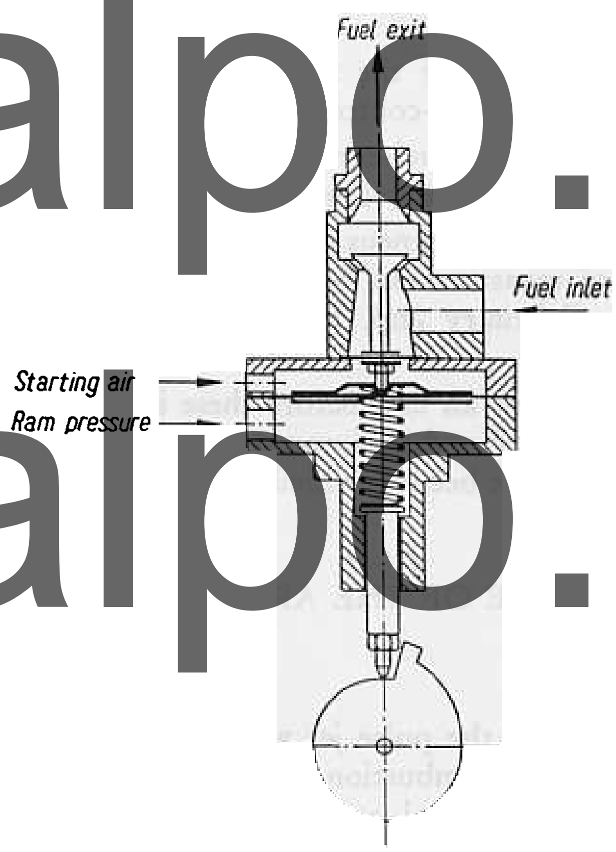


Fig. 12. Essentially simplified fuel-control system (end of 1944); adjustment of flight attitude by a cam

work of this valve was carried out by the throttle valve. Owing to the omission of the corresponding throttle losses we succeeded in using the full pressure of the fuel in the tank at the nozzles. Another 25 km/h of speed increase was thus obtained.

Fig. 13 shows the results. The upper curve shows the limit of the highest thrust obtained without superfattening. This limit was found by flight-testing.

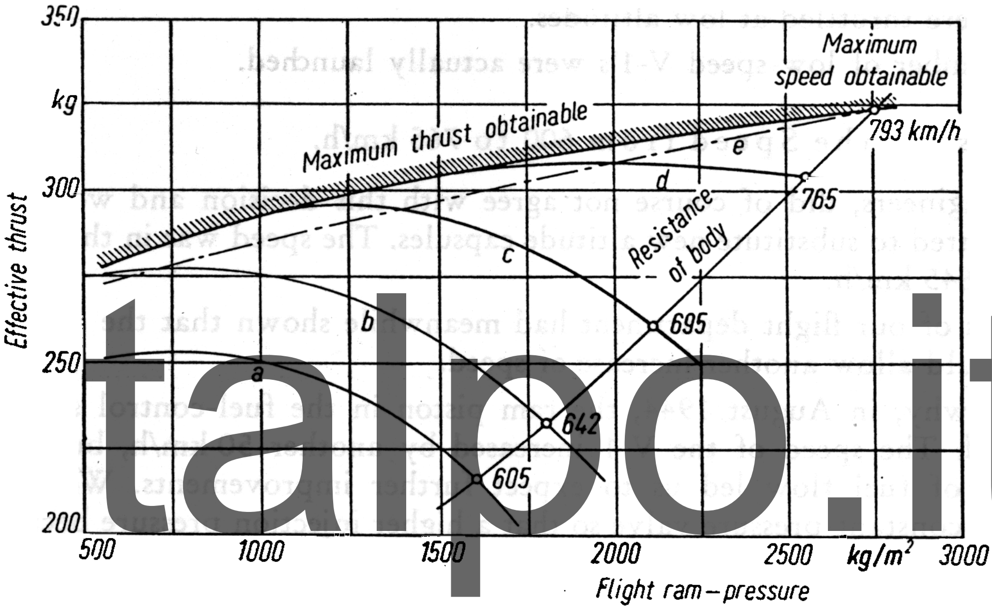


Fig. 13. Increase in flying speed of the V-1 from 650 to almost 800 km/h by adjusting the fuel-control characteristics to the possible fuel flow of the pulse jet As-014 which had been determined in flight tests

Other curves show the drag of the airframe and the thrusts achieved by means of the various types of fuel-control systems.

Only a few test types of the fuel-control system corresponding to curve *d* were constructed. The flying speed reached with them was 765 km/h.

We constructed only a few specimens of the single-valve fuel-control system (curve *e*). The results of measurement were reported in the last session of the V-1 Working Staff on February 2nd, 1945. The speed of the V-1 had been increased to 800 km/h!

However, the war came to an end before these improvements had reached the front. They had been achieved by improving the fuel-control system only, but the pulse jet itself had not been modified.

6. THE LAST TYPE OF THE ARGUS PULSE JET (1945)

6.1. Design

Fig. 14 shows that type of the pulse jet which was finally used for the V-1. The 3 m long pipe with the combustion chamber and the spark plug, the jet diaphragm, the valve box, the fuel nozzles with the fuel line and the intake cowling with the fork suspension, can be seen at bottom left.

The upper part of the photograph shows a sectional view of the head of the pulse jet. The line of the compressed starting air and the small tubes supplying

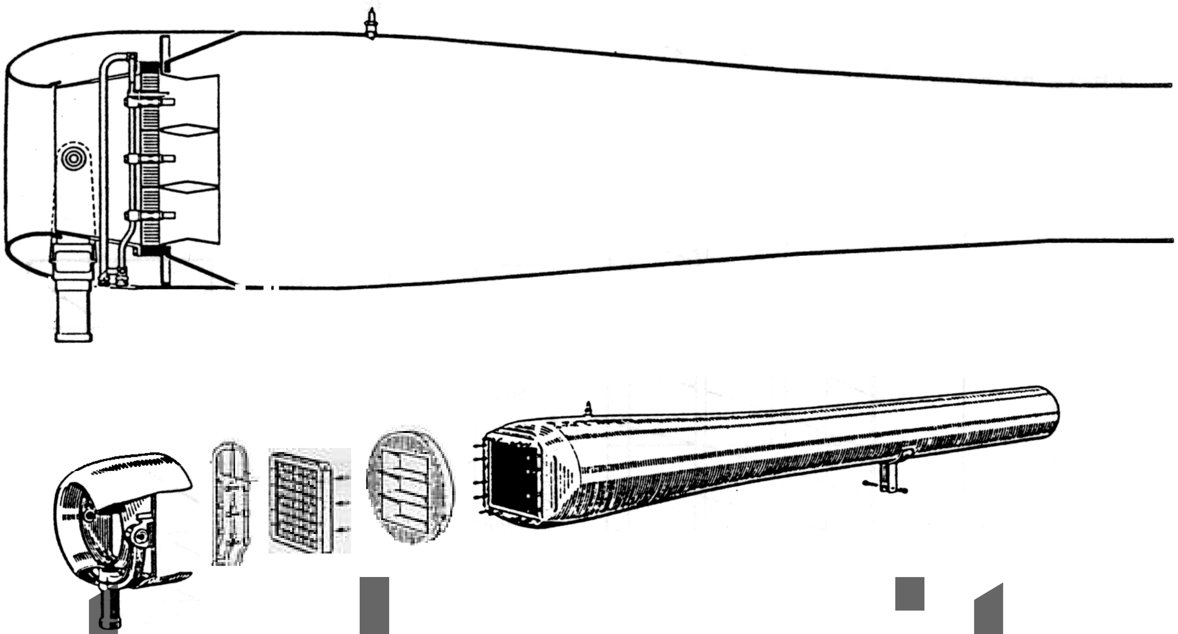


Fig. 14. The Argus pulse jet as constructed for the V-1 (1944/45)

the starting air under the upper three fuel nozzles can be seen. The fuel nozzles were constructed as swirl atomizers. At maximum speed they worked at a pressure of some 3 atm; good atomization was, however, also achieved at only 1 atm. These swirl atomizing nozzles contributed considerably to the good controllability and to the reliable starting of the pulse jet.

It was proved that the pulse jet could be controlled in such a way that it gave only 10 % of its full thrust without any irregular operation occurring.

The mixture formation plant was similar to that of our first model pulse jets. The fuel nozzle was also housed in a secondary chamber. The flame extinction was achieved by the increased mixture speed at the necked-down portion. It was proved that the nozzle diaphragm protected the sensitive valve spring flaps and the die-cast light-alloy nozzle webs from thermal overstresses, as the flame obviously did not reach the valve system.

Dimensions and Weights

This type of pulse jet gave a static thrust at sea level of 350 kg. Its weight was 138 kg for a length of 3.6 m. We achieved a thrust on the ground of 350 kg for a consumption of 0.8 g/kg.

6.3. Thrust and Consumption Curves

In June 1944 our flight-testing department had completed all the measurements which enabled us to draw the thrust and consumption curves.

Fig. 15 shows the thrust as a function of altitude and speed. The thrust continued rising with the speed in the measured range. Below 350 km/h the thrust was less than the static thrust at sea-level. We found later on that a diffuser at the end of the pipe was useful in this lower speed range, while it was disadvantageous above 400 km/h.

The absolute fuel supply increased according to the higher rate of air flow with rising speed (Fig. 16).

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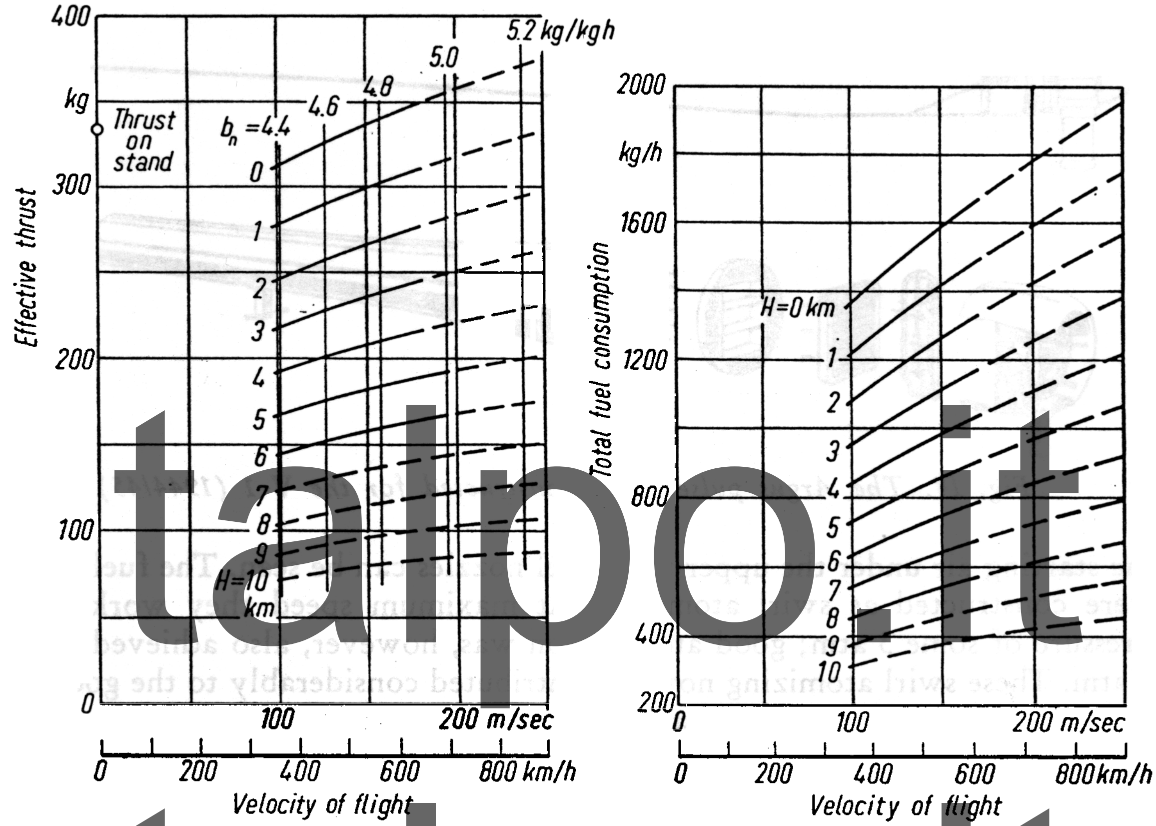
Our measurements had proved that the specific fuel consumption depended only on the flying speed (Fig. 17).

These were our last systematic flight measurements.



Figs. 15 and 16. Thrust and consumption of the pulse jet As-014

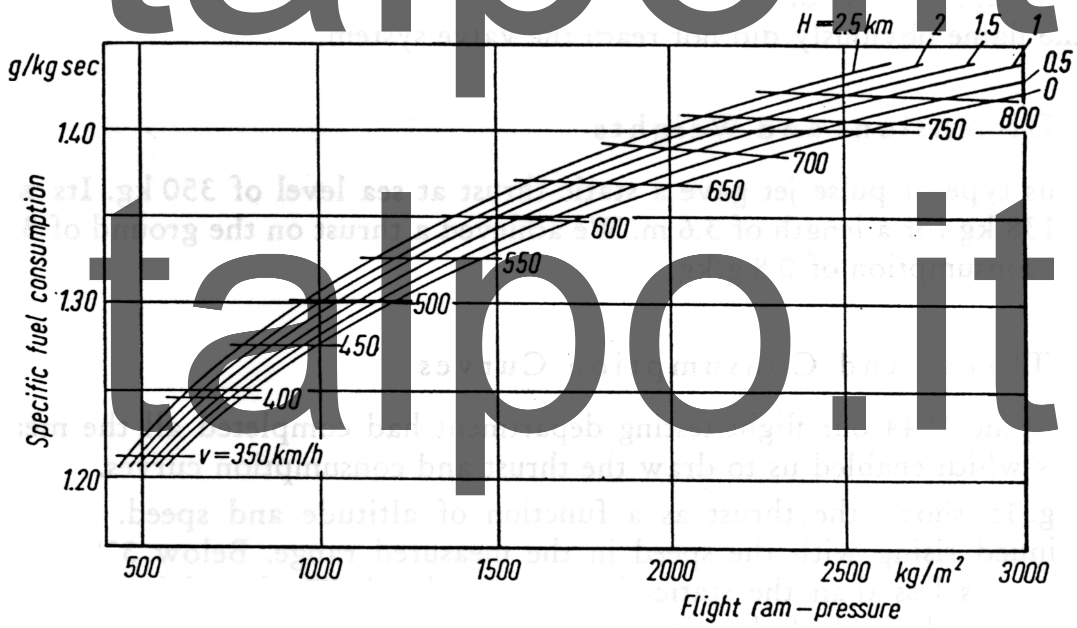


Fig. 17. Specific fuel consumption of the pulse jet As-014 at maximum thrust

7. THE FUNDAMENTAL WORKING PROCESS OF THE PULSE JETS

7.1. Ignition

The pulse jet was known to continue working after switching off the ignition. The phenomenon of self-ignition had already been observed by BARBEZAT. The following remark on this subject was published in the periodical "Die Turbine" in 1909:

"The new charge spontaneously enters the explosion chamber without any control and this process repeats automatically within a very short time. The upper part of the chamber and the nozzle pipe soon began to glow and the ignition could be stopped . . ."

This reference was interpreted in such a way that one could think the gas had ignited at the red-glowing wall.

A portion of our V-1 pulse jet began to glow, too, and we therefore had to ask whether the ignition were also started by the glowing wall in our case. Water-cooling was provided for the endurance tests of our pulse jet on the ground (Fig. 18). Under these conditions, however, the wall certainly did not glow.

Fig. 18 Endurance test of the Argus pulse jet on the ground with water cooling

The periodically switched-off or switched-on water-cooling showed that there was no difference in operation of the jet pulse with a glowing or with a cold wall. We therefore assumed that the wall temperature did not influence the ignition.

7.2. Gas-Exchange Process

It remained to be investigated how this simple apparatus could periodically suck in a new charge without needing any mechanical devices (as e. g. pistons, etc.). This subject had also been discussed in technical journals as early as 1909.

Then it was asked whether or not the cooling down of the combustion chamber played a part.

It was explained later on that the burning gases left the pipe like a piston and sucked in the fresh charge behind them. Still later on it was clear that the pulse jet worked in resonance. But this is a summarising explanation only.

We made it our task in the ARGUS Company to find out in detail the physical processes inside the pulse jet and we first succeeded in doing so in May 1941. We calculated the processes and showed them in an animated film *.

8 APPRECIATION OF THE PIONEER WORK

If we estimate the whole importance of these processes for the principle of the plant, we shall find that the long pipe is the essential part of the pulse-jet unit. The physical processes which are necessary for the working principle take place in this pipe and the ingenious thought of such a pulse jet is obvious. A very long pipe which is shut off by a valve on one side and which is acoustically excited by pulsations can suck in and discharge gases without the aid of any movable parts and can thus carry out a thermal cycle without any ignition device.

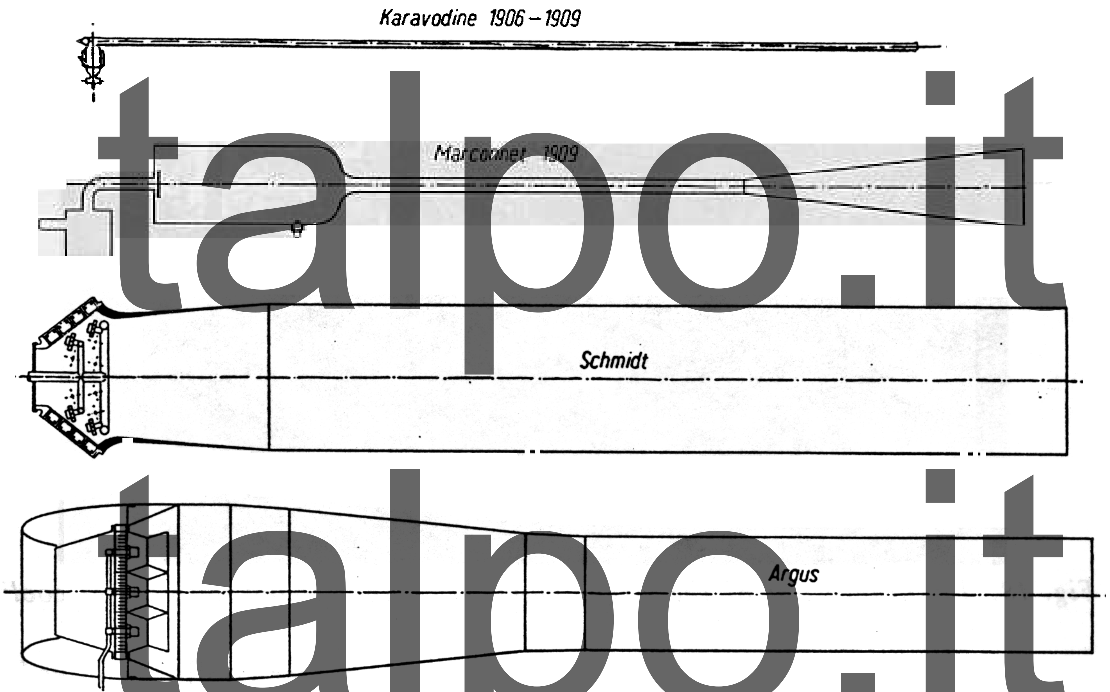


Fig. 19. The historical development of the pulse jet from 1909 to 1945

The realization of flying speeds of more than 750 km/h by means of so simple an apparatus is the success of an idea, and I think that we should remember the inventors and the pioneers of this peculiar engine, who are (Fig. 19):

* This strip demonstrates the movement of the waves in the pipe; it shows in particular how the pressure wave arriving from the combustion chamber turns at the open end of the jet, moves back as an expansion wave, opens the valves, and sucks in the fresh air load.

KARAVODINE, who talked about his idea in 1906 and who made endurance tests of many hours with a turbine;

BARBEZAT, who discovered and published in 1909 the principle of self-ignition;

MARCONNET, who suggested the use of the pulse jet as an aero-engine in 1909 and who was thus far ahead of his time;

PAUL SCHMIDT, whose merit and struggle for this unit which had gone on for many years will not be forgotten in the history of engineering.

The ARGUS Company was given the opportunity to develop this unique engine until it reached the stage where it could be used in a flying body. Thus ARGUS contributed to the realization of the long-distance missile in aeroplane form which had been suggested by the author in the first days of World War II.

DISCUSSION

Dipl.-Ing. PAUL SCHMIDT (Munich): The "tedious repairs to the bodies", which Dr. GOSSLAU quoted in his lecture as having been necessary after each test flight, were probably originated by insufficient elasticity between engine and body. This was, at any rate, the case with the V-1.

The Supreme Command of the LUFTWAFFE informed me in January 1945 of tests which were run during 1944 and which had shown strong oscillations of the bodies. It stated: "Moreover, it showed that the amplitudes decreased with increasing temperature of the pulse jet, but by then the navigation system had already been destroyed."

Several months before, I had received three or four pulse jets with their supports for testing purposes and I had found that the stiffness of the connection system between pulse jet and body was far too hard, and this resulted in a dangerous oscillation condition. Impulses with the period of the pulse jet could act on the body with a force of several thousand kilograms.

In 1942/43 the REICHSLUFTFAHRTMINISTERIUM had ordered an investigation on the previous works of MARCONNET and KARAVODINE quoted in the lecture, to find out if the power system of the V-1 was to be considered as a new type of engine. The results of this investigation led the ministry to call the engine of the V-1 the "ARGUS-SCHMIDTROHR".

Dr.-Ing. F. GOSSLAU: Based upon my remarks regarding the tedious repairs to the bodies, Herr SCHMIDT claims that the propulsion unit of the V-1 was not sprung softly enough against the body. In this connection he refers to an information obtained from the Supreme Command of the LUFTWAFFE in January 1945 concerning relevant tests in 1944.

I am under the impression that there errors in fact and in time are apparent.

Referring to the memoranda and notices which are still today in my possession, I want to reply as follows:

The propulsion unit was sprung against the body by voluminous rubber bumpers, the stiffness of which was altered in joint tests of the firms of ASKANIA and ARGUS so long until detrimental effects upon the control system were eliminated. These tests were performed on the test-stands of ARGUS at

Berlin from 22nd till 29th May 1943 for the compass. The main task of the "Working Committee V-1", which was strictly guided by the Air Ministry, was the permanent supervision of the operational safety and the permanent improvement of new weapons. If a fundamental constructional fault regarding the elasticity of the propulsion unit would have existed, quick and severe action would have been taken and an alteration would have been performed.

In fact, however, the damages to the bodies mentioned in my paper did not refer at all to the V-1, but to the manned test-carriers of our flight-test department (i. e. DORNIER and JUNKERS aircraft), and besides the damages occurring there had nothing to do with the transmission of thrust.

With those damages as mentioned by me we met for the first time in connection with transport gliders. Here the covering of the body consisting of woven material was often torn away in rags by the considerable variations of pressure caused by the rhythmic exhaust-bang of the operating pulse jet mainly near its outlet. Thus it was not the variation of thrust, but the accoustics (due to the working-principle of the pulse jet) the true cause of the damages.

Like the transport gliders, also the metal sheeting of the bodies of our test carriers (Do 17, Ju 88) was affected, and these repairs delayed so frequently the continuation of the flight tests.

The often misunderstood and criticized arrangement of the propulsion unit of the V-1 at the end of the body above the side control, and the duct which protruded far beyond of the end of the body were important factors for avoiding such damages with the V-1.

In brief, I would like to say to this subject that it was not the transmission of thrust which took so much of our time, but the enormous acoustics of this unit which damaged not only the lightly built aircraft, but even the brickwork of wind tunnels.

Prof. Dr. H. BLENK (Brunswick): I would like to add a couple of words to Dr. GOSSLAU's lecture. It must have been in 1942, when the LUFTFAHRTFORSCHUNGSANSTALT in Braunschweig-Völkenrode got an urgent inquiry from Peenemünde as to whether the ARGUS pulse jet could be tested in one of our wind tunnels. What had happened in Peenemünde was that the firing tests at high velocity showed that there was no longer a propulsive force. Obviously thrust and resistance compensated one another, so that the resultant force became zero. In Braunschweig we had a high-speed wind tunnel going up to MACH number 0.9, with a test diameter of 2.80 m, so that a full-size test pulse jet could be installed. Tests at those speeds actually revealed that the propulsion was nil, which means that the thrust equalled the resistance. In collaboration with the firm of ARGUS we then altered the pulse jet, especially the intake, from day to day and performed new tests. The firm of ARGUS based the alterations mainly on the proposals of Dr. ZOBEL — as far as I remember — with such haste that alterations were done within the day, and the new tests were done the same night. The wind tunnel tests led to a form which provided the necessary thrust for the V-1 at speeds of up to 700 km/h.

Prof. Dr. ERNST SCHMIDT (Munich): In his remarks dealing with the difference between the measurements of the effective thrust of the pulse jet placed on an aircraft and in the Völkenrode high-speed wind tunnel, Prof.

Blenk did not tell the whole story. I remember it in more detail. A careful investigation of the discrepancies of the measurements showed that the aircraft measurements which Dr. Gosslau mentioned in his report were actually wrong for the following reasons: the pulse jet was fixed above the carrier aircraft with the help of a frame and the thrust was measured electrically and integrated at the same time.

However, the integrating device worked quadratically and in this way the negative values of the thrust which really existed during part of each period of the pulsations were converted into positive ones. Thus, in contrast to the measurements, the effective thrust at the intended velocity of flight went down almost to zero and the whole V-1 would have been a complete failure if Th. Zobel had not succeeded in aerodynamically improving the air intake by adding an entrance-diffuser with a well rounded mouth. Only this favourable chance made it possible for the design flight speed to be reached.

Dipl.-Ing. Paul Schmidt: The remark made by Prof. Dr. Ernst Schmidt regarding an error in the measurement of thrust due to the periodical occurrence of a negative thrust points to too hard a springing between tube and body. It emerges from the curve in Fig. 14 of my paper (see page 23) that in the case of a too hard springing there will occur with the periodically generated positive thrust of 2000 kg a periodically occurring negative thrust of 1500 kg. However, with adequately soft springing no negative thrust is observed.

Dr. Gosslau: I would like to combine my replies to the remarks brought forward by Prof. Blenk and by Prof. E. Schmidt in this discussion. As I have mentioned before, work on the V-1 was speeded up with utmost energy and by all means available after the order was placed on June 19, 1942. In this connection the Luftfahrtforschungsanstalt in Braunschweig was asked in October 1942 to test the Argus pulse jet in the high-speed wind tunnel. A fast test plane equipped with an electronic device for thrust measurements was assigned to the Argus flight test department.

From this point there began a series of tragic errors which almost resulted in failure of the whole V-1 project. Braunschweig reported a disastrous decrease of thrust down to zero at 600 km/h. The thrust measurements of the Argus flight test department were wholly incomprehensible. The more we tried to reduce the resistance of the pulse jet, the worse became the effective thrust.

In this rather dangerous situation the German Air Ministry summoned, in the autumn of 1942, a committee of some 20 experts on research and production, the "Working Committee on Jet Propulsion Units". Here the results obtained by the Luftfahrtforschungsanstalt in Braunschweig and by the flight test department of Argus were discussed. The most important problem was: why does the pulse jet stop operating at high speeds of flight (in the Braunschweig wind tunnel)? — The general opinion was that at high speeds the flame was blown out of the pulse jet at its rear end which would terminate the working process. This statement was contradicted by our flying tests; yet the thrust measurements during the flying tests remained inexplicable. A pulse jet which was fitted with numerous collars on its outside to increase its rigidity, and which thus should have shown a high resistance, showed better effective thrusts than the same pulse jet without such collars. In view of this really senseless result, towards the end of November 1942 I sent Dr. Volland, our expert on measurements, to the flight test department with the order to check critically the measuring equipment. He found out on the same day that the measuring device recorded the negative thrusts, which necessarily occur in any working cycle, erroneously as positive values. This information was passed on by me on December 1, 1942 to the Working Committee on Jet Propulsion Units to which, as far as I remember, Prof. E. SCHMIDT also belonged, and his here remark probably refers to this fact. The measuring error was the fault of ARGUS, it was, however, also discovered by ARGUS.

Following the adjustment of the measuring device, the discrepancies in the results obtained in the Braunschweig wind tunnel became larger than ever before. Braunschweig insisted that the thrust would decrease to zero at 620 km/h; flight tests carried out by ARGUS revealed an effective thrust of about 300 kg at this speed. This was the state of affairs when, on December 24, 1942, the first test shot was fired which, apart from the unsatisfactory speed, was successful.

ARGUS then decided to use its own so-called blower test stand, i. e. a sort of wind tunnel generally used for testing air-cooled engines, for testing the pulse jet. A surprising result was obtained on the very first day of test. The relevant entry in the diary read as follows: "With a blowing velocity of 300 km/h the first test runs showed a thrust of 170 kg only. Running without blowing resulted in a thrust of 200 kg only. On the open-air test stand the same pulse jet showed the normal thrust of 320 kg."

The weekly report for the period January 6 to 13, 1943 stated: "The pulse jet measurements on the blower test stand were stopped due to the lack of coincidence with the measurements in the open, and following heavy damage caused by the tests to the brickwork."

In Peenemünde a wooden hut had been erected where the V-1 performed short test runs prior to being launched. After only a few such test runs there nothing but the timber frame existed. The walling had fallen off completely due to the effects of the operating duct.

I hope have shown by these remarks that in closed rooms a pulse jet can not be correctly tested as to its thrust. Any wind-tunnel measurement is bound to lead to faulty results, and this applies also to the measurements in Braunschweig quoted by Prof. Dr. BLENK. Of course, these critical remarks refer only to the pulse jet in operation. The cold resistance may be determined satisfactorily in a wind tunnel.

When, in May 1943, various intake-diffusers were suggested by Prof. Dr. BETZ, Dr. ZOBEL, Prof. Dr. RUDEN and by ARGUS, the diffuser proposed by Prof. Dr. RUDEN showed the best results with a gain of thrust of about 60 kg at 650 km/h. There can be no doubt that the effective thrust of the ARGUS pulse jet in the V-1 amounted from the very beginning to about 215 kg at 600 km/h (Fig. 13). The further increase of the effective thrust, resulting in the speed of the V-1 increasing to 790 km/h, has to be attributed to the knowledge that the pulse jet would stand a much higher rate of fuel flow than could be assumed in view of the initial lay-out of the governor. We owe this perception to the flight test department of ARGUS, to the Flugbaumeister STAEGE and SCHENK, to the evaluation of the results obtained by their flights by my collaborators Dr. ZAMMERT and Dr. FLÖSSEL, and finally to the constructional and experimental work on the adaption of the fuel governor for which Messrs. WEICHE, BELITZ, KREUZIGER and GEILER were responsible.

Admiral FAHRNEY (Philadelphia): The V-1 missile resembles, in most of its characteristics, the "Flying Bomb" project in America in World War I and the "Assault Drone" project in World War II. It was planned to use radio control in the earlier project and it was used successfully in the latter project. Since you were able to get good triangulation stations along the coast, why did you not use radio control in the V-1 for greater accuracy of directed flight?

Dr. GOSSLAU: Owing to tragic impressions received at the front towards the end of the first World War, the idea of an unmanned, teleguided aircraft has haunted me ever since. In April 1937, in agreement with the ARGUS factory, I submitted to the DEUTSCHE FORSCHUNGSANSTALT FÜR SEGELFLUG (DFS) and to the C. LORENZ AG, a scheme for collaboration on the subject of radio-controlled flying bodies which were not to carry persons, but only technical equipment.

The teleguided anti-aircraft target model, whose teleguiding equipment has been described by Dr. KLOEPFER was the first outcome. This model performed quite a successful teleguided flight on May 14, 1939 and may be regarded as the first teleguided flying body in Germany for military use between the two World Wars.

When, on November 9, 1939, I submitted to the Reich Air Ministry my first memorandum regarding a power-driven winged bomb having a range of about 600 km, I had of course visualized radio control. But it was just this proposal which delayed for so long the realization of the flying bomb. Electronics was one of the decisive bottlenecks of that period. Furthermore, interference and possible tracking by the enemy were feared.

Only when the Channel-coast was under German occupation and when compass guidance alone promised satisfactory hitting accuracy on large target areas, was the realization of this idea decided upon. Later on, as the V-1 actually flew, the idea of its teleguiding was taken up again, as Prof. FISCHEL has told this assembly.—