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ROCKETS AND GUIDED MISSILES

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COMBINED INTELLIGENCE OBJECTIVES

SUB-COMMITTEE

SECRET

ROCKETS AND DIRECTED MISSILES

Reported by
Mr. Gollin, M. of S.

CIOS Target Nos. 4/237 and 6/110
Rockets and Rocket Fuels
Guided Missiles

COMBINED INTELLIGENCE OBJECTIVES SUB-COMMITTEE
G-2 DIVISION, SHAEF (REAR) APO-413

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ELECTRO-MECHANISHE WERKE (PEENEMUNDE)

The Electro-Mechanishe Werke was a very large organisation divided into five departments. Each employee had a number on decimal system, the directors carrying single numbers, departmental heads two, section heads three, etc. The organisation was arranged as follows:-

EW.1.	Directors
EW.2.	Development
EW.2.1.	Design
EW.2.2.	Electrical
EW.2.3.	Ground Installation
EW.2.4.	Progress
EW.3.	Supply
EW.4.	Test
EW.5.	Purchase

In addition to the Peenemunde establishment various subsidiary works were maintained elsewhere such as at Anklam, Kummersdorf, Bleicherode, Lake Constance. As a result of the Russian advance, it was decided at the end of February to move most of the establishment to Bleicherode in the Harz Mountains. At the end of April with the collapse of the Western Front they were ordered to Ober Ammergau, but stated they feared extermination by the S.S. so they scattered to 12 villages around. They were collected for interrogation at Garmish-Partonkirchen. 5 rail cars full of radio and electrical test gear were found at the station at Peiting. The contents were examined and after an inventory had been made were returned to the trucks.

The Electro-Mechanishe Werke was set up to investigate liquid rockets using A stoff, a cover name for liquid oxygen. Separate reports are attached dealing with the three main weapons produced at Peenemunde, namely the A.4, Wasserfal and Taifun. The history of Peenemunde is given in Prof. v. Braun's "Survey of Development of Liquid Rockets in Germany and Their Future Prospects". (Appendix 1). Appendix 2 gives in chart form the particulars of the full range of "A" weapons from A.1 to A.7 and the future A.9 and A.10. These weapons were developed over the years 1933 to 1945. The work was originally done at the Rocket Experimental Station, Berlin, but Peenemunde was constructed in 1937 to 1938 at a cost of 300,000,000 marks to provide a secluded research station with apparatus to observe the rocket in flight along the Baltic coast. It was stated that the A.4 was the first of these weapons to be tested at Peenemunde. (DR.SCHILLING)

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A.T.O. Units

In addition to the weapons A.1 to A.10, Prof.v.Braun mentioned that they had developed in 1937 to 1938 a liquid oxygen assisted take off rocket which gave a thrust of 1 tonne for 45 secs. He could not remember the empty weight of the rocket, but thought that a pair would weight between 500 and 700kg. He stated that they weighed the same as Dr. Walter's H_2O_2 rockets but developed twice the thrust.

Expulsion was by nitrogen, ignition by firework and the oxygen vent valve was electrically operated. The combustion chamber was cooled by alcohol and they were dropped by parachute. These A.T.O. rockets did not get accepted by the G.A.F. because, due to evaporation, it was not possible for a number of aircraft to take off at the same time. About half an hour after they had been filled, a bell rang to indicate to the pilot that the appliance required topping up. If a flight of aircraft was about to take off, the bell might ring and delay the take off of some of the aircraft. Prof.v.Braun stated that he thought the empty weight of A.T.O. units was unimportant because of the greatly increased thrust given to the aircraft. He said that Dr.Walter's three fluid rocket was still in the experimental stage.

Test Stands.

There were 11 test stations at Peenemunde East, reading from North to South as follows:-

Test Stand No.7.

This was the test station in the large oval. The walls contained instrument "bunkers". The wall of the oval was not designed because of blast, but was meant to shield the test station from the sea wind which brought in sand.

There was a large rigid scaffolding in which the A.4 was strapped vertically, the whole was suspended from a large weighing machine so that from 1942 a complete rocket could be given a hot static firing test. The rocket was suspended about 7m above the ground and the gases were directed into a concrete pit shaped like a w. This pit deflected the gases upwards and was lined with molybdenum steel water pipes through which 500 litres of water per sec was circulated. The rockets were brought out of the large shed in which they were stored and adjusted. They were carried by a conveyor crane which lowered them into the scaffolding. The crane was kept there to protect the test workers from the weather and was then moved before firing. (ENG. TESSMANN)

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In spite of some evidence to the contrary a statement was made that actual flight firings were also carried out within the oval.

Test Stand No.1.

This was also designed to enable the test to be made of a complete rocket, but it was not regarded as satisfactory as No.7.

Test Stand No.8.

For static tests on thrust motors only.

Test Stand No.9.

For testing the Wasserfal.

Test Stand No.2.

This small stand was used for testing 1½ tonne rockets presumably A.3 and A.5. Later was used for testing valves and components.

Test Stand No.4 and 3.

Used for A.T.O. Units.

Test Stand No.5.

For testing Turbo-Pump units for A.4.

Test Stand No.6.

Wasserfal.

Test Stand 10 and 11.

Situated one on the sea shore and the other in the circle inland, were used for flight firings of A.4s and Wasserfal.

The A.4s arrived by railway and went into the big house where they were picked up by two cranes, the larger 32m high picked up the nose of the rocket by means of screw bolts screwed into the head. The small crane picked up the rocket in the middle and the rocket was transferred to vertical position. It was taken to Test Stand No.7 in a Brennstand wagon. (ENG.HEUER)

LIQUID OXYGEN

Liquid oxygen was made at Peenemunde. They had two compressors (each two cylinders). The storage tanks were spherical. They had two each 50,000kg capacity suspended from an iron scaffolding and insulated with magnesium powder. The liquid oxygen was made at the rate of 500 to 600 kg per hour. Peenemunde also received supplies of liquid oxygen by rail wagon holding 22,000kg. From the rail wagon or the storage installation the liquid oxygen was taken to the test stand in road wagons of which the smallest held 5,000kg and the largest 8,000kg. The road wagons were insulated with 30cm of magnesium powder. (DRIVER MANTEUFFEL) Eng. Barwald who was in charge of the liquid oxygen chambers for the A.4 said that the road wagon could hold 6,700 litres and were insulated with 5cm of glass wool (Hyporka) with a sheet metal outer covering. The loss from this wagon was 350 litres per 24 hour day. The liquid oxygen was pumped from the road cars to the A.4s by means of a portable petrol engine driven pump which could be carried by two men and mounted on the road cars.

The liquid oxygen was transferred from a road car to the inside of the A.4 by means of a long rigid pipe 7cm inside diameter covered with woven insulation.

Co-ordination of Peenemunde Technical Data.

Some 400 persons were maintained at Divisional Headquarters, Garmish-Partenkirchen for interrogation. Among these were many important men such as:

Gen. von Dornberger, in charge of all Rocket Development in Germany.
Prof. von Braun, Technical Director.
Dr.Steinhoff, Head of the Electrical Section.
Dr.Schilling, Static and Firing Tests.
Dr.Dannenberg, Head of the Design Section.
Dr.Fricke, Chief Designer for Solid Rockets of Rheine Metal-Borsig.

Unfortunately Dr. Tchinkel, the Chief Chemist was missing. All files and drawings were alleged to have been taken by S.S. Gen.Dr.Kammler, who may possibly have walled them up in a mine shaft at Bleicherode. Only 450 people were ordered to evacuate to Ober Ammergau out of the 4,000 who left Peenemunde for Bleicherode. Of the 400 in Garmish-Partenkirchen, Ben. von Dornberger and Prof.von Braun prepared a list of some 200 persons whom they said were of minor importance and could be sent to their homes. Everyone of these persons was interviewed and a proportion were earmarked for further retention.

The rest were given transport towards their home districts.

With regard to the 200 qualified engineers and scientists who remained at Divisional Headquarters, Garmish-Partenkirchen, it is obvious that in the course of two to three weeks work, it was quite impossible to extract the full story of the rocket weapons or to go deeply into any one of the scientific facts of this work. From the psychological point of view, although up to now most of the staff have been willing to talk, whether or no this will continue, will depend upon whether one can foster the confidence that the team will not be dispersed and may have the opportunity of continuing their work even if only on a very much reduced scale. The attitude of co-operation maintained up to now has been mainly due to the lead set by Gen. von Dornberger and Prof. von Braun, who take up the attitude that if they can convince the British and Americans of the value of their work, there is a chance that facilities may be offered in England or America for continuing it. Dispersal of the Section Leaders or removal of the management will destroy this attitude and the team as a whole may no longer be technically helpful. Should authorities wish to obtain the high altitude data as proposed by Prof. von Braun or to launch A.4s and A.9s, much time could be saved and risk to material and life avoided by utilizing the unique experience of this team of workers.

A.4. In the course of interrogating some 40 persons, the following details were obtained in respect to the construction, test and operation of Rocket A.4.

A. War Head.

Sometimes when rockets were launched they failed to fly along the controlled path, or due to a fault in the electrical connections the Power Cut-Off (Brennschluss) took place too early. Then the rocket would fall back to a place on or near the launching site. If the firing "programme" had not been completed the War Head did not explode on reaching the earth because the fuze was not armed until the end of the "programme". On the other hand such an accident usually resulted in an oxygen-alcohol fire and due to the heat generated the War Head was likely to explode at the end of half an hour. (PROF. v. BRAUN)

Skin Temperature.

Measurements have been made to ascertain the skin temperature reached during the rocket's downwards flight through the atmosphere at supersonic speeds. These were obtained:

(a) By means of models made of rubber-like materials in the surface of which thermocouples were inserted. The models were tested in the Peenemunde wind tunnels which were later removed to Kochel. The temperature of the skin was found not to exceed 600° C. (DR.HERMANN and DR.KURTSWEG)

(b) The skin temperatures were measured in flight by a method described by Dip. Eng. Schuler. Small discs of various metals of known melting point were inserted into the skin of the rocket and connected to electrical circuits. As each patch melted a signal was transmitted by telemetering to the observation station. The skin temperature now here exceeded 650° C. Prof. v.Braun demonstrated that although the film stagnation temperature might be as high as 1100° C, due to soakage and radiation, the skin temperature was not likely to exceed more than half this figure. He pointed out that if meteorological examination was made of fragments after an air burst, it would give a misleading result because such fragments would be heated to higher temperature than the normal skin temperature as they would be receiving heat on both sides of the skin during their passage as fragments through the atmosphere. Further the force of the explosion would give these fragments an abnormally high velocity.

B. <u>Alcohol Tank.</u>

According to Document B.14 which describes the choice of timing of the Brennschluss, the normal fuel content would be 3,797 Kg. of 75% ethyl alcohol and 25% water. During flight this tank was pressurized to 1.4 atmospheres. For 40 secs. this was achieved by ram compression through the pipe leading to the War Head. At the end of 40 secs the rocket reached a height where ram compression was no longer effective, so that the valve was shut by the "programme" control and thereafter by the nitrogen bottles in the radio compartment. The fuel tank was kept pressurized throughout the whole of the flight. (DR. ZOIKE)

No definite answers were obtained to queries regarding the cause of air bursts and it would appear that they were either uncertain regarding the cause, or unwilling to divulge it. Several persons (among them Prof. v Braun and Eng. Finzel) mentioned the difficulty of preserving the fuel tank during its downward path through the atmosphere. Apparently it was likely to be destroyed due to:

(a) Excess differential pressure between the external atmosphere and the pressure within the tank.

(b) Differential pressures on the fore and aft ends of the tank due to aerodynamic distribution of pressure on the outside skin of the rocket. As the skin was by no means air tight the pressure distribution within the rocket corresponded to that on the outside skin with a corresponding tendency for the tanks to have a large resultant force exerted on them towards the tail of the rocket. This tended to tear the tanks away from their connections to the chassis with consequent tank collapse which might cause an explosive mixture of alcohol and oxygen to be brought into contact with the external skin at a temperature of 500° C to 600° C.

In order to overcome these difficulties a new method of supporting the tank was developed. This involved holding the tank in broad sheet steel strips which were in turn attached to the chassis. Such a tank was found Blizna. About a hundred of this type were made and they avoided welding the suspension connections to the skin of the tank. They were rejected for operational use as it was too heavy. The capacity of the fuel tank was 4,460 litres. Some larger tanks were made for A.4 towards the end of the war, but were never used (ENG. FINZEL)

C. <u>Oxygen Tank.</u>

The capacity according to document B.14 up to the overflow point was 4,960 Kg. The same document describes the loss by evaporation while standing preparatory to being fired as 2 Kg. of liquid oxygen per minute. The range tables were drawn up on the assumption that a 30 minute wait before firing involved a loss of 60 Kg.

Prof. v. Braun said that sometimes during the filling operations they would be interrupted by enemy air raids. This caused a waste of liquid oxygen and under pressure from those responsible for the operational handling of the rocket, lagged oxygen tanks were tried. Prof. v. Braun said that the lagging was not successful as its heat capacity was such that it transmitted a large quantity of heat to the oxygen and this during the filling operation actually increased the loss of oxygen. The filling operation only took 12 minutes.

Although the Stoichemetric ratio of oxygen to alcohol-water was 1:0.64, they used operationally a ratio of 1:0.85

so that the equivalent of 3,797 Kg. of alcohol would be 4,480 Kg. of liquid oxygen. (PROF. V.BRAUN)

There would be some 400 Kg. of surplus oxygen and a quantity in excess of this might have been left in the oxygen tank after Brennschluss.

The vent valve was of an ingenious design and the object of the double seats was to enable the valve to open and shut at lower pressures. The valve served a double purpose. It could be held shut by high pressure nitrogen. It was so held shut to the moment of filling began and also during the firing period. The valve also acted as an automatic relief valve, opening and shutting to maintain a pressure of 1.2 atmospheres (gauge). During the operational period the heat exhanger was designed to maintain a pressure of 1.5 atmospheres (gauge) at the suction side of the oxygen pump. (DIP. ENG. ZOIKE)

In order to prevent collapse the oxygen tank was maintained with an internal pressure throughout the whole period of flight. They realised the danger involved if the vent valve failed to re-open at the end of the operational period, it being felt that the chance of it being iced up was remote. It was connected by a long pipe to the outer skin of the rocket. The valve was shut until filling began. Due to this the gases only passed in one direction, that is, from valve to atmosphere and hence there was no opportunity for moisture to get to the valve with consequent ice formation. It was agreed that the dangers associated with ice were far greater on wet days. The small Buna Piston used in the vent valve was adopted in spite of the advice of experts, but proved very satisfactory in operation. (PROF. v. BRAUN)

D. <u>Heat Exchanger.</u>
(Liquid Oxygen-Steam)

This was designed by Eng. Bodurfrig who was not amongst the staff kept for interrogation at Garmisch.

E. <u>Main Oxygen Valve.</u>

The main oxygen and alcohol valves when not pressurised by high pressure nitrogen were both open about 8 m.m. The oxygen valve with which we are familiar, having a small control valve, was an experimental type, the small valve being eliminated in later production models. The rhoostat was used to check the operation of the valve on the test stand by means of a Wheatstone Bridge and Oscillograph, but the troops in the field used the electric contact to check that the valve opened and shut correctly. (PROF.V.BRAUN).

They had a great deal of difficulty with the packing rings through which the operating piston of this valve slid. They tried Buna but it was not satisfactory because, although it did not break up at liquid oxygen temperature, it lost its resilience. Eventually they found a synthetic substance IGAMIT made by Venditor Kinstoff Fabrik of Fruisdorf, Nr. Cologne. They used this substance as the resilient outer sheath of the rings and had a centre hard core of tape wound construction vulcanized. The first samples of IGAMIT were extruded and proved to be very resilient at low temperatures. Later on when the rings were delivered, having been manufactured by pressure moulding, they were no good. (ENG. PASTWA)

F. Turbo-Pumps.

Eng. Hubner who formerly worked with Prof. Walter Keil went to Peenemunde and supervised the test of the Turbo-Pump units on Test Stand No.5. He gave the following data regarding this unit. The ratio of T stoff to Z stoff was 14:1. (Storage capacity 130 litres T stoff, 10 litres Z stoff). When the electrical contact was made to start the Turbo-Pump unit, both T stoff valves (main piston and solonoid by-pass) opened together and the unit came up to full speed in 3.5 secs. (Dip. Eng. Zoike in his description of the starting cycle said 2½ secs to full speed. Prof. v. Braun said 1/5 sec.) On the test stand the unit ran at 4,000 R.P.M. developing 540 H.P. During operation, the revs were from 3,600 to 3,800 R.P.M. At 4,000 R.P.M. the consumption of T stoff and Z stoff is 2.5 Kg/secs. Should anything go wrong with the turbine, least it should go too fast, it is provided with a "snellschlusse" which cuts off the T stoff at an over-speed.

The steam temperature as fed to the turbine was 400-420°C. It was essential that this should be kept constant. The T stoff as provided in the field would vary in its concentration and so adjustments had to be made by adding more or less water to the Z stoff. (PROF. V. BRAUN) This accounted for the rather unusual ratio of T stoff to Z stoff since for G.A.T.O.R. and H.S.293 the ratio was approximately 25:1.

The steam pipe was insulated for a dual purpose. To (i) keep the steam warm and (ii) to prevent fires which might occur should there be an alcohol leak in which case the alcohol might get splashed on to the bare steam pipe and ignite. The Z stoff was poured in from a can at the last moment before firing. It was warmed to about 30°C and might drop on standing to 5°C. The tank was described as being capable of standing for two hours at -20°C. If after a certain time the rocket was not fired, a door was opened in the side of the turbine chamber and a lance inserted which blew hot air over the Z stoff tank (the air was heated externally by electric means.)

Prof. v. Braun said the Turbo-Pump chamber did not get very cold due to a thin aluminium diaphragm which stretched right across the rocket underneath the liquid oxygen tank.

The range was controlled by the timing of the Brennschluss. They must have met severe difficulties due to "water hammer" which caused them to shut down in two stages. Stage 1 at the Vorkommando reduced the thrust from 25 tonnes to 10 tonnes in about 2 to 2½ secs. This was achieved by shutting off the main piston operating the T stoff valve, thereby reducing the flow of T stoff to 1/3 of its normal volume the revs now being 2,000 R.P.M. Later the solenoid T stoff valve was also shut and the thrust drops to nil in about 2 secs. There is a variation of this procedure which makes the pre-shut off stage 8 tonnes thrust.

Care is taken that no T stoff should enter the re-action chamber until there is an assured supply of Z stoff. The Z stoff on entry operates a diaphragm contact which in turn makes the necessary electric contacts to cause both T stoff valves to open. This diaphragm contact is known as the Rubidkontact.

G. Reducing Valve for Turbo-Pump Unit and Serve Valves.

The reducing valve was designed in Peenemunde. It had to control the low pressure at 33 atmosphere (gauge) with a reliable variation of 0.6 atmospheres. The valve was supposed to function while the high pressure bottles dropped from 200 atmospheres to 50 atmospheres (gauge). The valve contains two flexible diaphragms and its adjustment is sensitive to variations in temperature. When cold the valve does not function so accurately. In order to counteract this, the valve was electrically heated. (ENG. HOYER)

Eng. Bottcher was employed on testing reducing valves. The valve was tested by blowing nitrogen through from some high pressure bottles and allowing the high pressure to reduce slowly while the controlled pressure on the low pressure side was measured. He did not know the magnitude of the gas flow. The measurement was made by means of a Bourdon Tube, plus a Potentiometer, plus Oscillograph. The manufacture of these valves was carried out by three or four external firms. Another reason suggested for electrically heating the valves was to counteract the cooling of the nitrogen as it expands in the reducing valve. From 1944 onwards a great deal of the work on the rocket fittings was carried out at Anklam, about 40 to 50 Km. away from Peenemunde.

The normal delivery pressure of both pumps was 25 atmospheres (gauge). (ENG. HOFFMANN)

During the function of the power plant due to the quantity of liquid oxygen in passage from tanks to combustion chamber, the ambient temperature around the Turbo-Pump unit and combustion chamber fell to -10°C.

H. Combustion Chamber and Burners.

Prof. v. Braun said that the design of burner cups was his essential patent and formed the basis of all the "A" weapons. Just as T stoff was used as a cover name for Hydrogen-Peroxide, so A stoff was used for liquid Oxygen. There is a fair amount of evidence to indicate that most of the fundamental research associated with the "A" weapons was not done by Prof. v. Braun and his staff, but was carried out by various Professors at the Dresden Institute of Technology and at other similar institutions. The early work at Peenemunde before the war was concentrated on 1 tonne thrust chambers (probably for A.T.O. units). These chambers operated with only one burner cup with the type of which 18 are employed for A.4. The next stage was combustion chambers with 3 burner cups for 4 tonne thrusts. From this stage they went straight to the 18 cup assembly for A.4. It was preferable for the liquid oxygen and the alcohol to arrive simultaneously, but if one had to come first it must be the oxygen. In practice they found that it took about 1 sec to establish the flow of liquid oxygen. (ENG. LINDENBERG)

It is reported that in 1939 to 1940 Prof. Beck at the Institute of Technology, Dresden, carried out fundamental research on the combustion of alcohol and liquid oxygen. Small combustion chambers were built for experimental purposes. One of these had a thrust of 1 tonne. Experimental chambers were run for one minute. They were established in an experimental station at Kummersdorf. In 1940 Prof. Beck was transferred to the Institue of Automobile Engineering, Berlin, where he died the follwoing year.

It was reported that the combustion system of the A.4. was invented by Dr. Thiel. He was killed in the first large raid.

Eng. Hans Lindenberg said that from 1930 onwards he was doing research at the Technical School, Dresden on fuel injectors for deisel engines. He stated that the design of the fuel injection nozzles for A.4 was settled at Dresden.

They had a laboratory for measuring the output and for photographing the spray of the alcohol jets. Eng. Lindenberg said that:

(a) The output of the alcohol jets was constant for a given pressure drop across the jet, i.e., was not affected by the back pressure due to the pressure in the combustion chamber.

(b) The alcohol jets gave the same calibration during "hot" operation of the combustion chamber as was obtained during "cold calibration.

In the burner cups plain cylindrical alcohol jets were used at the cool end near the oxygen sprayer. Wide angled alcohol sprayers were developed for use at the hot end to keep the surface cool.

Eng. Lindenberg, from 1940 onwards, worked part of the time in Dresden and part at Peenemunde on the development of the combustion chamber. The normal atomizing pressure was 3 atmospheres.

Prof. v. Braun said that the flame front was established just inside or at the mouth of the combustion cups. He agreed that this condition was associated with a possibility that the combustion chamber head might get burnt, but pointed out that if the flame front is allowed to form at a distance away from the burners, the efficiency of combustion and specific impulse would suffer.

In respect to the cooling jacket, the frictional drop was reported as 5 atmospheres and the temperature rise would be from 10°C to 40°C, i.e. 30° C. (ENG. HOFFMANN)

Eng. Lindenberg said that the temperature rise was between 40° C and 60° C. He explained the functioning of the 36 screw plugs which are set in the wall of the combustion chamber in groups of 3 upstream of the ventury throat. Each plug is drilled with 4 small holes. What was not apparent from examination of a used rocket, was that before firing these 144 holes were filled with Woods or other low temperature melting metal. When the skin of the combustion chamber reaches a certain temperature the metal plugs melted and additional surface cooling is provided for the throat of the venturi. The metal strips in the cooling jacket serve a dual purpose of preserving the width of the cooling space and also carrying out the more important function of strengthening the combustion chamber at a point where it is most likely to suffer from any excessive pressure due to an impulsive start. There is one unexplained small connection to the large annulus at the feed-in and of the cooling jacket.

From this a small pipe was led to the outside of the rocket and this provided the only means of draining off the alcohol in the event of something going wrong during a combustion test on the test stand. (ENG. LINDENBERG)

Dr. Haller mentioned that for combustion chambers up to 1 tonne thrust spray cooling is necessary.

The mass flow of fuel was as follows as given by Dr. Palm:

During the first 5 secs operation (under gravity feed) 7 Kg/sec. (Eng. Hoffmann stated that there was approximately 8 kg. of each fluid per sec for the first 5 to 7 secs). When the pumps had reached full speed the mass flow of both fluids was 127 kg/sec which gave a thrust of 25 tonnes. (Dr. Zoike said that the mean thrust was 27 tonnes, the thrust rising by 4.2 tonnes in the course of flight.) (Eng. Hoffmann stated 135 Kg/sec which equals 60 kg/sec alcohol plus 75 Kg/sec oxygen.)

Various figures were put forward regarding the specific impulse obtained. Prof. v. Braun said that for operational purposes they reckoned on an impulse of 4.75.gm/kg/sec (210 lb/lb/sec) but on the test bed they had achieved an impulse of 4.5gm/kg/sec (220lb/lb/sec). The reported thrust of 25 tonnes with a mass flow of 127kg/sec is equivalent to a specific impulse of 5.08gm/kg/sec (197lg/lb/sec). Dr. Haller said that for relatively small combustion chambers they could use 95% alcohol as a fuel, but this gave too hot combustion chamber conditions for large chambers. The small chambers do not require surface cooling. Some six or seven years ago they tried using gasoline as a fuel. Prof. v. Braun said that it was unsatisfactory. Combustion conditions were not as good as with alcohol and persons working on the test stand were covered with soot. The main objection to the use of aviation spirit was that it did not function well as a coolant, tending to give unequal cooling to the different parts of the surface and also to form gas locks.

The venturi could not be designed to give the correct expansion, both at ground level and at the end of the firing period. During this period the thrust rose from 25 tonnes to 29 tonnes due to the decrease in the external pressure. As a compromise the venturi was designed for an expansion down to 0.85 atmospheres (absolute).

I. <u>Gas Rudders.</u>

Dr. v. Braun said that the graphite used for these rudders was the same as that used for electrodes in electric furnaces. He pointed out that the function of the gas rudders was to stabilize the projectile during the first part of its flight until it attained a sufficient speed for the tail fins to ensure stability. They had experimented and found that they could substitute oak gas rudders instead of graphite, because the oak would last for the necessary few seconds.

J. <u>Testing the A.4.</u>

All the fuel nozzles were independently calibrated and later were again calibrated in situ by means of a static cold blow-out test carried out on a combustion chamber unit from fixed weighed tanks. In this test the liquid oxygen was directed into flexible hoses back to a sump, while the alcohol was caught in a large funnel about 3 feet in diameter and led back to another tank.

Up to 1942 it was not possible to give the complete rocket a hot static test. The combustion chambers, however, were given a separate hot static test and the thrust was measured by large balanced arms weighing machines made by Sulz of Toledo, Nr. Cologne. The weighing machines had a needle on a dial as an indicator and this was photographed by high speed camera throughout the run.

They had tried to measure the thrust on a whole rocket before 1942, but the scales were not sufficiently accurate. From 1942 onwards, arrangements were made so that on Test Stand No. 7 the complete rocket could be suspended in a scaffolding which was hung from a weighing machine, so that the thrust during a hot static run could be measured. (ENG. TESSMANN)

The Establishment built up an elaborate range of instruments so that they could record the behaviour of the rocket during static tests. In order to ascertain the rate of flow of the working substances, special flowmeters and test gauges had to be developed for liquid oxygen and alcohol tanks and pipe. These instruments are described in a separate report recording information given during an interrogation of Dip. Eng. Schuler, whose sole concern was measuring and metering problems on the A.4 and other weapons.

In addition to making elaborate measurements on the thrust motor and the whole rocket during static tests, arrangements were made to measure and transmit to the ground station the more important data during flight. Dr. Schuler reported that he left Peenemunde with the second group evacuation and that he thought that most of the special instruments would be sent to Lehesten, near Salfeld, Leipzig where it was intended to continue work on combustion chambers.

All the instruments in the rocket were designed so as to operate indicators and recorders a considerable distance away. The instruments and observers were housed in underground observation chambers known as "bunkers". When testing thrust motors alone, the nearest bunker was 15 metres away. When testing whole rockets the procedure was regarded as being very much more dangerous and the instruments were housed in a bunker 100 to 150 metres away.

K. Firing the Rocket.

The range tables gave the brennschluss time and velocity for a given all up weight and desired range. Originally the Brennschluss was operated by radio command from a ground station. Later this was done by the Gyro-accelerometer and then by the Buchold Electrolytic Integrator. A fourth more accurate system was in process of being developed whereby the acceleration time curve would be kept constant by controlling the flow of T stuff to the Turbo-Pump unit.

The bearing was controlled by the rotating launching platform which was set in the same manner as when firing a gun. For this purpose a direction telescope and a Leitz Colimeter were used. The training of the projectile on the right bearing was done from the ground, so that it was first necessary to measure by optical methods the angle between the reference plate near the ground and the mounting of the gyro in the control compartment. (DR. ROSENTHAL)

Before filling the rockets the tanks and valves were tested for tightness by pressurizing the valves to 1.8 atmospheres and seeing if this was maintained for 5 minutes. The T stoff and Z stoff valves and tanks were also tested.

The liquids were put in the following order:

1.	Fuel)	
2.	T stoff)	These were all pumped direct
3.	Liquid Oxygen)	from truck to projectile.
4.	Z stoff	Poured out of a can.

L. Ignition.

When the rocket was ready to be fired an igniting torch was lit. There are two types:

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(a) A Pyrotechnic (black powder) ignitor, and

(b) A liquid operated torch using a "Hypergol" pair of fluids such as nitric acid and Visol.

They preferred the firework because the liquid ignitor required more attention and had to be refilled between each use. When the firework was alight the nitrogen was cut off from the main alcohol and oxygen valves, which caused them to open to their natural positions, namely about 8 m.m. open. The alcohol and oxygen now flows through the pumps under a gravity head from the alcohol tank and a pressure of approximately 1 atmosphere in the oxygen tank as the vent valve is held shut during the operational period. The flow of alcohol and oxygen which amounts to 7Kg/sec-15Kg/sec, according to different authorities, lights quite easily. If all 18 burner cups light simultaneously there is no shock, but if some ignite immediately and the rest later there is a moderate bang when this occurs.

These conditions are maintained for 5 or 6 secs until the operator is assured that ignition is satisfactorily attained and an adequate temperature exists in the combustion chamber. When only thrust motors are being tested the observer, being about 50 feet away, can judge by the glow in the exit from the venturi. If a whole rocket is being tested, the observer is much further away and they have used heat sensitive devices such as thermocouples to indicate electrically that ignition has been achieved. When this is so, the operator makes an electric contact which sets the T - Z stoff system in operation. The Turbo-Pump rapidly reaches full speed and while this is happening the thrust exceeds the weight of the full projectile, so that if it is not being statically tested it leaves the ground.

WASSERFAL. (C.2).

This guided anti-aircraft weapon had been in the course of development since 1940. At the end of the war it had not been used operationally, being still in the development stage. Evidence obtained at the Wind Tunnels at Kochel shows that at least six different shapes had been tried out to get the best aerodynamic results. The shape adopted for operational use is shown on Drawing No. on which all the dimensions are given in terms of the diameter. An approximate specification is given below.

Diameter - 88cms.
Overall length - 7.87 metres.
Span - 1.9 metres.

Empty weight - 1760Kg.
Weight of acid - 1600Kg. Weight of fuel 385kg.
Weight of high pressure nitrogen - 70Kg.
Thrust - 8 tonnes.
Duration of burning time - Slightly less than 45 secs.
Mass fuel flow - Approximately 45Kg/sec.
Specific Impulse - About 178lb/lb/sec.
High pressure N_2 260 atm. (gauge). Reducing valve 25-27atm(gauge)

Most of the information regarding the Wasserfal came from Drs. Heller, Palm and Zoike. The fuels to be used were mixed acid (90% nitric acid and 10% sulphuric acid) with Visol or Optolene. It is probable that the Visol (C_2H_5-O.CH=CH_2) would be mixed with Aniline to promote combustion, although mixed acid was described as being more readily self-igniting with pure Visol than straight nitric. The Optolene consisted of 5 components and was roughly made up of, 50% Visol, 10:20% Aniline, the rest being Optol (a coal tar raw product containing Phenol which inhibits the formation of C_4H_4), Benzol and Xylol (this also prevents the formation of C_4H_4 crystals.) The mixture is reputed to have a specific gravity of approximately 0.9. The Stoichemetric mixture was one part of acid:0.22 parts of fuel, but for operational purposes they used one part of acid:0.24 parts of fuel. The theoretical specific impulsefor mixed acid and Optolene was 214lb/lb/sec, but they actually obtained abour 183. Dip.Eng. Schilling who was over all experimental work at Peenemunde said that for practical purposes they accepted impulses 15% lower than the theoretical. Other figures quoted for these fuels were:

One part nitric acid plus 0.23 parts Visol, 214lb/lb/-sec.
0.9 parts nitric acid plus 0.1 part sulphuric acid plus Visol, 204lb/lb/sec.
0.9 parts nitric acid plus 0.1 part sulphuric acid plus Optolene, 204lb/lb/sec.

At a later interview Dr. Heller said that taking an average specific impulse of say 4.9gm/Kg/sec, changing the fuel from Optolene to Wisol etc only made a difference of + or - 1/10gm in the specific impulse.

It was hoped to store these weapons fully loaded with liquids for a minimum period of 6 months and preferably for a year before firing. As both liquid vessels were fitted at each end with aluminimum bursting diaphragms, it was essential that in storage the pressure within each tank should not exceed a pressure likely to burst the diaphragms which were designed to go at 10 atmospheres differential pressure. For experimental purposes a ullage space of 33 litres was left in the acid tank; for operational use 48 litres was left. In the fuel tank for experimental purposes they used a ullage space of 13 litres, but in the operational model this was between 18 and 20. The storage life was tested by filling at 10°C and then raising the ambient temperature to 40 or 50°C.

Below is given a description of the internal arrangements of the Wasserfal from fore to aft.

1. Radio and Fuze Compartment.

A great deal of work had been done on the radio steering device, proximity fuzes and Homing devices for this weapon. No definite decision had been made regarding the types to be used for operational purposes.

2. War Head.

Believed to be about 300Kg.

3. High Pressure Gas Bottles.

Diameter - 70cm.
Storage capacity - 235 litres (70Kg) nitrogen at 260 atmospheres (gauge).

They had experimented with compressed air instead of nitrogen, but the results were not available. The nitrogen bottle is equipped with hand operated valve, pressure gauge and filling connection. After this is an explosive operated starting valve presumably similar in design to that used on H.S.293.

4. Reducing Valve.

The reducing valve for this weapon had been specially designed because the gas used for the expulsion of fluids at such a high rate was a very large quantity, i.e. 33 litres/sec at the controlled pressure of 25 atmospheres (gauge). The low pressure controlling compartment was in a bellows and the loading was by a long powerful spring with an adjusting screw. The whole valve might weight as much as 10Kg and also from 50cm long.

After dispersal from Peenemunde in 1944, work on the internal fittings of the Wasserfal went on at Anklam.

The valve was manufactured for Peenemunde by Messrs Hubner, Maier of Vienna. Under test the valve did not give fully satisfactory results, as the controlled pressure apparently fell off when the high pressure side got as low as 90 atmospheres. They had apparently spent a lot of time trying to make the valve work well both at the start when it was subjected to heavy shock on the firing of the initiating valve, and at the end of operation when the gas bottle was nearly exhausted. (ENG. HIRN, ENG. TONNESSEN)

5. Three-way Valve.

According to Eng. Tonnessen, the gas after passing the reducing valve went to the three-way valve. This valve had four connections, one leading to atmosphere, one to the reducing valve, one which branched to the fuel tanks and one to a safety valve which opened in the event of the control pressure exceeding a certain limit during operation. The three-way valve was described as being operated by cartridge before the firing valve was fired. It carried two poppet valves and during storage the one leading to atmosphere was opened and the one leading to the fuel tanks was shut. On firing the first cartridge, this condition was reversed. If before launching the projectile one had fired the cartridge to close the vent valve and then decided for operational reasons not to fire the projectile, a second cartridge could be fired which would reset this three-way valve to its storage condition.

6. Tanks.

The gas line branched to the two liquid tanks which formed part of the skin of the projectile. The upper tank contained the fuel, while the lower tank contained the acid. They had apparently tried many methods of making the acid tank in order that the projectile could be capable of being stored for a long period. The following methods of construction were mentioned.

Dr. Palm. Steel with aluminum inner skin.
Eng. Tutz and Hellebrand. Maganese steel.
Eng. Tonnessen. Enamelled steel.
Eng. Bringer. 4% Chrome steel (Luftwaffe Specification No. 1604).

Before entering the tanks the compressed nitrogen had to burst two diaphragms made of aluminimum in which circular V grooves had been cut. The groove did not form a complete circle, the diaphragm being left uncut for a sector of about 30° in order to form a hinge when the gas pressure burst open the diaphragm and bent back the disc.

The forward acceleration of the projectile with a thrust of 8 tonnes must have been approximately 2.1g at the start and 4.5g at the end. It was designed for a lateral acceleration of 12g. With such lateral acceleration the meniscus of the fluids was described as standing at an angle of 20° to the axis of the projectile. There must have been alternative designs for the fuel tanks because Dr. Palm said that the swing of the fluid was dealt with by suspending a delivery pipe from the roof of each tank. The delivery pipe was articulated by means of a metal bellows. On the other hand Eng. Binger drew a sketch of the tanks which showed a central passage way through each tank. This passage way was used for the fluids and gas lines and the lateral acceleration was apparently countered by the provision of rotating feed pipes which followed the fluids to the side of the tank.

7. Jets - Combustion Chamber.

After leaving the tanks both fluids passed through aluminimum burster diaphragms and the fuel passed through a choke which compensated for the frictional pressure drop of the acid in its passage through the cooling jacket. (ENG. TONNESSEN) The acid passed through the cooling jacket at a maximum velocity of 4m/sec (width of annulus 5-6mm.) and rose in temperature 60°C with a pressure drop of 1.5 atmospheres. At arrival in the combustion chamber head both fluids were sprayed into the chambers by means of the arrangement shown on Drawing No. made by Dr. Palm. By this arrangement a quarter of the holes were devoted to jets of fuel and acid spraying against each other for ignition purposes, while the remaining 75% of the holes were arranged in pairs, fuel against fuel, and acid against acid to promote atomization. The pressure drop in the fuel jets was 2 atmospheres and in the acid jets 3 atmospheres. The combustion chamber had a capacity of 75 litres and a venturi throat of 192m.m. The L* was therefore 100". The designed combustion chamber pressure was 20 atmospheres (absolute) with a theoretical temperature of 2800°C. The molecular weight of the gas complex in the combustion chamber was about 26, the possible temperature after expansion 1600°C. They assumed that the gas complex "froze" at 1800°C. The combustion chamber was made of mild steel. There is no surface cooling.

With regard to ignition it was mentioned that no pair of fluids was used in a combustion chamber if it did not ignite in an open cup test within 0.05-0.1 secs. A check test was done in an atmosphere of nitrogen. Shortest ignition time for any pair of fluids was 0.025 sec.

8. Wings and Fins.

The general dimensions of these can be obtained from the Wind Tunnels at Kochel, but verbal information was obtained as set out below.

Eng. Dahm gave the span of the wings as 1m.60 and the length of the wings 1m. He stated there were no jet rudders, saying that these cut down the performance. He confirmed that the steering rudders extended beyond the span of the wings.

Eng. Hellebrand drew a sketch of the Wasserfal, in which the wings are dimensioned as span 1.88m., chord at the body 1.7m, chord at the tip .06m. section bi-convex. Steering rudders 80cm x 30cm. Eng. Hellebrand said that gas rudders were used.

9. General.

The Wasserfal was launched vertically. One engineer said that there were no gas rudders, but Dr. Heller confirmed that there were. It was possible that these were made out of oak.

Dr. Schilling and Heller were interrogated regarding the times of arrival of the fluids. One witness said the fuel arrived first because of the shorter path, but another said the acid arrived first. Dr. Schilling said that for the small rockets the time of arrival is not very important, but for the large rockets the nitric should arrive first. There is a double danger if either liquid is allowed to accumulate because an accumulation of fuel may go off suddenly, while an accumulation of acid may nitrate the fuel on arrival and form an explosive compound.

The accuracy of the metal burster diaphragms is uncertain and there may be a variation of as much as 1 sec in the timing of the bursters. Dr. Heller said that from the time you fire the firing valve to obtain ignition was about 5 secs, while from the ignition time to full thrust would be about 4 secs.

10. Testing

Instruments and valves were tested for their behaviour over one years storage by keeping them for 24 hours in a BIER-DAVIS bomb filled with oxygen at 25 atmospheres (gauge). This English apparatus was reputed to give the equivalent in 24 hours of one years life in storage. (ENG.PASTWA)

The Wasserfal was tested statically by mounting it vertically in a parallelogram so that it was free to move against a rigidly held MESS-BIEGEL. This consisted of an oval steel ring. The minor axis contracted when subjected to the thrust of the rocket. The dimensions of an air gap were thereby altered, modifying the induction in a coil mounted around the bar which formed the minor axis of the oval ring. This device was operated at 500 cycles, gave a deflection of $1\frac{1}{2}$mm for a thrust of 8 tonnes and was reputed to register the thrust to an accuracy of $\pm$ 1 to 2%.

Most of the instruments used for testing the Wasserfal were the same as for A.4, but special instruments had to be made for use in acid. (ENG. SCHULLER)

The Wasserfal was fired from a mobile circular platform carried on four wheels and pulled by tractor. Eng. Tutz saw a test firing of the Wasserfal and said that the combustion was rather spasmodic.

It is difficult to believe that such a long time could be tolerated for an anti-aircraft weapon and it is possible that the true time is 0.5 secs. The exhaust gases were a reddish-yellow colour. It swayed slightly as it went up.

TAIFUN.

This bi-liquid rocket was reputed to be fired in groups of 65 from a launching machine known as the Dobgerat named after General Dornberger the inventor. War head 500gm with contact fuze, range 12Km (can be vertical), maximum velocity 1200m/sec. The projectile is approximately 2.1m long and 10cm in diameter. The greater part is taken up with the fuel tanks which contain Vizol and acid. The acid is housed in a central aluminimum tank, capacity approximately 6 litres, while the Vizol is contained in the annula space between the outside tank and the shell of the skin. This has a capacity of approximately 2.75 litres. As the gravity of the acid is 1.59 the tank when full would hold 9.4kg, while the fuel tank, assuming a gravity of 0.91, would hold 2.5kg. The walls of both tanks were 1mm thick. The acid tank is supported in the rocket shell by two aluminimum end plates bolted to its end flanges. These end plates are perforated so as to connect the fuel tanks at the upper end to the cartridge pot and at the lower end to the liquid sprays. It is probable that at both ends a rupturing diaphragm of aluminimum covers the holes in the two end plates.

Behind a solid steel nose there is a hollow chamber for the 500gm of explosive, the fuze and the igniting device for the cartridge which, when burning, provides the gas to expel the liquids.

The combustion chamber and venturi are made of mild steel mostly 1mm thick, but the thickness increases at the venturi throat to $2\frac{1}{2}$ to 3mm. At the end of 2 secs operation, the temperature of the venturi reached 300 to 400°C. They could use a venturi experimentally for 5 runs, after which it had to be renewed. The sprayer was not found, but it was described as being in three parts and to resemble the rose from a watering can. (ENG SIEFERT)

It was reported that in the early stages of development they had repeated trouble due to the venturi burning. (ENG. FINZEL) The design of the stabilizing fins was modified several times. They had tried fins of different lengths (ENG. SIEFERT)

Total fuel content is possibly about 12Kg or, if one allows a 10% ullage space to prevent bursting of the diaphragms in storage, the workable fuel would be 11kg. As the firing lasted between two and three secs the mass flow of fuels must have been between 3.7 and 4.4Kg/sec. The thrust is described as being between 600 and 1000kg. Unless the design of the jets and jet plate added appreciably to the volume of the combustion chamber, the L^* with a throat of 45mm dia is very low, being in the order of 27". Prof. v.Braun said that they sacrificed the combustion chamber to get larger fuel tanks and accepted a S.I. as low as 160lb/-lb/sec. The empty weight including war head and cartridge would be about 12kg, as the proportion of liquids carried would be about 0.48:1. With such a small combustion chamber complete reaction must have been difficult, but if they obtained a S.I. of 180 the thrust would be somewhere between 660 and 800 kg. Mention was made of an acceleration of 60g, but this must have been at the moment of "all burnt". The starting acceleration possibly did not exceed 35g.

Testing.

When testing a Taifun on a static test bed, they often used nitrogen for expulsion. The thrust was measured by hydraulic piston. There was no evidence that the Taifun has passed beyond the experimental stage. (DR. SCHILLING)

B.M.W.

I visited the works of the Bayeriche Machine

Werkes near Munich with Lt. Oxol, Sqd/L. E.J.A.Kenny, Dr. H.A.Leibhafsky (U.S. Ordnance, and G.E. Co.) On the way we picked up Dr. Hemmersath the Chief Chemist. In this factory they concentrated their research on the use of nitric acid and mixed acids as the oxidant. They used hydrazine and a number of amines as the fuel. The acid was known as Salbei and the fuel as Tonka. Dr.Hemmersath said that they had tried 6,000 combinations of acid and fuels.

We inspected 12 pairs of combustion test chambers each pair having a control room. Each test chamber had two explosion proof windows. These windows consisted of two panes of submarine glass each 10cm. thick. Each pane was made of layers of glass placed alternatively at right angles to each other so as to avoid distortion. The two panes were about 12" apart, the inter-space being electrically heated and containing a drying agent. The walls of the test chambers were reinforced concrete 3 feet thick. The inspection windows during a test were covered by expanded metal counterweighted grills which were lowered into place. The chamber was lit by four floodlamps, one in each corner protected by metal grills. The object of the metal grills in front of the windows was not to protect the observer, but to keep the glass of the windows from being damaged by flying fragments. In all their work on liquid reaction chambers they have had many explosions, but have only had one casualty and that apparently was due to his own fault.

The exhaust end of each chamber was open to atmosphere, but about 30 feet away from the test chambers and parallel to them was a large thick flue, at one end of which there was a square brick stack with a compressed air injector. A mobile telescopic cylindrical flue could be wheeled into place opposite the open end of a test chamber, so that the products of the reaction could be led into the brick flue and hence to the stack. In the test chambers were thrust motors carrying cradles and thrust measuring gear of varied types and sizes according to the kind of thrust motor to be tested. There were small cradles for the double coil X.548. When tested these had a mass flow of 2 litres of fuel plus 8 litres of acid in a firing time of 20 to 22 secs. The average ratio of oxidant to fuel was 5:1 and the mass flow about 0.8Kg/sec. The liquid fuels were expelled by nitrogen pressure at 40 atmospheres and the combustion chamber worked at 35 atmospheres. Dr. Hemmersath said that the impulse was 1,000k/tonne/sec and also mentioned 1200 to 1400 k/tonne/sec. It is difficult to collate these figures with other known methods of specifying the impulse. Dr. von Braun at Peenemunde could not understand them, but suggested that they might represent the area of a thrust-time curve. If the mass flow was

0.8k/sec. and the specific impulse 180lg/lb/sec., the thrust would be 144Kg. which, over 21 secs., would give 3000k/secs. It is possible that in these figures there is some factor concerning the all up weight of the appliance. A similar curious figure was given for the larger model, the X.558, for which Dr. Hemmersath described the impulse as being 10,000 to 14,000 k/tonne/sec.

Dr. Hemmersath said that not all the pairs of fluids used were "hypergol", that is auto-igniting with each other, in which case they used independent means to initiate ignition. These are:-

a) Firework (Powder).
b) Electric spark.
c) A pair of fluids which reacted when brought into contact.

In this station besides testing X.548 and X.558 they ran the thrust motors for the Me.163 on acid and Tonka and there is some evidence that they also ran A.4 combustion chambers, Wasserfal and Enzian reaction chambers on these fuels.

There was a large test chamber for the calibration of acid and fuel jets. There was also facilities for testing thrust motors in any chamber from central tanks supported on accurate weighing machine.

Each control chamber had two complete sets of instruments and control gear, one for each test chamber. The chief instrument was that which recorded the thrust (as measured by hydraulic thrust piston) and the pressure in the combustion chamber. The control chamber also contained a great amount of electrical gear and indicators, so that continuity tests could be easily carried out on units before firing. In the control chambers were also the high pressure bottles and control gear for pressurizing liquid vessels in the rocket units. Towards the end of the test chambers was a large chamber in which spherical stainless steel or aluminimum tanks about 12-14 feet in diameter. These were suspended from the roof. There was also elsewhere mobile tanks for transporting nitric acid and H_2O_2.

I was given to understand that this factory, which also makes Turbo Jet Aircraft engines had been already covered by a C.A.F.T. team and by an investigation team, but if this is not the case, I consider it would be a first class target which should be thoroughly examined. This examination will be helped if Dr. Hemmersath and the other principal members of the research team, whom are apparently dispersed, are brought together and induced to part with the relevant information.

While interrogating the Peenemunde staff we found an Engineer Johann Tutz who had worked in 1940 to 1942 at the B.M.W., Berlin. There he was concerned with the design of the following rocket weapons:-

(a)	A.T.O. Units	Methyl alcohol plus nitric acid (self-lighting). Thrust 1 tonne for 30 secs. Liquids expelled by gas pressure from a combustion chamber. After use the units were dropped in with a parachute. Eng. Tutz could not say whether these units were used operationally.
(b)	Glide Bomb	This was the same as the H_2O_2 motor for HS.293, but used acid and fuel.
(c)	Rockets	They were planning to build rockets using acid and fuel as the propellent.

SURVEY OF DEVELOPMENT OF LIQUID ROCKETS IN GERMANY AND THEIR FUTURE PROSPECTS

by Prof. W. von Braun.

We consider the A.4 stratospheric rocket developed by us (known to the public as V-2) as an intermedicate solution conditioned by this war, a solution which still has certain inherent short comings, and which compares with the future possibilities of the art about in the same way as a bomber plane of the last war compares with a modern bomber or large passenger plane.

We are convinced that a complete mastery of the art of rockets will change conditions in the world in much the same way as did the mastery of aeronautics and that this change will apply both to the civilian and the military aspects of their use. We know on the other hand from our past experience that a complete mastery of the art is only possible if large sums of money are expended on its development and that setbacks and sacrifices will occur, such as was in the case in the development of aircraft.

A few private groups of inventors started serious work on liquid rocket development in Germany in the years 1929-1930. One of these groups, called "Rocket Flying Field Berlin", located at Berlin-Reineckendorf, had Prof. Dr. von Braun as a student among its members. Simple fundamental tests with rocket combustion chambers were carried out there, and small uncontrolled liquid rockets were fired, which reached heights up to 1,000 meters, and landed by means of a parachute. At the end of 1932 the work of these groups were slowed down by lack of cash, but the Army Weapons Department was interested in carrying on the work, and took over the services first of Prof. von Braun, and later of most of the other engineers.

This special division of the Army Weapons Department was put under the direction of Dr.Ing. h.c. DORNBERGER, and the first rockets developed by them were designed solely for experimental purposes, and were of no military value. In 1934, liquid rockets of the "A-2" type were successfully tried out. They had a thrust of 300kg., were directly stabilized by means of a large gyro, and reached a height of approximately 2,000 meters. In 1938 the first trials were carried out with liquid rockets of the "A-3" and A-5" types, which were fitted with an automatic control system and rudders in the gas stream. These rockets reached a height of

12km when fired vertically, and had a range of 18km when fired at an angle. They could land in both cases by means of parachutes, and be used again.

In view of the successful results achieved with liquid rockets, it was decided in 1936 to begin with the construction of a large experimental establishment for rocket development at Peenemunde on the Baltic. It was already recognized at that time that the development of rocket showed great promise in the field of aeronautics as well as in that of artillery, and it was therefore decided to build two separate establishments at Peenemunde, one for the Army and one for the Air Force, which are two distinct branches of the "Wehrmacht" in Germany. At Peenemunde-Ost, comprehensive test beds and work-shop facilities were set up for the construction and testing of rocket drives and controls, whilst at Peenemunde-West an airfield was built for testing rocket aircraft, and pilotless rocket propelled aircraft, as well as auxiliary drives for standard aircraft, such as rocket assisted take off devices. The cost of construction of the complete installation at Peenemunde totalled approximately 300,000,000 Marks after completion. This close proximity of the rocket development work to the aeronautical development side is one of the principal reasons for the success of the work undertaken at Peenemunde.

The following considerations were decisive in the choice of Peenemunde, and these considerations will always be important when choosing a site for rocket development work.

a) Secluded position, far away from large towns (Safety during launching, nuisance caused by noise of large test beds).

b) Favourable weather conditions (during firing and flight trials of rocket and rocket aircraft blue skies are always desirable).

c) Reasonably satisfactory communications. The development work necessitates constant close contact between development engineers and certain branches of industry.

The successful experimental rocket "A-5", previously mentioned had a thrust of 1500kg lasting 45 seconds. Basing on the results obtained with the rocket, the order was given to develop a long distance rocket with a range of 250km., as high an accuracy as possible, and a warhead weighing 1,000kg. This rocket, known as "A.4", was first

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launched successfully in October 1942. The "A.4" has a thrust of 25 tons, for combustion period of 68 seconds max. It is fired vertically from a firing table, without guides of any sort, as was the case with all the previous rockets. The steering of the rocket to an inclined position is effected by means of a "programme" apparatus. The lateral direction is determined by the exact setting of a turn-table on the firing table. The exact range is determined by shutting off the propulsion unit upon reaching a previously calculated speed.

The development of the "A.4" required a great number of preliminary scientific investigations, the most important of which are briefly outlined below:

a) Wind tunnel tests at all ranges of air speeds between 0 and 1500 meters per second. During these tests, such factors as the stability of the rocket, the distribution of the air pressure, the working of the rudders and several moves were investigated, apart from the drag measurements, both with and without exhaust gas stream. Both the supersonic wind tunnel and the measuring methods had to be developed over a period of years of hard work.

b) Test bed investigations on the combustion chamber of the rocket, and on the complete propulsion unit. This too necessitated the development of appropriate test beds and measuring methods.

c) Investigations connected with the steering of the rocket at all ranges of airspeeds covered by the rocket. For this purpose, a special technique of models, reproducing the attitude of the rocket in flight, was developed.

d) Development of measuring methods for plotting the complete flight path of the rocket.

e) Investigation connected with the influence of the exhaust gas stream on the wireless communication between rocket and ground, etc.

In view of the increasing strength of the numbers of flight aircraft in England, and the resulting increased losses of bombers operating against England, orders were given at the end of 1942 to produce the "A.4" rocket in quantities. The accuracy of aim was still unsatisfactory, and limited the use of the rocket to large area targets, foremost of which was London. Nevertheless, some 60 to 65,000 drawing modifications were required before the first experimental "A.4" rocket became a real series production job. This indicates how many absolutely new problems arose during the trials of the "A.4", which was subjected to hither unknown physical conditions.

Meanwhile the development side was attempting to improve the accuracy of aim of the rocket. To this end, radio guide beam devices were developed to improve the lateral direction, and improved propulsion unit out off devices to reduce the dispersion in range. These improvements however were incorporated operationally on a small scale only, and were in use chiefly in the attack on the harbour at Antwerp.

The original objective of further development was to produce long distance rockets of greater range. It should be noted here that the maximum ranges up to 480km. were achieved thanks to certain improvements, which however never came into operational use.

Certain A.4 rockets were used to carry out vertical trajectory trials, and a maximum ceiling of 172 km was reached during these trials.

It was planned in the spring of 1945 to fire vertically from an island situated near Peenemunde a few A.4 rockets equipped with special instruments for research into the top layer of the atmosphere. The measuring instruments were put in a watertight container capable of floating, which was to have descended by parachute. This project, all preparations for which were completed, could not be carried out on account of military events. It could be done in a short time however, with some of the A.4 rockets still in hand.

The problem of increasing the range of the A.4. after completion of the A.4 development programme could only be carried on at a greatly reduced rate, as the development of a guided anti-aircraft rocket was given first priority and absorbed much of the personnel, in consequence of the increasing air superiority of the Allies. A rocket for this purpose was developed at Peenemunde, bearing the code name "Wasserfal". This rocket was also propelled by liquid fuel, and could be guided by radio from the ground on to flying targets. Various successful tests were carried out, but series production of the weapon was not achieved.

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A further development of the "A.4" long distance rocket is the "A.9", on which work was done as far as the priority work on "Wasserfal" would allow. The propulsion unit was the same as for A.4. The A.9. rocket however had wings, which enabled it to glide through the stratosphere. This enables the flight path to be increased to such an extent that the range of the A.9 was nearly double that of the A.4, v.e. approx. 600km., notwithstanding the fact that the fuel consumption of the A.9 was no greater than that of the A.4 owing to development could not be completed on account of the end of the war. Special control devices would have given the A.9 at least the same accuracy as the A.4. It was proposed that the weapon should go into a vertical dive at the end of the glide, similar to that of the V.1.

As a further development, it was intended to design the A.9 winged rocket to carry a crew. For that purpose the rocket was to be equipped with a retracting undercarriage, a pressurized cabin for the pilot, manually operated steering gear for use when landing, and special aerodynamic aids to landing. The landing speed of this piloted A.9 rocket would have been as low as 160km per hour, as it would have contained very little fuel on landing, and would consequently have been light. This piloted A.9 rocket would cover a distance of 600km in approx. 17 minutes.

The range of the A.9, both in the piloted and the pilotless versions, could be increased considerably if the propulsion unit were switched on only after the rocket had attained a certain initial velocity. There were two possible ways of achieving this end.

1) Use of a long catapult with only a slight gradient, which would have given the rocket an initial velocity of approximately 350m/sec. There was experience of this type of catapult to hand at Peenemunde, as such a catapult developed by an industrial firm for launching the V.1, was tried out at Peenemunde. Experience showed that catapults could be built for launching at supersonic speed. These high speeds are essential for rockets such as A.9, because the rocket is completely filled with fuel at the start and would not fly if it left the catapult at lower speeds.

2) Development of a large assisted take off rocket of 200 tons thrust, on which the A.9 rocket would be mounted, and which would give the latter an initial velocity of 1200 meters per second. After the

assisted take off rocket has exhausted its fuel, the A.9 would become separated from it, and its own propulsion unit would be switched on. The maximum speed of the A.9 at the end of its power drive under these condition would be approx. 2800 meters per second, which would mean that this combination could give the A.9 a range of approx. 5000 km., both in the piloted and the pilotless versions. The large assisted take off rocket, called A.10, was to be equipped with air brakes and a special parachute, which would have enabled it to be used again after alighting on water.

It was proposed to launch the A9/A10 combination vertically this obviating the necessity of erecting large ground launching devices.

In the more distant future, the development of liquid rockets offer in our opinion the following possibilities, some of which are of tremendous significance:

1) Development of long range commercial planes and long range bombers for ultra high speeds. The flight duration of a fast rocket aircraft going from Europe to America would be approx. 40 minutes. It would even be possible to build very long range bombers, which would turn round at supersonic speeds in a very wide curve after having released their bombs, and return in and glide to land at their point of departure. The high speed of such aircraft would make defence against it ineffective with present day means.

2) Construction of multistage piloted rockets, which would reach a maximum speed of over 7500 meters per second outside the earth's atmosphere. At such speeds the rocket would not return to earth, as gravity and centrifugal force would balance each other out. In such a case the rocket would fly along a gravitational trajectory, without any power, around the earth in the same way as the moon. According to the distance of the trajectory from the earth, the rocket would complete one circuit around the earth in any time between 1 1/2 hours and several days. The whole of the earth's surface could be continuously observed from such a rocket. The crew could be equipped with very powerful telescopes, and be able to observe even small objects, such as ships, icebergs, troup movements, constructional work etc. They could

also carry out physical and astronomical research on problems which could only be tackled at that altitude, due to the absence of the atmosphere. The importance of such an "observation platform" in the scientific, economic and military spheres is obvious when the crew of the rocket want to return to earth, all they need to do is to reduce the speed of the rocket slightly, which can be done by rocket propulsion. The rocket then entered the upper layers of the atmosphere tangentically, and its speed is gradually reduced by friction. Finally it can land like an ordinary aeroplane by means of wings and auxiliary gear. It would also be possible to relieve the crew and provision the "observation platform" by means of another rocket, which would climb up to the platform and pull up beside it.

3) Instead of having a rocket set up an "observation platform" outside the earth, it would be possible later on to build a station specially for the purpose, and send the components up into the interstellar spaces by means of rockets, to be erected there. The erection could be easy, as the components would have no weight in the state of free gravitation. The work would be done by men who would float in space, wearing divers suit, and who could move at will in space by means of small rocket propulsion units, the nozzles of which they would point in the required direction.

4) According to a proposal by the German Scientist Prof. Oberth, an observation station of this Type could be equipped with an enormous mirror, consisting of a huge net of steel wire on to which thin metal foils could be suspended. A mirror of this nature could have a diameter of many kilometers, and its component facets could be controlled by the station which would enable the heat and light of the sun to be concentrated on selected points of the earth's surface. This would enable large towns for instance to get sunlight during the evening hours. The weather, too, can be influenced by systematic concentration of the sun's rays on to certain regions. Rain could be induced to fall on regions hit by drought, by concentrating the sun's rays on to distant lakes and seas, and increasing their evaporation. The clouds thus formed could be driven to the required spot by influencing the centres of low and high

pressure through radiation from other facets of the mirror. If the mirror is made large enough, and it could be of extremely light construction, it would even appear possible to generate deadly degrees of heat at certain spots of the earth's surface.

5) When the art of rockets is developed further, it will be possible to go to other planets, first of all the moon. The scientific importance of such trips is obvious. In this connection, we see possibilities in the combination of the work done all over the world in connection with the harnessing of atormic energy together with the development of rockets, the consequence of which cannot yet be fully predicted.

To conclude, we think after what has been said above, that a well planned development of the art of rockets will have revolutionary consequences in the scientific and military spheres, as in that of civilization generally, much in the same way as the development of aviation has brought revolutionary changes in the last 50 years.

A prophecy regarding the development of aviation, made in 1895 and covering the next 50 years, and corresponding to the actual facts, would have appeared at least as phantastic then as does the present forecast of the possibilities of rocket development.

In the same way as the development of aviation was not the work of a single man, but became possible thanks to the combined experience of many thousands of specialists, who concentrated exclusively on this one branch of science for years, so the development of the art of rockets will require a systematic effort by all specialists who have gained experience on this subject.

PROJECTILES SERIES "A" (LIQUID OXYGEN AND ALCOHOL)

NUMBER	YEAR	DIA. CMS	LENGTH M.	THRUST KG	TOTAL WT	FUEL	POWER TIME SECS	NOTES
1	1933	30	1.4	300	150	40	16	Directly stabilized by one large gyro (weight 40Kg) in the nose. Never launched. Many difficulties. N_2 expulsion. Intended to launch from a table vertically. S.I. 143
2	1934	30	1.4	300	150	40	16	As in A.1 but gyro placed in the centre. Successfully launched to 2000 metres. Launched vertically from table. S.I. 143
3	1938	75	7.6	1,500	750	450	45	Shape similar to A.4, launched vertically from table. Auto steering and rudders in gas stream. Did not obtain supersonic speed. Reached 1200m. in height. S.I. 167
4	1940 1942	1700	14	25,000	12,500	8000	68 max	Range 250 Kms. Warhead 1000Kg. Propam motor to bend over the trajectory. Vertical launch. Bearing from launching table. Range by fuel cut off. S.I. 208
5	1938	75	7.6	1,500	750	450	45	Experimental unit. Prototype of A.4. First model to use graphite blades. Could be landed by parachute and used again. Maximum range with slanting launch 18 Kms.
9	1945	1700	14	25,000	13,000	8000	68 max	As A.4 but with wings permitting a guide in the stratosphere. Total range increased to about 1600 Kms. Same accuracy as A.4 Vertical dive at end of glide. Also one man crew so retractable undercarriage. Pressure cabin and hand control for landing at 140-160metres/hr. 80% of construction as in A.4.
6								Designed but not constructed. A.5 did not reach supersonic speeds. Design modified to give higher speed and considerably different from A.5 so given new number.
7	1941	75	7.6	1,500	800	500	45	Designed only. A.5 plus wings. Launched horizontally from aircraft to obtain experimental data.
10		350	8	200,000	87,000	62000	50	Project only. Calculations completed for a unit to be used as a starting device for A.9. When A.9 and A.10 reach 1200m/sec, A.10 is jettisoned and descends by parachute. A.9 continues and reaches an "all burnt" velocity of 2800m/sec. Then A.9 glides. Total range A.9 + A.10 = 5000km.

GARMISCH 23.5.45.

FROM DOCUMENTS B14 - EX 5 RAIL TRUCKS AT PEITING.

Explanations of the Range Tables of the z.G.V. (Special purpose) Units.

August 1944

Example
for Radio Control (Switching off)

Distance (taking into consideration the curvature of the earth		225.0 km.
(1) B5 setting on line of site 3.5 km. back from the firing point II	= 3.5 km.	
1 km. to the left 1 to line of sight III	= 1 km	
Improvement to CA		- 2.1 km.
		222.9 km

(2) Improvement in starting weight according to Table A2

Empty weight according to papers		2,873 kg.	
Elefant (War Head)		1,000 kg.	
Additional load		-	
Fusing		5 kg.	
Batteries		45 kg.	
Druckstuche (H.P.Gas)		60 kg.	
A Stoff to overflow	4,960		
for 30 minutes waiting at 2 kg. per min.	60	4,900 kg.	
B Stoff to Table A1		3,797 kg.	
Starting weight		12,680 kg.	
Starting weight according to range tables		12,650 kg.	
Actual starting weight is greater by 30 kg.		30 kg.	
Correction according to Table A2 reduction of range = 0.9 km. per 100 kg. .•. for 30 kg.			- 0.3 km
			222.6 km.

June 16th, 1945
GJG/MP

FROM DOCUMENT B14 - EX 5 RAIL TRUCKS AT PEITING.

October 1944

Greater Range.

(1) Through charge to a higher value propellant, i.e. to. pure Ethanol-Water mixture filling from Methanol-Ethanol Water mixture.

(2) Higher reducing valve setting

The magnitude of the result at range is approximately:-

13 km. through charges from Ethanol Water mixture against Methanol-Ethanol Water mixture.

22 km. by increasing by 4 atmospheres the setting of the reducing valve.

---

35 km. from the combination of the two.

---

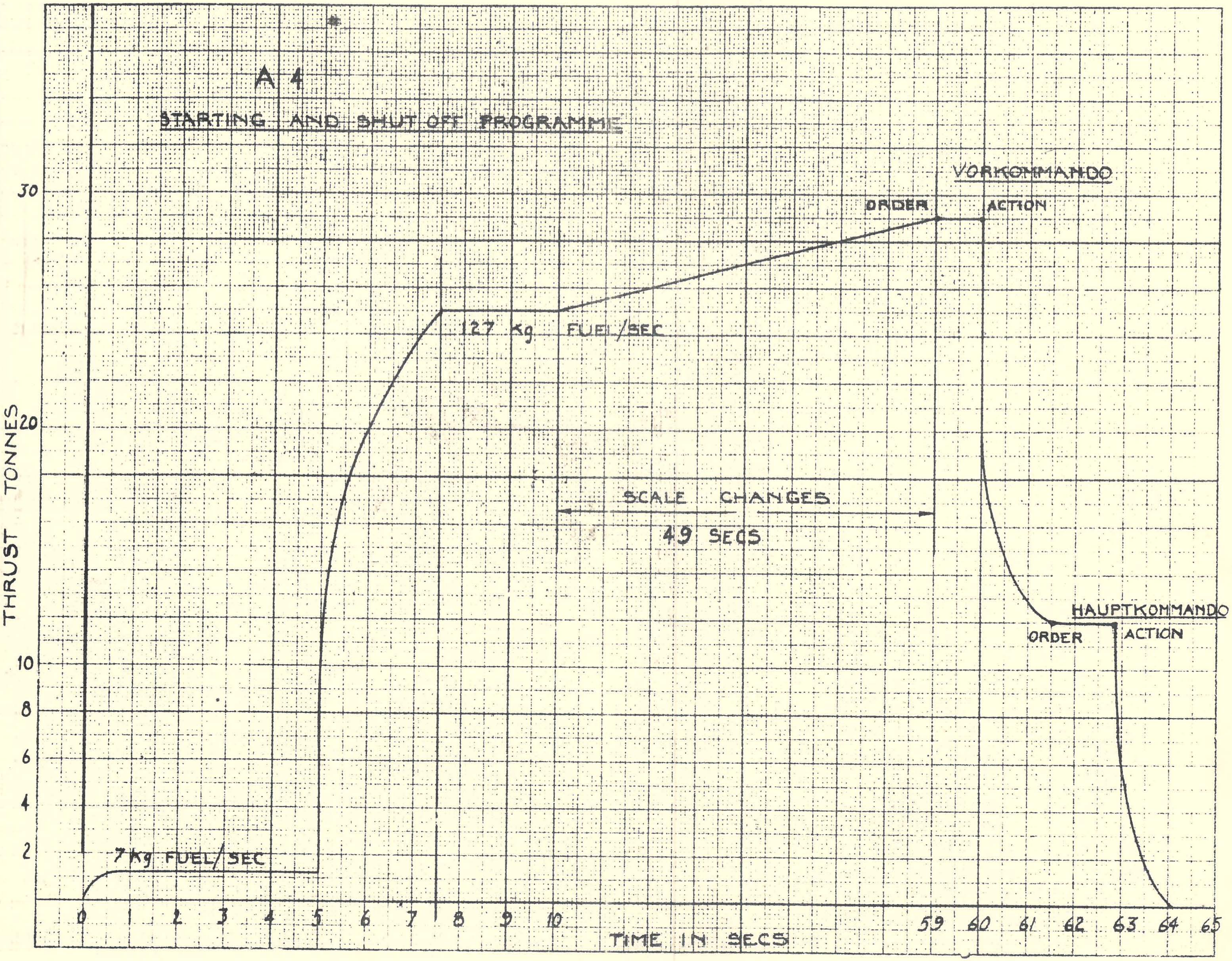
295 km. + 22 = 317 km.
317 + 13 = 330 km (205 miles)

Equivalent of the above in miles

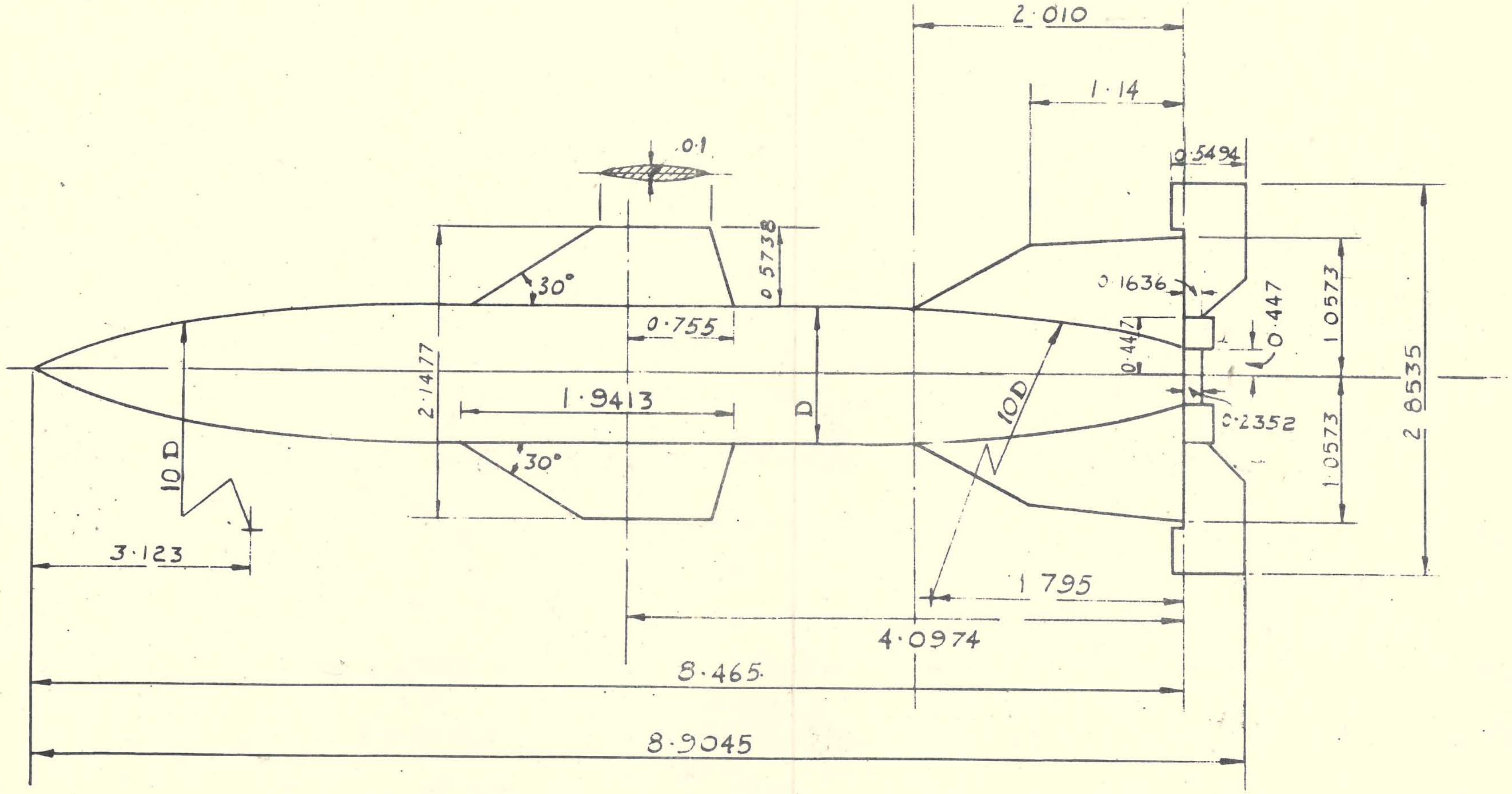
183 miles + 13.65 = 196.6 miles
196.6 " + 8.05 = 204.65 "
Athanol

June 16th. 1945
GJG/MP.

DRAWING No. 1



39209-2



WASSERFAL

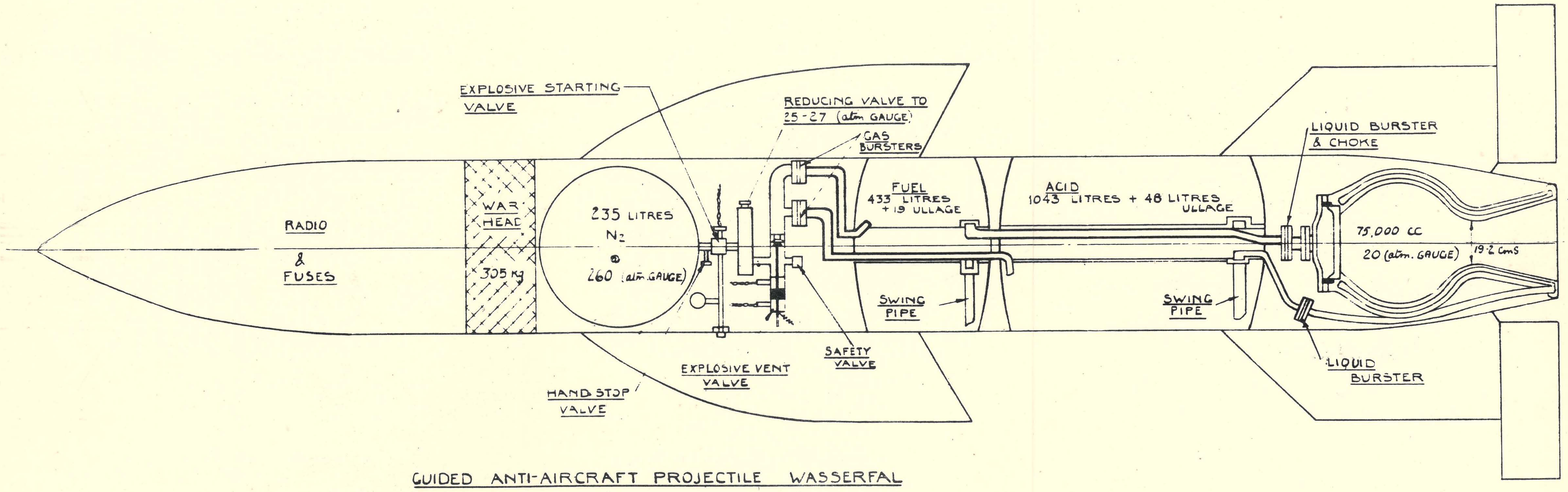
FROM WIND-TUNNEL MODEL (COCHEL)

DATE - 23·5·45

ALL DIMENSION ARE IN TERMS OF DIA
(ACTUAL DIA 0·88 METRES)

39209-2

DRAWING No.3



GUIDED ANTI-AIRCRAFT PROJECTILE WASSERFAL

DIAGRAMATIC LAYOUT OF PROPULSION UNIT

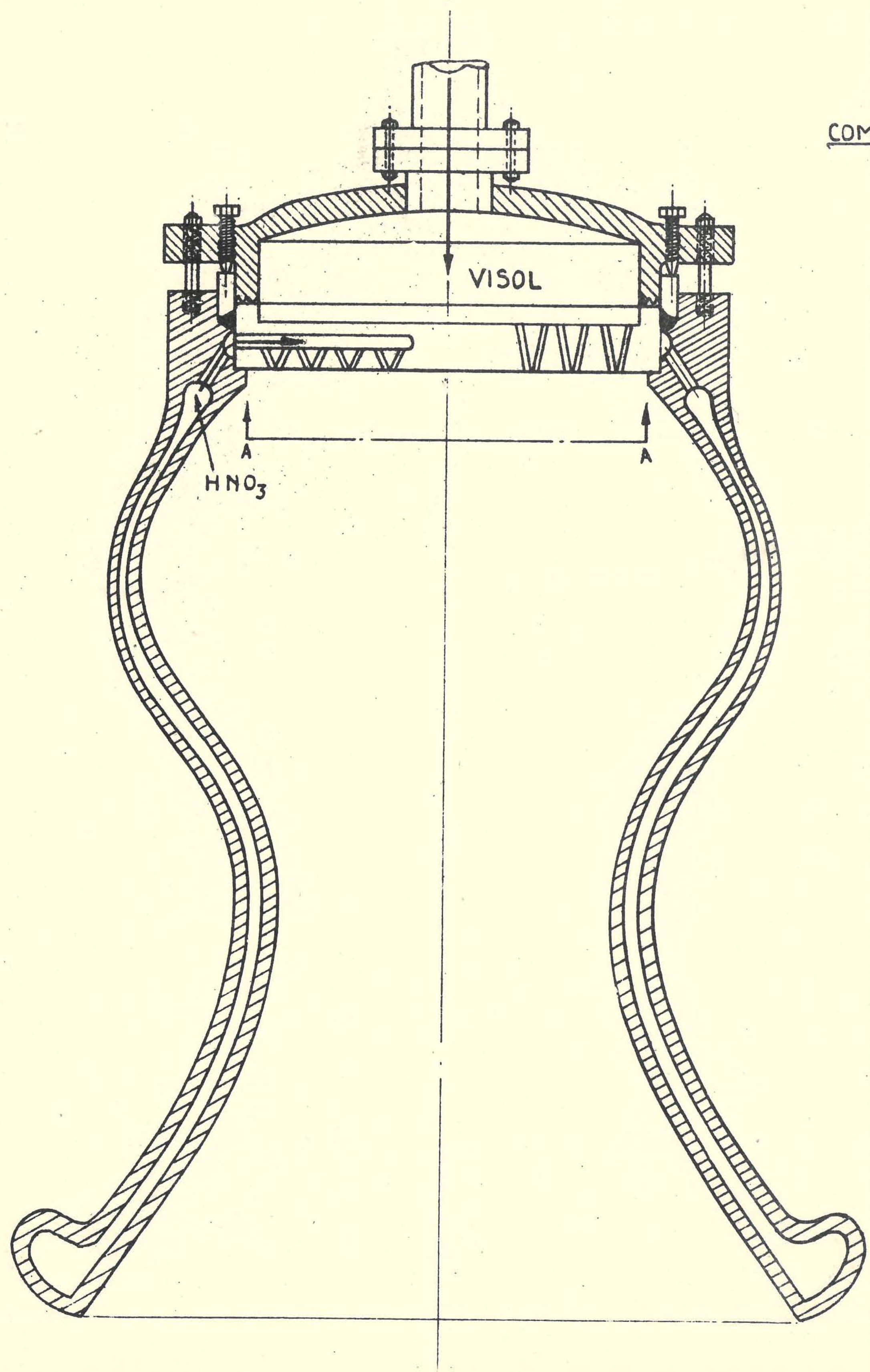
TARE 1760 kg FUELS 1988 Kg + N_2 70 kg

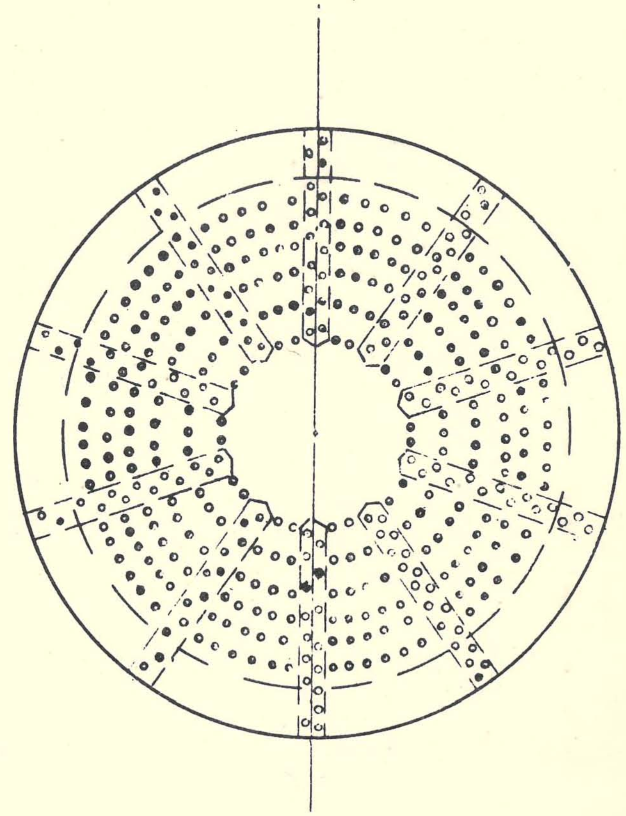
1/20 FULL SIZE

39209-2

WASSERFAL

COMBUSTION CHAMBER & JETS



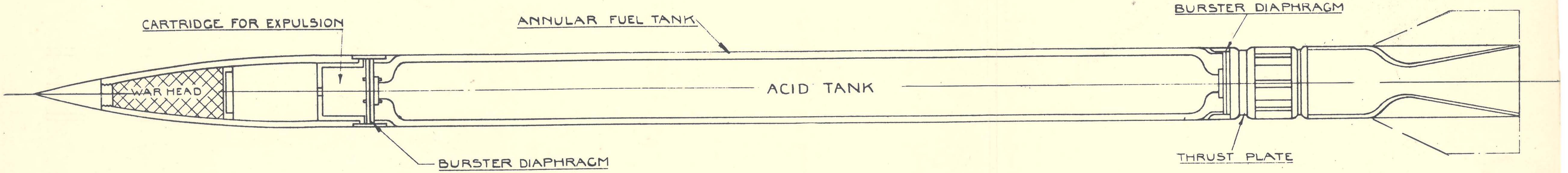


VIEW ON A-A

39209-2

TAIFUN — GENERAL ARRANGEMENT

1/5 FULL SIZE DATE 23·5·45



TOTAL LENGTH = 2·1 METRES

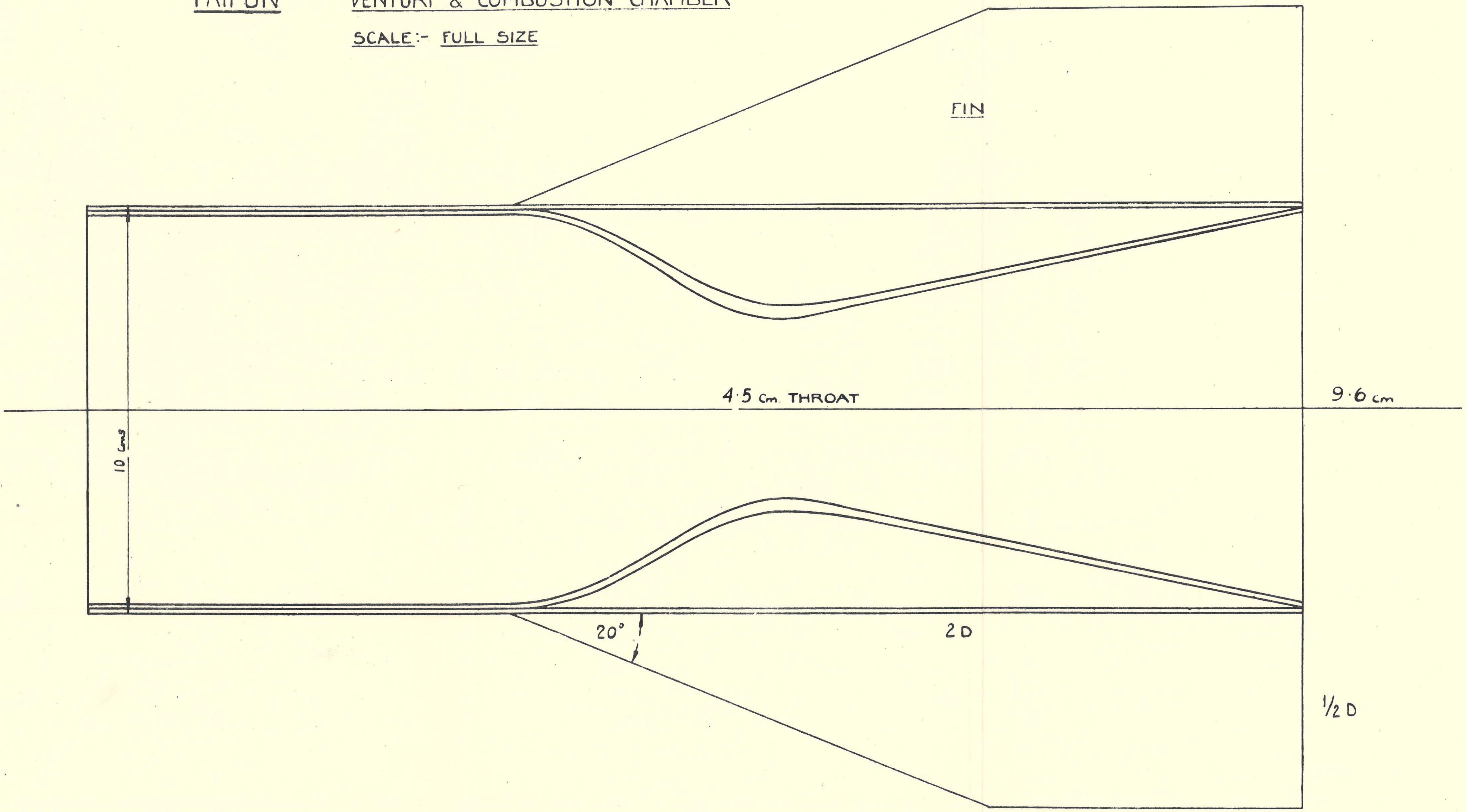
NOSE	1·3	KILOGRAMMES
OUTER SHELL	3·25	
INNER TANK	1·75	
COMBUST. CHAMBER	1·5	
THRUST BLOCK	0·73	
THRUST DISC	0·7	
REST	1·77	
	11·00	EMPTY WEIGHT
CHARGE ON W H	0·5	
EXPELLANT CARTRIDGE	0·5	
ACID	8·6	
FUEL	2·3	
TOTAL WEIGHT	23·0	KILOGRAMMES

39209-2

DRAWING NO. 6

TAIFUN VENTURI & COMBUSTION CHAMBER

SCALE:- FULL SIZE



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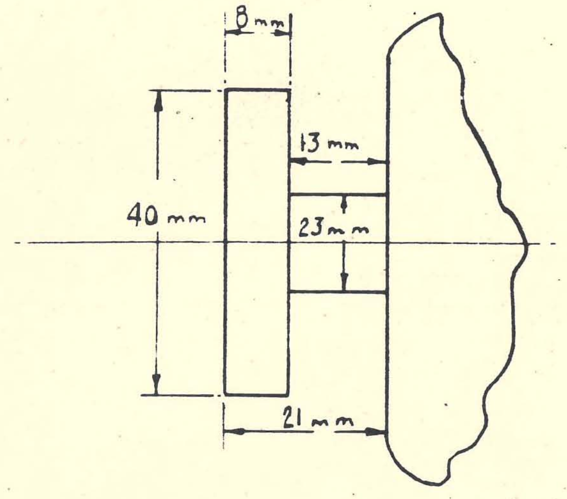
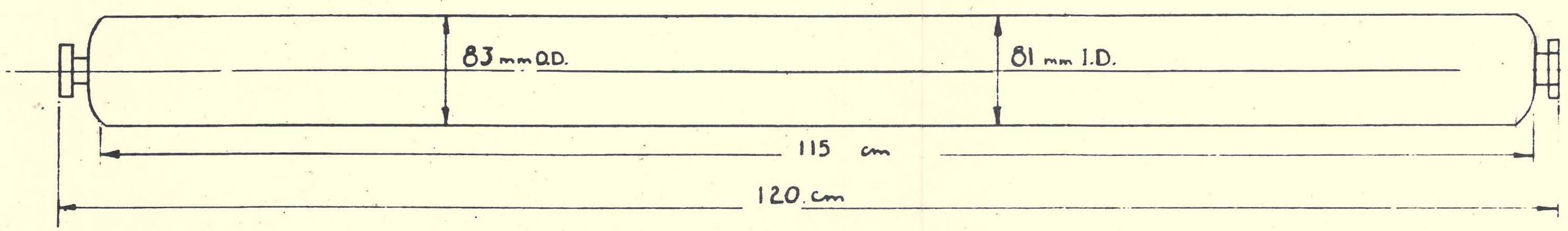
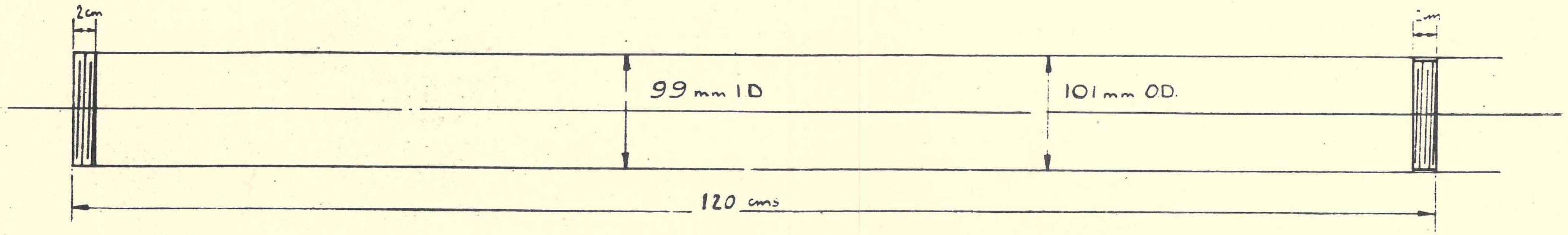


DETAIL OF TANK ENDS
FULL SIZE

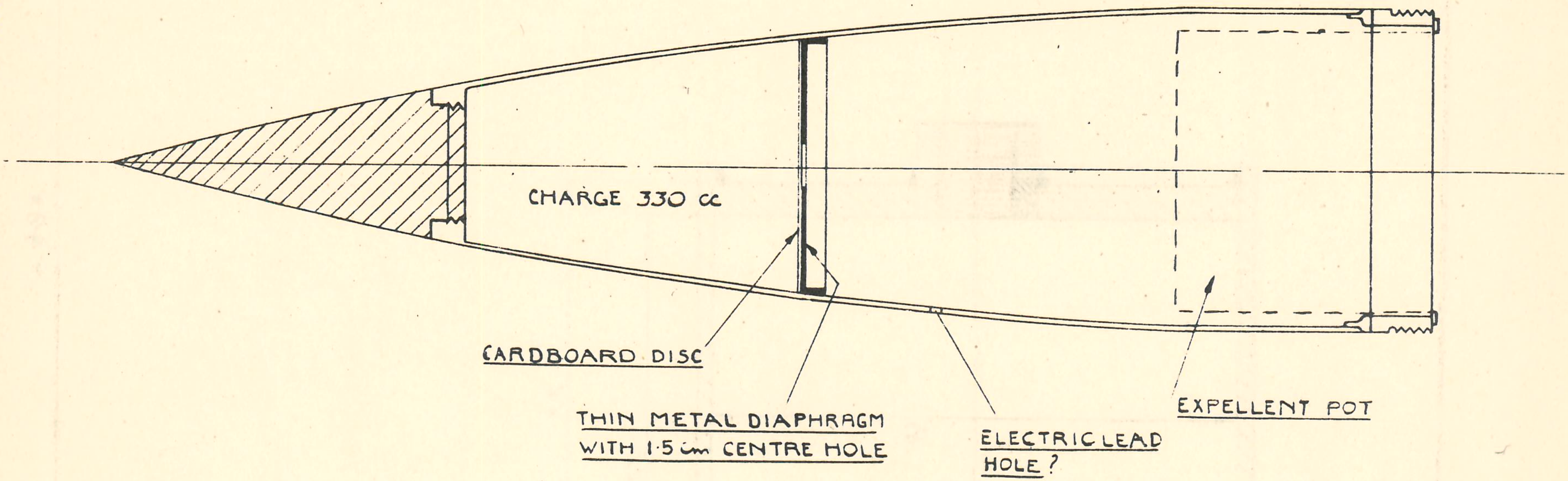


TAIFUN ACID TANK ALUMINIUM
SCALE :- 1/5 FULL SIZE

DATE - 23 5 45



TAIFUN ANNULAR FUEL TANK MILD STEEL
SCALE :- 1/5 FULL SIZE

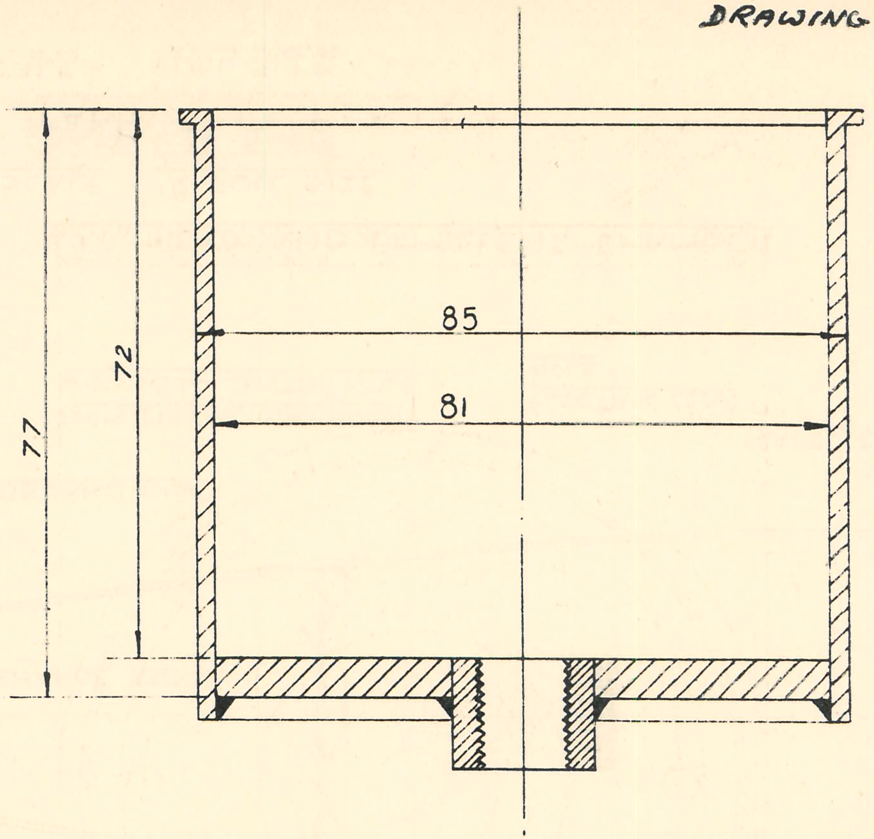


TAIFUN WAR HEAD AND EXPELLENT CHAMBER

SCALE :- 1/2 FULL SIZE

DATE :- 24 · 5 · 45

DRAWING No. 9



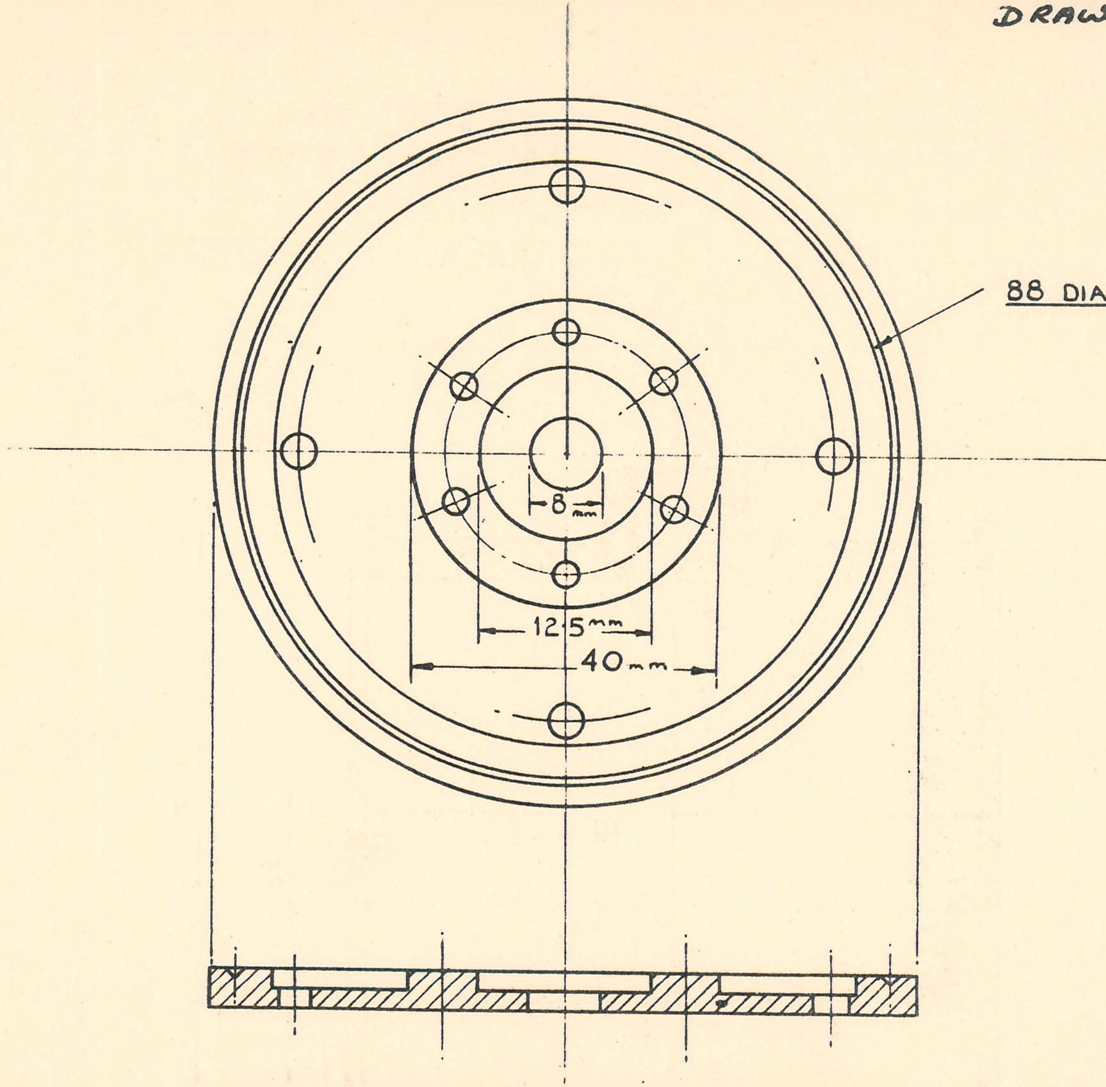
TAIFUN POWDER POT FOR EXPULSION

SCALE - FULL SIZE

DATE - 24·5·45

39209-2

DRAWING NO. 10



TAIFUN. TANK END PLATES

SCALE:- FULL SIZE

39209-2