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FILE No. XXVI-30

GAS TURBINE DEVELOPMENT
BY
B. M. W.

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COMBINED INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON—H.M. STATIONERY OFFICE

GAS TURBINE DEVELOPMENT BY B.M.W.

Reported by:
F/Lt. P.R. PRICE, R.A.F.
M.A.P.

CIOS TARGET NOS. 5/2, 5/74
JET PROPULSION

COMBINED INTELLIGENCE OBJECTIVES SUB-COMMITTEE
G-2 Division, SHAEF (Rear) APO 413

NOTE: This Report is based on the interrogation of those persons marked in the list on Page 5, et seq. and is intended to assist those concerned in further exploitation of BMW.

CONTENTS.

Investigator: F/Lt. P.R. Price, R.A.F., attached to Combined Advanced Field Team, Group 4, from 25.4.45 to 30.5.45.

B.M.W. AIRCRAFT POWER PLANT DEVELOPMENT ORGANISATION.

DEVELOPMENT MANAGER (O)
BRUNO BRUCKMANN.

- TECHNICAL MANAGEMENT — DR. SEIDEL. (K)
- MATERIALS & STRESSING — DR. WIEGAND. Dr. Scheinost. (O.Sp.St.)
- GOVERNORS — DR. NOACK (O.Sp.St.)
- PROJECT STUDIES — DIPL.ING. KAPPUS, Huber (O)
- FLIGHT TESTING — FLUGKAPITAN STAEGE, Dr. Denkmeir. (O.Sp.)
- WORKS SERVICES — EFFENBERGER (F.Bu.)

PISTON ENGINE DEVELOPMENT — DR. AMMANN (O)
- PROJECTS (& basic design calculations) (O) — SPIEGEL
- DESIGN (K) — DUCKSTEIN +
- EXPERIMENTAL (O) — DR. AMMANN, Willich
- MANUFACTURE (K) — DÄUMELING

JET ENGINE DEVELOPMENT — DR. ÖSTRICH (O)
- PROJECTS (& basic design calculations) (St) — HAGEN.
- DESIGN (St) — ROSSKOPF
- EXPERIMENTAL (St.Sp.) — H. WOLFF
- MANUFACTURE (St.) — OTTO

HIGH ALTITUDE TEST PLANT — DIPL.ING. SÖSTMEYER (linked by dotted lines to Piston Engine Experimental and Jet Engine Experimental)

ROCKET DEVELOPMENT — H. ZBOROWSKI (A)
- PROJECTS (& basic design calculs. — DR. RISTAU (A)
- DESIGN (A.Br.) — SCHNEIDER, ZIEGLER
- EXPERIMENTAL (A) — SCHNEIDER, MUCHA
- CHEMISTRY (A) — DR. HEMESAT
- DEVELOPMENT (Z) — SCHELL
- MANUFACTURE (Br.) — ZIEGLER, HOERL.

O-SERIES PRODUCTION (O) — DR. DONATH.

(For Key, see over).

KEY TO PLACES.

A = ALLACH near MUNICH

Br = BRUCKMÜHL near ROSENHEIM

Bu = BURG near Magdeburg.

F = FURSTENFELDBRUK near MUNICH

K = KOLBERMOOR near ROSENHEIM

O = OBERWIESENFELD near MUNICH

Sp = SPANDAU near BERLIN

St = STASSFURT

Z = ZÜHLSDORF

+ = Killed since the occupation.

NOTE: These places indicate where the work was carried out in the state of dispersal which existed immediately before the occupation.

BOARD OF DIRECTORS AT B.M.W.

Dr. Shaaf - Managing Director. Came from Speer's staff. Was General Manager at BMW/Eisenach for many years.

Dr.Stroffregel - Technical Director at Stassfurt. Responsible for archives. Came from Speer's staff.

Dr.Bruno Bruckmann - Development Director at Oberwiesenfeld.

Dr. Fiedler - Automotive Director.

Dr. Scholl ; Director for Finance.

This Board had been in office for about six months. Prior to the occupation it had decided on a policy of full co-operation with Allied investigating agencies.

Shaaf's predecessor was named Fritz Hille.

NOTES ON B.M.W. PERSONALITIES.

* interrogated by the writer
ø should be interrogated by U.K. and U.S.A. equivalents.

* Biefang, Dr.

Deputy to Bruckmann for the Kolbermoor plant where design work on 003 and 018 was to have been continued. Previously occupied Ammann's position as head of reciprocating engine development. Of those interrogated he had the best knowledge of design features of piston and jet engines, and I would judge him to have more influence in questions of mechanical design than anyone else at B.M.W. Fairly good English. Home address: Pang (a small village), near Rosenheim.

* Bosse, Dr.

Design section leader in drawing office for 018. Located at Kolbermoor.

* Bruckmann, Bruno.

On Board of Directors. Development Manager for all reciprocating engine, jet engine and rocket development at B.M.W. Originated idea for TLR combination. Speaks very little English. Fully co-operative. In common with most, he claims not to have been a Nazi party member. Is a sick man as result of recent abdominal operation. Has addresses of all important employees. Office at Oberwiesenfeld plant. Home address: Gronsdorferstrasse, Haar, Near Munich.

* Däumbling.

Production manager at the Kolbermoor plant. Previously Experimental production manager for reciprocating engines. Good English. Lives adjacent to Kolbermoor plant.

* Denkmeir, Dr.

In charge of Jet Flight Test Section since July, 1944. Previously i/c reciprocating engine test at DVL, Berlin.

* Donath, Dr.

Production Manager at the Oberwiesenfeld plant.

* Dorls, Dipl.Ing.

Production Manager at the Allach plant.

ø * Hagen, Dipl.Ing.

In charge of the department which makes detail examinations of jet projects and supplies the drawing office with the basic design data. Is Östrich's right hand man. Prepared various reports at my request. Has further reports in course of preparation for American A.T.I. Home address: c/o Arndt, 23 Rheinstrasse (a little to the North of the Oberwiesenfeld plant).

Huber, Dipl.Ing.

Deputy chief of Project Department. Project reports and other important documents found in his safe. Home address: Rotwandstrasse, Fischhausen, at South of Schliersee.

ø * Kappus, Dipl.Ing.

Chief of the Project Department which covers all engine and rocket types and their combination with aircraft. An almost complete set of his project reports was found with his aid. He has been in the Project Department at B.M.W. for six years, of which the last 2-1/2 was principally devoted to TL, PTL and TLR engines and applications. He was also a qualified test pilot and in 1943/4 had started the flight test section for jet planes and had himself flown most types; he returned to his own department after nine months having trained Denkmeir as his successor. Home address: 19, Kemnatenstrasse, Nymphenberg, Munich. Good English.

* Menz, Dipl.Ing.

Assistant to Bosse on design of 018. Located at Kolbermoor.

* Noack, Dr.

Chief of the department which deals with control problems on all B.M.W. products. Designed control box for 801 and automatic variable nozzle control for 003. Home address: 16, Fasanenweg, Grolienzell, Near Munich.

ø Östrich, Dr.

Head of Jet Engine Development Departments, responsible directly to Bruckmann. Has been located at Stassfurt.

* Rucker.

In charge of 003A series "pilot line" production. Prior to the war worked on B.M.W. racing cars, and had associations with Frazer-Nash. Has good general knowledge of BMW organisation, and recent developments. Received technical education in America. He is the best interpreter ever encountered for technical matters and was extensively used by all teams exploiting BMW targets around Munich. He assisted materially in organising the work of building the six 003 engines I ordered for shipment to U.K. and U.S.A.

Schneider.

Designer of 718 rocket motor.

■ Seidel, Dr.

Runs technical management department which assists Bruckmann in co-ordinating the work of the various departments. Good English. Has worked in America. No very reliable technical information as his job was largely administrative. Went out of his way to deliver documents (pre-1942) on jet propulsion to me. Home address:
Cottage on Tinning See. Near Riedering, Near Rosenheim.

■ Söstmeyer, Dipl.Ing.

Designed the high altitude plant at Oberwiesenfeld of which he is now in charge. He will be useful in getting the plant into operation for the Allies. Speaks a little English. Home address: 12, Bismarckstrasse, Suecking, on Stanberg See. S.W. of Munich.

Staege, Flugkapitan.

Chief of Flight Test Department. Apparently he exercised only administrative control over the jet section.

Stoeckicht, Dipl.Ing.

Leading man on design of front section of 028 (air entry, airscrew drive, etc.) Located at Solln near Munich.

■ Ulsamer, Dr.

Manager of Northern Factories (including Spandau and Stassfurt). Speaks some English. Familiar with production figures and general development policy. Home address: 25, Chiemiring, Stötthamm, on E. of Chiem See.

■ Wiegand, Dr.

Chief Metallurgist. His department deals equally with problems of reciprocating engines, jet engines and rockets, but I got the impression that his assistant Dr. Scheinhost (at Spandau) was likely to be more familiar with turbine blade problems.
Home address: 7, Merowingerstrasse, Graefeling, Near Munich.

Zborowski, H.

Nominally head of Rocket Development Department but apparently he was more concerned with his membership of the S.S. and political affairs and left most of the technical matters to Schneider and Ziegler. Called to arms shortly before the occupation and has not been located.

■ Ziegler.

Deputy head of Rocket Development. Designer of 548 and 558 rockets

Located at Bruckmühl plant. Is making further samples of 548, 558 and 718 for us.

Burkhardt of Wurtenberger Metallwaren Fabrik (WMF) at Geislingen.

Expert on forging of compressor blades and pressing of turbine blades.

Ebert, Dr., of V.D.M. Frankfurt, and Stoeckicht, were leading men in design of front section of 028 (air entry and airscrew drive). Located at Haddernheim.

Friedrich. Prof. Dr., of Daimler Benz.

Associated with design of 021. Office in shoe factory at Faurndau near Göppingen. Lives nearby.

Kamm.

Associated with Daimler-Benz on jet and reciprocating engine developments. Designer of the 48 cylinder engine type 809A (with axial compressors) which has been shipped to U.K.

Lippart. Dr., of Robert Bosch at Stuttgart, is an expert in fuel nozzles and pumps and has worked on the use of injection pumps for jet engines.

List.

Prof. of Dresden Technical College. Has done much fundamental work on thermodynamics of jet engines, including after-burning.

Müller, Alfred.

Associated with Kraftfahr Technische Versuchsanstallt der S.S. at St.Aegyd, Niederdonau, near Vienna, and their work on gas turbine and heat exchangers in connection with tanks. Was once with B.M.W. Believed to be adviser to R.L.M.

ø * von Ohain, Dr.

Head of jet engine development at Heinkel-Hirth. Can now be located at B.M.W. plant at Kolbermoor.

Porsche, Dr.

Had his own firm. Designed various jet engines including an expendible one to replace impulse engine on V.1. Located at Zel-am-See.

Reuter:

Associated with Brown Boveri of Mannheim in development of an

axial compressor for jet engines. Evacuated to
Harz area.

ø Schelp.

Head of jet propulsion section at R.L.M. Is writing a report for Allied commissions on Air Ministry policy on jet propulsion.

Located at Luftfahrt Forschungs at Ottobrunn, Near Munich.

Sörensen, of M.A.N. Augsberg.

Expert on ceramic turbine blades.

* Sachse, Helmut.

Has his own firm of same name at Kempten. Manufacturing control box for 801. No work on TL or PTL controls.

ø * Sanger, Dr. of D.F.S. Ainring, near Slazburg. Expert on athodyds. Is preparing report on flight tests etc. for any interested Allied commission.

B.M.W. GAS TURBINE ENGINES.

R.L.M. TYPE No.	TYPE *	THRUST (lbs).	ALT. (ft)	FWD.SPEED. (m.p.h)	WEIGHT (lb)	R.P.M.	No. of STAGES Comp.	Turb.	SPEC.FUEL CONSUMP. ON J.2	PROGRESS.
109-003.AO,A1,A2 E1,E2	TL	1760	0	0	1340	9500	7	1	1.47	Production
109-003.C.	TL	1980	0	0					1.27	Experimental
109-003.D.	TL	2420	0	0						Design calculations
109-003.R.	TLR	as 003.A. series + 2700 lbs. thrust from type 109-718 rocket motor								Experimental
109-018	TL	7700	0	0	5500	6000	12	3		Experimental
109-018.R.	TLR									Project
109-028	PTL	7900 HP	26,300	500	7700	6000	12	4		Design
None	TL	3740	0	0	Was to be interchangeable with Heinkel-Hirth 011.					Project
None	PTL	Version of 018 with enlarged compressor supplying air to two separate combustion/turbine/propeller units.								Project

* TL = Turbine/jet (Turbine Luftstrahl)
TLR = Turbine/jet + liquid rocket motor
PTL = Propeller/turbine/jet.

B.M.W. ROCKETS.

RLM Type No.	
109 - 510	Better known as Project 90A. Rocket motor for Me.163 weighing 180 kg. and giving 1500 kg. thrust using Salbei and Methanol propellants with igniter of 50% oiludin (?) and 50% triethylanalin (?). Scheme dropped.
109 - 548. Also known at DVL as X-4, at RLM as Geschoss 344.	Airborne rocket projectile developed by Dr. Kramer of DVL and controlled by fine copper wire for ranges up to 4.5 km. Mean impulse 1350 kg.sec. Max. thrust 130 kg. Max. velocity 1100 kph. Burning time 20 seconds. Fuel: 2 litres of Tonka 250 plus 4.2 litres of Salbei. In experimental production. Samples sent to U.K.
109-558 Code name: Schmetterling"	Rocket motor for ground launched radio-controlled glider bomb designed by Prof. Wagner and designated Hs.117. Mean impulse 14,000 kg.sec. Thrust 400 kg. maintained constant by regulator which kept flight speed just below sonic velocity. Burning time 60 seconds. Fuel consumption 5 kg/ton thrust. . Fuels as for 109-548. In experimental production. Samples sent to U.K.
109 -708	Rocket motor for Me.163. Max. thrust 2500 kg. Complete drawings sent to U.K.
109 - 718	Rocket motor for 109-003R engine. 1250 kg. thrust. Fuels:- Tonka and Salbei; aimed later to use J.2 diesel oil (as used on turbo-jet engines) and Salbei, with an igniter injected independently. Samples sent to U.K.

NOTE: Tonka is petrol with traces of catalysts) These fuels react together
Salbei is 97% pure nitric acid.) spontaneously.

B.M.W. RECIPROCATING ENGINES.

RLM Type No.	
9 - 801D.	Produced at Allach plant
9 - 801S.	Produced at Allach plant
9 - 801I	Latest experimental engine. Exhaust turbo blower maintains full power to 40,000 ft. (or 46,000 ft. with ram). Six of these engines in working order were found at the Oberwiesenfeld plant and are being shipped to U.K. Intended for Ju.188
9 - 803A	28-cylinder liquid-cooled engine comprising two 14-cylinder units in tandem, with cylinders in line. Rear unit drives rear hub of contraprop through lay-shafts. Front unit drives front hub independently. Complete engine found at State Farm, Grub, Near Munich and shipped to U.K., also sample of cylinder with rotary valve. 4,000 HP at 2,950 RPM for take-off.

COMPRESSOR.

The seven axial stages supply at full RPM 19 kg./sec. (41.8 lbs/sec.) of air at a compression ratio of 3 : 1 on the test bed, and 24 kg./sec. (52.7 lbs/sec.) at 3.9 : 1 at 900 kph. (560 mph) and at sea level.

The compressor efficiency based on torque and total head measurements when driven by a steam turbine was 78% at full RPM. Temperature measurements of efficiency usually work out about 2% higher. The efficiency curve is said to be very flat.

The design Mach No. is 0.8. A large number of stages with small camber on the blades is favoured by B.M.W. rather than vice versa. No surging had been encountered.

Ice formation had been anticipated but tests in the high altitude plant to 13 km. (42,500 ft.) indicated that the oil cooler in the intake casing was probably sufficient to prevent serious trouble.

The compressor runs on three forward thrust ball-races and one rear roller race. Each compressor disc is balanced statically, then the complete compressor rotor is balanced dynamically. Next the rotor is dis-assembled for interleaving with the stator rings. No check is made on the run-out of the rotor after it has been combined with the stator, neither is there a second check on balance.

The compressor blades are forged by W.M.F. of Geislingen, the first three stages being in Elektron (Normen No.3510) and the remainder in duralumin.

COMBUSTION

The combustion is a straight through annular type with one ring of forty sandwich mixers providing secondary air from the outer region and another ring of forty feeding air from the inner region. The sixteen main burners operating on J2 diesel-type fuel are housed in individual short primary mixing chambers. Six auxiliary burners for starting, operating onpetrol are provided and igniter plugs are situated adjacent to two of these.

Sicromal 9 deep-drawing stainless steel is used for the combustion equipment, having the following composition:- Carbon .15 approx., Manganese .4, Silicon and Aluminium 1.0 approx., Chromium 18.0. Aluminised mild steel was used in later engines.

The temperature traverse at the turbine was found to be very sensitive to the disposition and angle of the sandwich mixers. A fairly good traverse was obtained eventually, and hot spots on the combustion are now very rare although they are sometimes visible on the exhaust cone. The change last year from petrol to J.2 as fuel introduced some coking difficulties but these are overcome by correction of the spray angle. Sufficient testing at altitude had not been carried out to discover coking characteristics.

Combustion chamber loading was quoted at 2×10^8 cals/cu.m./hr. at full speed.

TURBINE.

Blade Manufacture.

The hollow blades are made by W.M.F. Geislingen utilising a process developed by Östrich and one of his assistants named Domsgen.

The material has the following composition:- Chrome 16.5 to 17.5%, Molybdenum 2.0%, Nickel 15.0%, Tantalum and Niobium 1.15%, Silicon 1.0%, Carbon 0.1% max.

The manufacturing process is as follows:-

1. The sheet is hot-rolled at 1100°C

2. The sheet is cold-rolled to a wedge shape in 15 to 20 passes, finally tapering from 0.7 mm at the tip to 2.6 mm at the root. Annealing is carried out between each pass.

3. The material is cut to size where the section thickness is just right, and slots are cut to form the cooling air inlet.

4. The material is folded longitudinally.

5. With a profile core inserted the blade is pressed to shape in an eccentric press, leaving a box-shaped root.

6. The blade is arc-welded down the trailing edge.

7. The flaps of the box-root are folded outwards (the ends of the box were slotted out in operation 3). A blade liner consisting of a thin pressed and folded metal strip is looped over a solid pin and pushed inside the blade. The flaps of the box-root are then pressed over this pin so that the root of the blade now has a more-or-less cylindrical form. The function of the liner is to limit the cooling air flow through the blade to a narrow space between the liner and blade.

8. The base of the root is now welded to join the ends of the flaps.

9. The base of the root is ground to true cylindrical shape. For location during this operation centres are put in the ends of the pin, these being jig-drilled relative to the blade profile.

10. The remainder of the root is ground including the flats on which the fixing wedges locate.

11. The blade is heated to 1150°C and quenched in water.

Creep Stress Limits for Blades.

Test No.	Temp. °C	Stress		Times Hrs.	Max. Permissible permanent set.
		kg/mm²	tons/in²		
1	600	20	12.7	45	0.1%
2	600	21	13.3	300	1.0%
3	700	8	5.1	45	0.1%
4	700	12	7.6	300	1.0%

Blade design and fixing.

The blades have no twist. Each blade is retained by two solid pins locating on either side of the bulb-root. A small wedge on either side of the blade serves to prevent tangential movement of the blade tip; these wedges jam under centrifugal load. The blades and fixings are retained axially by the discs placed on either side of the turbine disc to duct the turbine cooling air.

Due to distortion of the shroud ring and settling of the blade root fixing it is necessary to build new engines with a tip clearance of about .150". The minimum permissible tip clearance is .060".

Running experience on blades.

The blades hardened and cracked after about 50 hours running and were considered to be the limiting factor on the life of the engine.

Disc.

The turbine disc has the following composition:- Carbon .15 to .19, Manganese .80, Silicon .40, Chromium .90, Molybdenum .80. It is heat treated to give a tensile strength of

80 to 90 kg/mm² (50 to 57 tons/sq.in.) and the following creep tests are applicable:-

Test No.	Temp. °C.	Stress kg/mm²	Stress tons/in²	Time Hrs.	Max. permissible permanent set.
1	600	11 to 17	7 to 11	45	0.1%
2	600	24(?)	15(?)	300	1.0%

The disc is bolted to the shaft and the bearing arrangement consists of one forward thrust ball-race and one rear roller-race; the latter is on the forward side of the turbine.

EXHAUST UNIT.

The variable final nozzle is operated by a screw-jack driven through gears from an electric motor, and controlled by a four-position switch in the cockpit. The switch positions below are taken from an He.162 found at Riem near Munich, while the corresponding final nozzle areas were quoted by Hagen:-

		sq.cms.	sq.ins.
A.	Starting up	1200	186
S.	Take-off and normal for 0 to 8 km	1000	155
H.	Normal over 8 km	1020	158
F.	High speed at 0 to 4 km. and over V_a= 650 kph.	970	150

The purpose of the two fins on the moving bullet is to reduce vibration.

The cooling air for the exhaust cone is admitted direct from the atmosphere through scoops and after a devious path is exhausted through the rear hole of the bullet where the main gas stream produces a marked ejector effect.

The exhaust unit is of aluminised mild steel. The surface treatment is one of the following processes:-

1. "Alumitieren" - the part is immersed in molten Aluminium or heated with Aluminium powder.

2. "Alumakieren" - the part is painted with an Aluminium lacquer developed by Zarges-Weilheim and then baked at 400°C. This is considered to be the best process.

FUEL SYSTEM. : this is basically the same as on the 004.

Burners. The swirl-type burners face downstream. They each contain a .008 mm. filter and a check valve which closes at 0.8 atmos. gauge pressure to prevent dribble on shutting down. They are flow checked to a ± 3% tolerance, and also checked for patternation and spray angle. The starting burners have no filter or check-valve.

Fuel. Petrol is now used for starting only, as an R.L.M. directive introduced J2 diesel type fuel for all jet engines last year. This change also necessitated a change from the Henschel centrifugal pump to the Barmag gear pump, in order to reach a pressure of 60 atmos. (880 lbs/sq.in.) which is required at sea level. When the burners were finally matched to this fuel system the heat distribution was better than with the petrol system.

The pilot has separate switches to control the starter motor and the starting burners, but it is said that unlike the 004 he can switch on to J2 immediately after starting.

J.2 fuel is apparently very little refined and varies a lot in quality; attempts were being made to grade it into a -15°C quality for test and -20°C for flight. Consideration had been given to pre-heating the fuel, but no tests had been made.

Governor Unit. A centrifugal all-speed governor controls a spill valve. The pump delivery is not much in excess of engine requirements at sea level on a cold day, and this gives some protection against overspeeding should the governor fail. Over-speeding on a quick acceleration amounts to about 150 RPM. The permissible variation in maximum governed speed on official tests is ±1%. The governor servo-system is supplied from the aircraft hydraulic tank.

To limit the speed of accelerations a special valve is used, operated by compressor delivery pressure; apparently this is intended to prevent full fuel flow until a pre-determined compressor delivery pressure is reached. It was developed by the firm of Kinsler at Donau-Eschingen.

The centrifugal part of the governor unit does not become effective until a speed of 6,000 RPM is reached; below this, the pilot's lever operates directly on a throttle valve. The present governor unit and burner combination was designed for altitudes up to 12 km. (39,400 ft.); for greater altitudes a duplex burner fuel system was under development.

LUBRICATION SYSTEM.

The lubricant consists of equal parts of oil and hydraulic fluid, and no trouble was experienced with freezing at altitude. The only temperature control on the lubrication system consists of a valve which opens when the oil pressure reaches 150 lbs/sq.in., permitting the oil to bye-pass the oil cooler. Oil flow to each rotor bearing is in the region 30 to 45 gall/hr., fed through spray nozzles.

COOLING AIR SYSTEM.

Turbine Blades: Cooling air for the turbine blades is tapped off the compressor after the 4th stage and fed through pipes to the turbine. It is fed to the space between the turbine disc and turbine disc forward cover, sealing being effected with labyrinths. It passes through holes in the turbine disc to the space between the turbine disc and turbine disc rear cover. Assisted by centrifugal action the air now enters the holes at either end of the blade root, passes up the hollow blades and exhausts at the tips. The liners inside the blades are considered important in reducing the cooling air mass flow in this circuit to 1% of the total engine air mass flow; this figure is based on mock-up tests which are believed to be accurate.

Nozzle Guide Vanes: At the forward end of the combustion chamber, holes admit air at full compressor delivery pressure to the space between the cylindrical inner wall of the combustion chamber and the conical turbine bearing housing. The air then enters the inner ends of the nozzle guide vanes and exhausts through a number of transverse slots in the trailing edge of each vane. The mass flow through this circuit, based on mock-up tests, is also said to be 1%.

Exhaust Unit. As already described, this is cooled by atmospheric air admitted through scoops.

ENGINE STARTING.

The engine lights at about 1200 RPM and the two-stroke Riedel starter motor cuts out at 2,000. The Riedel motor was always started with its electric motor as the wire-pull was not satisfactory. The Riedel was very liable to overheating, and the automatic clutch also gave a lot of trouble.

The idling speed on the ground is 3500 RPM with a corresponding thrust of 120 lbs. but tests in the high altitude chamber up to 43,000 ft. indicated that an idling speed of at least 6500 RPM was necessary to prevent blow-out at altitude.

The automatic valve described under the heading "Fuel System" limited the time for accelerations from idling (3500 RPM) to full speed (9500 RPM) to between 5 and 7 seconds.

In the Ar.234.B. (2 X 003) re-lighting in the air was satisfactory at altitudes below 10,000 ft. but above that altitude lights could not be obtained. At 6,500 ft. lights could be obtained at speeds as low as 155 mph., the corresponding windmilling speed being 2,000 RPM. At the same altitude the engine would just light at a speed of 340 mph., the corresponding windmilling speed being 2,500 RPM.

003.A1 and A2 ENGINES.

The differences between the AO, A1 and A2 types were mainly in the nature of detail design changes intended to facilitate production, and the performance was said to be almost identical. It is known, however, that the 003.A2 had 66 turbine blades, whereas the 003.A1 had 77. The cooling air for A1 and A2 turbines was tapped off after the last compressor stage and was restricted by a labyrinth instead of tapping directly from the 4th stage as on the AO. Later production models of the A2 were to have a surface oil cooler integral with the cowling to combat icing and because it was a simpler type to make; this had already been flight-tested.

The test bed performance of the 003.A2 was given as follows:-

Thrust 800 kg.	=	1760 lbs.	
Weight 610 kg.	=	1340 lbs.	
Max. speed	=	9500 RPM	
Specific consumption (with J.2)	=	1.47	x
Specific consumption (with petrol)	=	1.33	x
Exhaust temp.limitation at 15°C day temp. (full dynamic)	=	620°C.	

x The ratio of calorific values of petrol to J.2 is 1.05 : 1.

003.C ENGINE.

This type had a compressor of Brown-Boveri design and manufacture, and design curves indicate its static thrust as 900 kg. (1980 lbs.) at 9500 RPM with 1.27 specific consumption on J.2. It is believed that one only was made.

003.D. ENGINE.

An order was received from RLM in April 1945 to improve the performance of the 003 type to 1100 kg. (2420 lbs.) and preliminary design calculations only were made. The engine was to be interchangeable with the 003.A series.

003.E1 and E2 ENGINES.

These are identical respectively to the A1 and A2 series except that engine mounting points are also provided at the bottom of the engine to suit the He.162 installation in which the engine is supported above the rear fuselage.

003.R.ENGINE.

This is similar to the 003.A.series engines but a B.M.W. type 109 - 718 rocket motor is mounted over the rear of the engine. This operates on Tonka (petrol + igniter) with Salbei (concentrated nitric acid) as an oxygen-giver, and together these liquids ignite spontaneously; the rocket motor can therefore be turned off and on at will. The separate pumps are mounted on a gearbox at the forward end of the rocket and the 150 HP required to drive them is provided by an extension shaft from the 003 wheelcase. The 003.R. weighs about 200 lbs. more than the 003.A.

The rocket motor gives an additional 1250 kg. (2750 lbs.) thrust. The endurance is 100 to 120 seconds with the normal fuel load (thought to be 1500 - 1800 kg. fuel for rockets and 900 kg. for jet engines in Me.262). Bench tests showed that the rocket motor was still serviceable after fifty 3-minute periods,

The chief purpose of the rocket motor is to obtain temporary increases in the rate of climb and the critical altitude. It is not intended for take-off assistance. One flight test only was carried out and this was in Me.262. Apparently the results were in good agreement with design and at sea level gave a rate of climb of about 70 m/sec.(13,800 ft/min.) compared with 20 m/sec. (4000ft/min.) with the rocket switched off. At 9 km. altitude (29,000 ft.) which is nearly the ceiling with the rocket switched off, use of the rocket gave a rate of climb of 110 m/sec. (21,700 ft/min.) These figures are all taken at the best climb speed of 800 kph.

The best increment in critical altitude is obtained by switching on the rocket when at the normal ceiling. Using the rocket in this way the Me.262 could reach 14 km. (46,000 ft.) while the theoretical ceiling (if more rocket fuel could be carried) was 18 km. (59,000 ft.)

The best increment in range is obtained by switching on the rocket immediately after take-off to get quickly through the denser air, then fly relatively light at the most efficient altitude for the jet engines. Calculations indicated that with a drop tank faired into the fuselage of the Me.262 a range of 1700 km. (1060 miles) could be achieved in this way.

The 718 rocket was in experimental production at Allach and Bruckmuhl and was about a year behind schedule due to bombing and dispersal.

PRODUCTION OF 003 ENGINES.

The aim had been to produce the engine in 500 man-hours, although it was actually found to take considerably longer.

About 100 of the 003.AO series were produced of which 60 were for flight. Parts were produced at Basdorff and Spandau, while final assembly was at Eisenach.

The total production of 003.A1 and 003.E1 amounted to about 500 and was lar at Zuhlsdorf. The best production month was March 1945, when were produced of which about 60 were the 003.A1 version. RLM production requirements varied regularly between 1000 an a month. The production of the A2 and E2 types was fully med at Eisenach near Essen and the BMW aim was 1500 a month by mn 1945; most were to be used in the He.162.

The ch from petrol to J.2 fuel was said to have delayed production con ably, as some fuel system development was involved.

TESTING OF 00 NES.

Total bed running on all 003 development engines (excludes prod n engines) was between 4000 and 5000 hours and total flying ncluding production engines was between 500 and 1000 hour

APPLICATION IGHT TEST OF 003 ENGINES.

003 s were intended for installation in the following aircraft:-

1. He.162 (Jager") - has single engine supported above rear fuselage

2. 234. X 003

3. Ar.234. X 003 (a pair of engines set close together under each .

4. Me.262 X 003

Ju.88 003 - flying test bed.

Ju.287 X 003 (or 2 X 018)

rter ss.

had been carried out on the first five aircraft. Al .234.C. had been made they were mostly waiting for en or three flights were made. The following test on the Ar.234C:-

Gross weight 18,000 kg. = [illegible] b.
Bomb load 2,000 kg. = [illegible] s.
Rate of climb at sea level = [illegible] /min.
Climb to 8 km. (26,000 ft.) in 4 mins.
Speed at 10 km. (32,800 ft.) = [illegible]
Range 1400 km. = [illegible] s
Take-off run 800 m. = [illegible] s.

The Me.262 was said to snake very noticeably [illegible] the Ar.234 at the highest speeds.

RELATIVE STATE OF DEVELOPMENT : 003, 004, 011.

Bruckmann estimated that the 003 was nine mon[illegible] and the 004 in state of development and about two years ahea[illegible] e 011.

EXPERIMENTAL & DEVELOPMENT WORK IN HAND FOR 003.

Pressure Cabin. Work was about to commence [illegible] use of the engine compressor to supply air to pressure cabins.

Intake Icing. A programme of flight tests c[illegible] rface oil cooler integral with the intake casing was under way [illegible] estigations into electric heating of the 1st stage compressor st[illegible] re in hand.

Duplex Burners. The present fuel system was [illegible] ed for altitudes up to 40,000 ft. The use of a duplex-type [illegible] with separate spray nozzle for the higher altitudes was u[illegible] vestigation. Interest was also expressed in the Bosch fuel syste[illegible] ying injection pumps.

Automatic Final Nozzle Control. An automat[illegible] rol for continuously variable operation of the final nozzle [illegible] signed and made at Stassfurt under the Code designation "T.5." [illegible] s about to be flight-tested at Neubieberg near Munich. Unsucces[illegible] attempts were made to find this. The principle of operation w[illegible] at a pitot tube outside the nacelle and a bi-metal temperature-s[illegible] just upstream of the compressor, each operated on a potentiometer. [illegible] electric motor of the exhaust unit was also fitted with a poten[illegible] meter. The three potentiometers were connected in a balanced bri[illegible] circuit to a relay box which controlled the rotation of the electr[illegible] motor, the system being in the nature of an electric follow-up de[illegible] e. At full speed this maintained the exhaust temperature const[illegible] within ± 10°C, while a mechanical linkage between the throttle lever [illegible] the relay box catered for other engine speeds.

Exhaust Unit. A hydraulically controlled vari[illegible] le final nozzle was being designed on the lines of that already designed for 018.

Water Injection. Experiments in progress with water injection into the combustion chamber showed that up to 20% increase in thrust could be obtained, using roughly twice as much water as fuel. Injection through the hollow turbine blades in amounts up to 400 kg/hr. was also tried. Injection into the compressor was abandoned due to the adverse affect on compression efficiency, and injection after the combustion chamber gave very poor results.

After-bu[illegible]ing. Experiments in injecting additional fuel into the exha[illegible] unit were carried out on the lines of the Junkers work but, due [illegible] the fact that the 003 has a shorter exhaust unit than the 004 [illegible] the gas velocity is higher, the results did not compare favo[illegible] and stability of burning was not achieved.

Work on after-burning and water injection was on low prior[illegible] because the rocket motor as used on the 003.R was considered [illegible] the ideal method of thrust augmentation, for interceptor [illegible]ers.

Lar[illegible]cket Motor. Design calculations were in hand for a devel[illegible] of the 718 rocket motor having a thrust rating of 2,000 kg. f[illegible] to 90 seconds.

B.M.W. would have preferred if permitted by R.L.M. to [illegible] this as a tri-fuel rocket using J.2, Salbei and small quant[illegible] of an igniter. This would give additional safety; also if the [illegible] did not need the rocket he could use its allocation of J.2 fue[illegible]ve the jet engines additional cruising range.

Co[illegible] Mach Number Control. Hagen had originated a method of [illegible] control which apparently resulted in a constant flight Mac[illegible]r for constant throttle setting. His report on this subje[illegible] brought back. The control method was considered more compl[illegible] than the combination of the all-speed governor with the [illegible]ariable nozzle control, but it was nevertheless intended [illegible]it although on a lower priority.

018 TYPE ENGINE.

Design Data.

12-stage axial compressor
Mass flow at sea level and 500 MPH . . . . 220 lbs/sec.
Compression ratio . . . . 7 or 8 : 1
Compressor efficiency 0.79
Compressor work capacity . . . . 72,000 ft/lbs/lb.

3-stage turbine
Turbine efficiency 0.80
Temperature before turbine . . . . 770°C
Coefficient of loss through exhaust unit 0.96

R.P.M. 6,000
Static thrust . . . . 7,700 lbs.
Total weight . . . . 5,500 lbs.
Specific fuel consumption at sea level and 500 MPH . . . . . 0.48 (?)

Overall length . . . . 158"
Maximum diameter . . . . 50"

Description.

The general construction of the compressor, turbine, and blades is similar to the 003. The turbine is however, supported on one roller bearing to the rear of the disc, while the forward end of the turbine shaft is supported in a spherical seating within the compressor shaft. A tie-rod transfers the thrust load on the turbine to the forward end of the compressor shaft; this rod is screw-threaded and also serves to expel the turbine during disassembly. The compressor rotor is supported on two ball thrust bearings at its rear end and a single roller bearing at its forward end. The through bolts holding the turbine discs together are said to be the only items in the engine subject to selective assembly.

The combustion chamber is similar to the 003 with identical sandwich mixers, but 24 burners and 8 starting jets are provided.

The exhaust cone has a hydraulically operated adjustable bullet to vary the final nozzle area. The valve for this is situated within the cone and operated by means of a Bowden cable.

The cooling air for the turbine blades amounts to about 1% of the engine mass flow and is tapped off the compressor after the 5th stage and fed into the hollow turbine shaft. For the nozzle guide vanes the cooling air is bled off after the last stage and passes rearwards through the annular space between the combustion chamber and its housing; this flow is about 1½% of the engine mass flow.

The fuel system is similar to the 003.

The lubricant pump has a capacity of 4,000 kg/hr. The total oil circulation is 1200 kg/hr. of which 100 kg/hr. is for the turbine bearing, 150 kg/hr. for the front bearing, 300 kg/hr. for the double centre bearing, 300 kg/hr. for cooling the Riedel starter and for the hydraulics of the exhaust unit; the remainder is for the wheelcase. A scavenge pump is driven from the rear of the turbine and another from the rear end of the compressor shaft, while a composite pump is provided for the front rotor bearing. In the final version it was proposed to provide de-aerators in the lubrication system.

The engine auxiliaries are grouped around the nose as in the 003, but a separate gearbox was to be used forthe aircraft accessories.

At first a 50 H.P. Riedel motor was to be used for starting as this was already made, but later a small gas-turbine unit which was under development by Heinkel-Hirth was to be used.

The chief design difficulty was that the size of the engine necessitated the use of fabricated structure instead of alloy castings, and although all such parts were to be normalised the distortion under running conditions was likely to give trouble.

State of Development.

One compressor had been completed but was wrecked by a bomb before testing. Tests on this had been planned either at Dresden or Oberhausen. Three engines were nearing completion at Stassfurt. Combustion test-work to determine the best angle for the sandwich mixers was about to commence.

Under the emergency plan (March 1945) it was decided that the engines were to be completed at the Kolbermoor plant and that development and testing would take place at Oberwiesenfeld. Most of the special tools, including those for blade manufacture, are now at Kolbermoor, but complete parts were not found.

Applications.

It was intended to instal the engines in the Ju.287 (2 X 018 or 6 X 003)

018.R. TYPE ENGINES.

The necessary design work on the 018 for the addition of a rocket motor had been carried out. Apparently there was no serious intention of putting this into effect as the TLR combination was considered suitable for fighters only, and no fighter of sufficient size was envisaged.

Design Data, etc.

This PTL version of the 018 was in the design stage. The design data quoted for the 018 applies equally to the 028 with the following exceptions and additions:-

4-stage turbine with about 30% reaction.

Airscrew : contra-rotating, 3.5 to 4.0 m.dia., 950 RPM, 3 blades per hub.

Total power at 26,300 ft. and 500 MPH (design condition) - 7900 H.P.

Deduced sea level performance at 500 MPH - airscrew power - 6900 H.P.
- jet thrust - 3000 lbs.

Overall length - 200"

Total weight - 7700 lbs.

The engine accessories were to be driven by a radial shaft between the compressor and combustion chamber capable of transmitting 300 H.P. at full speed.

Stoeckicht of B.M.W. and Ebert of V.D.M. were chiefly responsible for the airscrew drive and air intake design. Flow tests of this section had not yet been carried out.

No aircraft had been designed for this engine but it was intended that preliminary flight tests should be made in the He.177. Calculations had been made for its application to Me.264 (2 X 028 instead of 4 X 801) but although the combination was very satisfactory from the performance angle too much work would have been involved in strengthening the under-carriage.

A considerable amount of work had been done on the control system. In principle the system was to be as follows:-

1. Final nozzle area is adjusted by altitude and forward speed. The associated cam profile is calculated so that the airscrew power cannot exceed the 6900 HP for which the reduction gear is designed.

2. The all-speed governor of the V.D.M. hydraulic airscrew is set by a cam profile calculated to give good fuel consumption at part load.

3. The exhaust temperature is limited by a valve which measures the air mass flow (in terms of temperature and pressure upstream of the compressor) and meters the fuel flow to suit.

PROJECTS.

3740 lb. thrust TL engine. In anticipation of an RLM directive work had just started on an engine of this size which was to be interchangeable with the 011.

New type of PTL engine. On the advice of Dr. Alfred Müller, an independent consultant, RLM recently directed BMW to work on a new type of PTL engine. This was to consist of an 018 with enlarged compressor, air being tapped off to supply an independent unit in each wing comprising combustion chamber, gas turbine, and airscrew. These latter turbines were to operate at a temperature in the region of 900 to 1000°C. This type of power plant was intended to overcome the great difficulty of designing a good air intake for a PTL engine.

TL engine with constant volume cycle. Initial project work was underway on a jet engine with rotating combustion chamber and valves which was intended to burn fuel at constant volume

Athodyds. A number of projects had been investigated, but no tests were made and lack of knowledge of supersonic diffusers limited the value of calculations. It was said that many considered that work on athodyds would have proved more profitable than rockets for the V.2 bomb.

MISCELLANEOUS DEVELOPMENTS.

Heat Exchangers. No work on this subject at B.M.W.

Combustion experiments at DVL, Rechlin. Work had been done on the use of pre-heated tar-oil as a fuel for gas turbines, also on the use of coal dust.

Precision casting. No work had been done in this field. Vitallium and other cobalt alloys were not available.

Ceramic combustion coatings. Have not been tried for TL engines but a few experiments have been made for application to expendible rockets.

Ceramic turbine blades. B.M.W. thought it would be many years before cast ceramic blades as developed by Dr. Sörensen of M.A.N. Augsberg, would be applicable to gas turbines for aircraft.

Bosch igniter for TL engines. Robert Bosch at Stuttgart had under development an igniter with an insulator of Aluminium oxide pressed with a binder to obviate the usual high temperature sintering process which causes considerable shrinkage and deterioration of the electrode.

THE HIGH ALTITUDE TEST PLANT.

The high altitude test plant at Oberwiesenfeld/Munich is believed to be the finest in the world. As soon as it was first completed, it was damaged by bombing, but after repair, it was run every night for five months before the occupation. Söstmeyer, its designer, said he could have it in full working order within one week.

The plant employs electric power and the load is such that it is only possible to operate it at night. A crew of ten was employed for day-time maintenance and a crew of only ten for night test running.

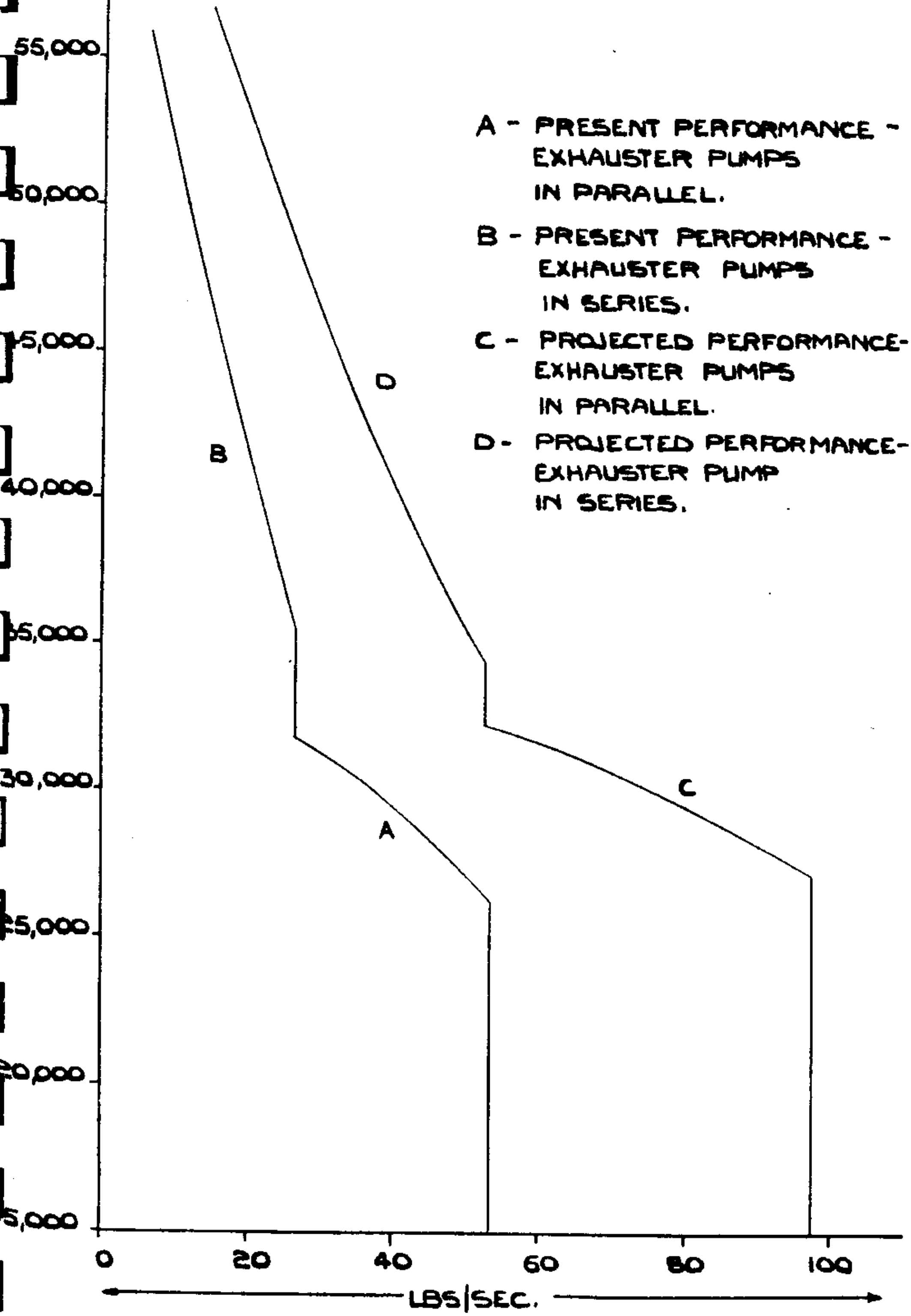
The 003 and 004 had already been tested in the chamber, and the 011 was expected for test in the near future. Instructions were given that two of the available 003 engines were to remain at Oberwiesenfeld pending a decision on the proposal to test them in this chamber.

The nature and the performance of the plant is best expressed in the diagram and mass flow curve which follow. The apparatus necessary to achieve the projected performance shown in the graph o was said to be ready but was dispersed in various parts of Western Germany. A dynamometer is provided for use with PTL and reciprocating engines.

It is strongly recommended that immediate steps be taken by interested parties to instruct the re-opening of this plant. In view of the apparent lack of full performance test data on German jet engines, it is suggested that the 003 and 004 be tested in the chamber as a first step. The adjacent Oberwiesenfeld airfield would make it convenient to fly in Allied engines for test.

BMW ALTITUDE CHAMBER

FLOW CAPACITY VS ALTITUDE.



P.R.P/C.M.W. 9.6.45

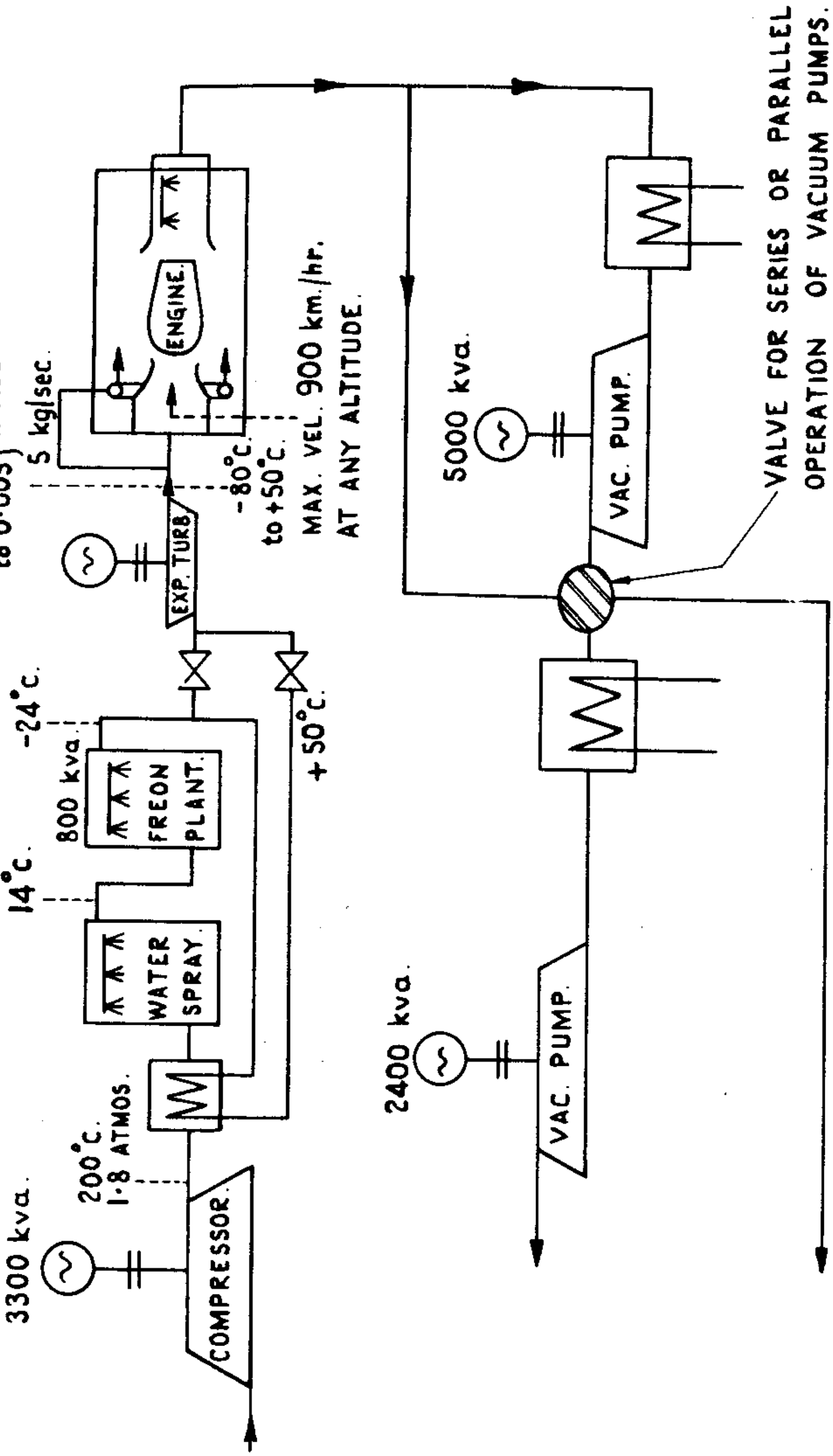


DIAGRAM OF B.M.W. HIGH ALTITUDE CHAMBER.

WORK CARRIED OUT OR IN PROGRESS AT B.M.W. FOR ALLIED AGENCIES.

1. As only one complete 003 engine was found (at Allach) in the Munich area, I instructed further serviceable engines to be built from available parts at Oberwiesenfeld and from six damaged engines recovered from Riem airfield. In all six engines were built and tested in three weeks, and a seventh was assembled although not in working order. Military Government passes were issued by me to 46 Germans, 20 of whom were actively employed on engine assembly and test; the remainder were mostly engineers whose presence each day was desirable to give information to the various investigating agencies.

2. Instructions were given to Ziegler at Bruckmuhl to build three 718 rocket motors and four 558 rockets, and these should now be ready.

3. Soestmeyer is writing a report on the high altitude test plant; this should now be ready.

4. Hagen is responsible for a composite report on the history of jet propulsion at B.M.W. under preparation for the A.T.I. agency. This should now be ready and he is reserving a copy for me on behalf of the C.I.O.S. agency.

5. Von Ohain at the Kolbermoor plant is preparing data on the Heinkel-Hirth 021 engine.

6. Schelp is writing a report on the R.L.M. policy on jet propulsion.

7. Six 011 engines are being built at the Kolbermoor plant under Däumbling's direction.

8. Three 018 engines could be built within six months, but no orders have been given.

NOTES:

(a) Items 2 - 7 are not included in the lists which follow.

(b) Bruckmann suggested that it would assist co-ordination if Allied agencies give him their orders for the Munich plants and southern dispersals.

MATERIAL SHIPPED OR AWAITING SHIPMENT FROM BMW/OBERWIESENFELD AT 30.5.45.

Item	No.off.	
1	10	548 rocket - despatched per Nav.Tech.Miss.
2	1	548 rocket mock-up - despatched per Nav.Tech.Miss.
3	2	003.A1 engine - despatched per A.T.I.
4	3	003.A1 engines - awaiting despatch but instructions given that two are to be retained for high altitude chamber tests.
5	1	003.E1 engine - awaiting shipment
6	1	003 engine (unserviceable) - despatched per A.T.I.
7	2	718 rocket motors - despatched per A.T.I.
8	1	803.A engine - despatched per A.T.I.
9	2	801-I engines - despatched per A.T.I.
10	4	801-I engines - awaiting crating and despatch.

DOCUMENTS BROUGHT BACK TO AIR MINISTRY FROM B.M.W.

File 1.: Project Department reports by Kappus and Huber; contents:-

Report No.	Date	Subject.
62	9.2.45	Calculations of performance of He162 with 1 X 003R
61	27.1.45	Calculations of the performance of Ar234 with 2 x 003A + 2 x 003R (2 copies)
60	27.1.45	Characteristics of TL engines (2 copies)
57	23.9.44	Comparison of 003A and 004B
56	20.9.44	Aerodynamic loads in TL engines
55	14.9.44	The athodyd as an artillery weapon
54	15.8.44	Basic principles of aircraft power units
53	8.8.44	Possibilities of further developments in fighters
52	31.7.44	Airscrew design for 028
51	31.7.44	High speed bomber with combined PTL - TL power unit.
50	?	Cooling of 801TH
49	9.6.44	Installation of 028
48	6.6.44	Calculation of performance of TL bombers
47	4.6.44	Influence of improved power units on flight performance.
46	9.6.44	Performance characteristics of PTL
45	29.4.44	Performance of TLR fighters with increased power.
44	29.4.44	Performance of TL fighters with increased power.
43	2.4.44	Cooling of 801R
42	21.3.44	Improving the thrust of TL engines.
41	2.3.44	Comparison between tailless and normal TL fighter.

FILE 18 : Miscellaneous TL flight test reports, and log book for Ju88 flying test bed.

FILE 19 : Miscellaneous inspection schedules.

FILE 20 : Miscellaneous organisation and dispersal data.

FILE 21 : Analysis of Merlin 61

FILE 22 : Installation data on 003

FILE 23 : Various photographs - a helicopter and 803.

FILE 24 : Diagram of automatic variable nozzle, principle of PTL variable nozzle and speed control, and leading data on 02

FILE 25 : Miscellaneous 801 data.

FILE 26 : Lecture by Prof.Dr.Friedrich

Plus 7 files of pre-1942 reciprocating engine, PTL and rocket data.

Items 1, 2, 3, 4 : Photo-transparencies of 003 drawings - almost a complete set, including heat treatment specificatio

Item 5 : Report by Zbrowski on rocket development at BMW up to Nov.

Item 6 : Reports by Prof.List of Dresden Technical College, with the following titles:

(a) Increase in thrust by after-burning as a function of combustion loading, jet pipe loading and compression ratio.

(b) Output of jet engines, including losses, as a function of combustion loading and compression ratio.

(c) Curves comparing TL with PTL etc.

Item 7 : Drawings of 018

Item 8 : 1 Roll containing complete tracings of the 003-A2 less turbine details.

Item 9 : 1 Box containing all German material specifications, also drawings, calculations, specifications for rockets and jet engines.

Item 10 : 1 Box containing incomplete drawings of 003, and drawings of the control box of the 801.