CHAPTER XV

The Results of German and British Turbojet Development Compared

The Military Utility of German Turbojets

The Germans had one turbojet engine in quantity production and service before the end of the war; this engine was the Junkers 004, the power plant of the Me 262 fighter. This airplane as produced in quantity had a speed of 520 mph at sea level, 526 mph at 3,300 feet, and a maximum speed of 541 mph at 26,300 feet. This was about 100 mph faster than the Meteor I with the Welland engine, the only jet-propelled fighter used in service before the end of the war by the Allies, and about 70 mph faster at altitude and about 100 mph faster at sea level than any Allied conventional fighter. By the fall of 1944 Me 262 fighters were going into service with such results that the Allies were seriously alarmed. Their first really impressive exploit was the destruction of every airplane in an American squadron of 12 bombers in January 1945. The speed of the Me 262 was so great that an escort of conventional fighters was no protection, and the only thing which made possible the continuation of Allied bombing was the numerical insufficiency of the Me 262.[1] These might have existed in far greater numbers than they did had not first the Air Ministry delayed their development by giving them relatively low priority until 1943, then delayed putting them in production for about half a year after they were ready, and finally had not Hitler himself then lost another half year by his insistence that the airplane be converted into a bomber.

[1]On the service record of the Me 262, see L. E. Neville and N. F. Silsbee, *Jet Propulsion Progress* (New York: McGraw-Hill Book Company, 1948), pp. 12-18.

Comparison of the Junkers 004 and the Rolls Royce Welland

The British were the only other nation to have jet engines in service before the end of the war, and they too had only one model which saw service in quantity, the Rolls Royce Welland, which was the power plant of the Meteor I.[2] Since active work on the development of turbojets began at almost exactly the same date in both countries, late 1935 or early 1936, and since this work began to receive government support in appreciable amount at almost exactly the same time, the middle of 1939, a good deal can be learned about the effectiveness of the two programs of development by comparing these two engines as they performed in service.

No superiority of design or development is shown for either engine by comparisons of their ratios of weight to thrust or frontal area to thrust, since Junkers chose to minimize the diameter of its engine at the cost of increased weight by using an axial compressor whereas Whittle made the opposite choice. The Welland weighed only 0.53 lb per pound of thrust while the 004B weighed 0.83 lb/lb, but the maximum frontal area of the nacelle housing the 004B was only 0.46 sq in./lb of thrust while the figure for the Welland was 0.94 sq in./lb.[3]

In fuel consumption, however, the German 004 was very distinctly inferior to the British Welland: where the Welland burned only 1.12 lb of fuel per pound of thrust per hour, the 004B burned between 1.40 and 1.48 lb. The principal determinants of fuel consumption in a gas turbine are: the pressure ratio, the compressor efficiency, the combustion efficiency, the pressure losses in the combustion chamber, the turbine inlet

[2]The Welland was in production by May 1944. The next British engine to be put in production was the Derwent I, in November 1944; production of the BMW 003 began at about this same time.

[3]At least the largest part of the margin by which the specific weight of the 004 exceeded that of the Welland is inherent in the axial type of engine, and was not due to inferior design. This can be seen by comparing the 004B with the British axial Metrovick F-2 turbojet. In November 1943, about the time when the design of the 004B was fixed for production, the F-2 weighed 1,510 lb and was cleared for experimental flight at 1,800 lb thrust. The specific weight of the F-2 was thus 0.84 lb / lb. of thrust, or a shade more than the 0.83 of the 004B.

temperature, and the turbine efficiency. An examination of each of these factors in order will be instructive.

The pressure ratio of the 004, and also of the 003, was only about 3.1:1, while that of the Welland was about 4:1. While the efficiency of the German compressors was nearly 80%, and that of the Welland compressor was barely 75%, it is easier to obtain a given efficiency at a lower pressure ratio; and in addition the axial compressor in the 004 should have had a higher efficiency even at the same pressure ratio than the centrifugal compressor of the Welland. The chief fault of the compressors of the 004 and 003 seems to have been the principle of design employed by Betz and Encke of the AVA, which obtained all or almost all the pressure rise on the rotor blades only,[4] and which both made necessary the use of a larger number of stages to obtain a given pressure ratio and lowered the efficiency of the compressor. These two factors together were probably the leading reasons why the Germans chose to use a lower pressure ratio than the British. On the other hand, it must be remembered that the design of the compressor of the 004 was virtually fixed before the end of 1941, the only subsequent change being a slight modification of the first two stages in 1943, whereas development of the Welland compressor was not complete until early 1943.[5] The 004 was flown in July 1942; the Welland not until June 1943. By the second half of the war the Germans were able to do nearly as well as the British. Hermann Reuter of Brown-Boveri designed a compressor for the 003C with a pressure ratio of 3.1:1 at an efficiency of 84%, and Rudolf Friedrich designed a compressor for the 003D which had 89% efficiency at a pressure ratio of 3.2:1. Neither of these compressors was in production before the end of the war, but neither were the British axial compressors.

The combustion system may have contributed something to the higher fuel consumption of the 004 compared with the

[4]Construction of a compressor with this type of blading was considerably cheaper than when pressure rise was obtained on the stator blades also, both because the stator blades could be made of sheet metal and because the clearances were not critical. It is not known, however, whether this cheapness of construction was actually a motive in the choice of this type of blading.

[5]For this same reason it is scarcely fair to compare the 004 compressor with the axial compressor of the F-2, which delivered a pressure ratio of 4:1 with 90% efficiency by the end of 1943.

Welland, but the amount was small at most. Although the combustion efficiency of the 004 was poorer than that of the Welland, it was still about 95% at full power, while the pressure losses through the combustion chamber were very small compared with those in the Welland. The fact that the combustion system of the 004 was as good as it was is rather surprising, in view of the fact that it was designed and developed almost entirely by Junkers alone. The combustion system of the Welland was the product of a long process of development which had begun in 1936 and to which many different sources had made important contributions. After the first successful system had been designed by Lubbock in 1940, many improvements were made by a number of different people cooperating through the Gas Turbine Collaboration Committee. This was, in fact, the field in which the Collaboration Committee did what was probably its most important work. The combustion system of the 004, on the contrary, was first designed in 1939, and did not profit at any time either from the results of earlier work or of the contemporary work of other manufacturers, although the Luftkriegsakademie at Gatow did assist Junkers to some extent. This situation is typical of German turbojet development in general; there was almost no exchange of information among manufacturers.

The gas temperature at the inlet to the turbine of the 004 was just about the same as that of the Welland. Since the German materials for turbine nozzles and turbine buckets were very seriously inferior to those available to the British, the design of hollow air-cooled nozzles and buckets which made possible the use of these temperatures was a product of really remarkable ingenuity and good engineering.

The aerodynamic design of the turbine wheel, on the other hand, was probably the poorest feature in all the German engines and was certainly by far the most important factor in their high fuel consumption. The efficiency of the turbine of the 004 was only 79% or 80% "total to total", while the Welland turbine had an efficiency of about 87% on this basis,[6] and this difference alone is nearly enough to explain the entire

[6]The Whittle WU bench engine had already had a total to total turbine efficiency of about 84% in 1938.

difference between the fuel consumptions of the two engines. In part the lower efficiency of the German turbine was due to conditions imposed by the design of the engine as a whole,[7] but the chief reason for it was simply the failure of the Germans to depart from current steam-turbine practice and use free-vortex blading, as the RAE had advocated before 1930 and as Whittle had independently urged before 1936.

The greatest inferiority of the 004 to the Welland was in reliability and durability. The Welland had gone through repeated 100-hour tests before it was put in production and had a reliable life in service of 100 hours. Even the rated life of the 004 was much inferior to this: until almost the end of the war it was scheduled for overhaul at the end of 25 hours, and when this limit was raised just before the end of the war, it was raised to only 35 hours. In actual service, moreover, it was not uncommon for an engine to fail before the expiration of 25 hours. Apparently the least durable part of the production engine was the combustion system; the engines with solid blades and those with deep-drawn blades of Tinidur suffered from turbine failures fairly frequently, but the folded and welded Cromadur buckets used on the rest of the 004B-4's were almost never the first part of the engine to fail.

The relatively short life of the German engines cannot, however, be attributed to inferior engineering: it is simply a consequence of the fact that the metals needed for high-temperature alloys were so scarce in Germany that the engine could not be made of materials even remotely comparable to those used in profusion in British and American engines. The weakest part of the 004, the combustion chamber, was made of ordinary mild steel, protected only by an aluminum coating, where the Welland used Nimonic 75 containing about 20% chromium and about 75% nickel. The 004 turbine wheels with Cromadur buckets, containing no nickel anywhere and no chromium in the disk, were more durable than any the British could make until

[7]The most important of these minor factors was probably the fact that an axial engine necessarily turns more slowly than a centrifugal, while turbine efficiency falls off as speed decreases. The turbine of the British axial engine, the F-2, had an efficiency slightly below that of the turbines of the British centrifugal engines. Another minor factor was the fact that the 004 was designed to have a certain residual pressure after the turbine, since this was thought to facilitate afterburning.

they adopted Nimonic 80, containing about 20% chromium and about 75% nickel for the buckets in 1942; and the ultimate British disk material was Jessop G 18 B, with 13% nickel, 13% chromium, and 10% cobalt.

Finally, no comparison between German and British turbojet engines can be complete unless it is emphasized that the German engines were incomparably easier to produce. The total man-hours required for the Junkers 004 were only 700; the exact figure for the Welland is not available, but it was very much larger than this. It is likely that the Germans deliberately sacrificed a certain amount of performance or reliability or both in order to secure greater ease of production. This was certainly true in the case of the BMW 003, where the original type of turbine bucket, formed of two separate pieces of metal welded together, was given up in spite of the fact that it produced a turbine with a reliable life of about 200 hours in favor of a folded and welded blade with a much shorter life. In Britain, on the contrary, it was only very late in the war that methods were developed for automatic machining of buckets of Nimonic 80 which permitted anything which could be called quantity production.[8] There can be no doubt that the Germans were fully justified in making the choice that they did: in the military situation of 1943 and later, there was no sense in developing any engine that could not be produced in quantity with the materials and manpower available.

British and German Turbojet Development: Conclusions

If the wartime development of turbojet engines and of aircraft for them is considered as an attempt to produce a weapon of use during the war, then there can be no doubt that the Germans succeeded to a much greater extent than the British. The Me 262 was a serious threat to Allied bombardment, in addition to performing useful tasks as a reconnaissance

[8]It is interesting to observe that one of the most important reasons why GE in the United States adhered to Hastelloy B instead of Nimonic 80 for the buckets of the I-16 engine was the fact that it could be forged to size and thus produced much more rapidly. The British refused to use Hastelloy B when it was offered to them in 1943 despite the fact that at that time they were unable to produce buckets of Nimonic 80 at more than an experimental rate.

airplane, whereas all that was accomplished by the Meteor was the destruction of a number of flying bombs, and the Meteor was not much better for this purpose than the conventional Hawker Tempest V used for this purpose in much greater numbers than the Meteor.[9] Published accounts of turbojet development, however, have generally emphasized the fact that German engines were technically inferior to British engines in reliability and in fuel consumption. The reasons for this technical inferiority have been discussed in the preceding section, but owing to the frequency with which certain other explanations have been offered it will be well to consider them explicitly.

First, it is very frequently alleged that the German engines were all alike, and that this similarity was due to the insistence of the Air Ministry that they should all follow a certain general design. This is complete misstatement of the facts. When the general program of government-supported development took shape at the end of 1939, there were six engines under development,[10] by four different companies, and every one of these engines had been designed with complete freedom by the company developing it. In the case of BMW and Junkers it remained true to the last day of the war that every design projected was made by the company exactly according to its own ideas of what should be done; Schelp of the Ministry continually urged these companies to try for higher performance than they were inclined to attempt, but he never compelled them to alter any feature of their designs. The two cases in which the Ministry ultimately did dictate or virtually dictate the design of an engine were the mixed-flow Heinkel 011, begun in 1942, and the turboprop version of that engine, the 021, begun by Daimler-Benz in 1943. In each of these cases, however, the company in question had fallen so far behind BMW and Junkers and was so completely without well-thought ideas of its own that it was quite glad to follow the Ministry's suggestions. The very considerable German uniformity in the use of axial compressors is

[9]The Tempest V with a Sabre engine could do 390 mph at sea level or 435 mph at 17,000 feet; the Meteor I did only 410 mph at sea level.

[10]These were the Heinkel centrifugal 001 and axial 006, BMW counterrotating 002 and axial 003, Junkers axial 004, and Daimler-Benz counterrotating ducted fan 007.

to be explained not by dictation from a government authority but by the facts that: (1) the Germans were designing for a speed of 528 mph where the British were designing for about 400 mph, (2) the double-sided centrifugal compressor simply did not occur to German engineers, and (3) the Germans more or less agreed in rating very highly the straight-through air flow obtained with an axial compressor.

Second, it is argued that the British were able to progress more rapidly than the Germans because all their gas-turbine manufacturers collaborated wholeheartedly, exchanging all their experiences and results, whereas each of the German firms worked by itself. There is no question that the Germans did not cooperate to the extent that the British did. The actual firms developing turbojets exchanged very little information, as can be seen, for example, in the case of combustion-system development. BMW could certainly have had a workable combustion system in operation much sooner if it had had full access to Junkers' results, and when it finally did get access to these results it was not directly but through the Luftkriegsakademie at Gatow. It is interesting, however, to observe that even though it worked almost entirely by itself, Junkers developed for the 004 a combustion system which was about as successful as that developed for the Welland as the end product of the collaboration of a large number of sources.

The Air Ministry was well aware from the beginning that genuine cooperation among the firms developing gas turbines would be of great value and did everything it could to foster the exchange of information in order to hasten development, but with little success. In January 1941 the Ministry promoted a symposium on jet propulsion under the auspices of the German Academy for Aeronautical Research (DAL), but the published papers and discussion at least can have been of virtually no assistance in the real problems of development. After such methods failed, the Ministry tried to bring about cooperation by direct order, not only in turbines but in all fields of development. An Arbeitsgemeinschaft für Triebwerksplanung was formed, and at its first meeting, on April 11, 1942, the head of power plant development in the Ministry, Eisenlohr, declared

in words written by the man directly in charge of turbines, Schelp: "I have recently had several opportunities to observe that one firm had no notion of what other firms had contributed in similar fields, although the Air Ministry has explicitly emphasized — and not just once — that this information should be exchanged. Now compulsory exchange has been introduced." Even this had little effect, however, and the only effective cooperation ever brought about was a result of the Speer program late in the war, and that cooperation related largely to production rather than to development. It seems to have been as a result of this program, for example, that BMW was enabled to get into production more rapidly by adopting the Junkers control system.

It is also true that not all the German research institutes collaborated as far as they might have done in the development of gas turbines. Oestrich of BMW complained in January 1941 that except for the AVA of Goettingen he had found no institute willing to assist in the solution of the aerodynamic problems he was encountering. The only important assistance received from a research institute on other problems of the BMW engines was the work on combustion done by the Luftkriegsakademie of Gatow. Before the actual development of turbines was begun, the head of the engine research department of the DVL, Friedrich Seewald, was quite unwilling to do basic research in this field,[11] and after research had been outrun by development he was even less willing to do anything.

There was, however, very good cooperation between the Aerodynamic Research Institute (AVA) of Goettingen and the industry. The AVA made model tests for BMW which led to the rejection of the piston-driven ducted fan and collaborated in the design of the air intake and the compressor for the 003. BMW had had no experience with axial compressors before this, and the AVA's share in the design was probably quite large. In the case of Junkers, the company seems to have laid out the general lines of the design itself, and the role of the AVA was restricted to the design of the blading, but this was carried out both for the 004A and for subsequent engines in

[11] Karl Leist, however, did do some work on the theory of turbojets and ramjets at the DVL after Schelp left in 1937.

very close cooperation, with frequent visits of personnel from Dessau to Goettingen and vice versa.

It would be very difficult, moreover, to show that more extensive cooperation either among the firms developing turbines or between them and the research institutes would have had any material effect on the success of turbine development in Germany. The superiority of axial compressors designed in Britain to those actually used in service in Germany was not the result of collaboration but of the almost unaided efforts of the RAE; the engineering of the RAE was simply better than that of the AVA, although it must also be remembered that the AVA designs were fixed at a much earlier date in the 003 and 004 than the RAE design in the F-2. By the end of the war Brueckner & Canis had developed an axial compressor which was approaching although it did not equal the results of the RAE. In the case of turbines, the most significant element in the British superiority was the use of free-vortex blading, which again was not the result of cooperative development but of excellent engineering by two sources working independently, the RAE and Whittle. British progress in turbine design after about 1939 was certainly very materially aided by the continual cooperation between Power Jets and the RAE, but this cooperation was no closer than the cooperation on aerodynamic matters between the German companies and the AVA, and the differences in the results are to be explained rather by better engineering and better materials.

Thus, aside from the points in which the superiority of the designs of one country over those of the other is to be explained simply by the fact that one engineer did a better job than another, almost all the differences between the results of turbojet development in Britain and in Germany are to be explained by differences between the conditions under which the engines were developed in the two countries and the purposes for which they were developed. The most important differences in the conditions surrounding development were the lack of certain raw materials in Germany and, beginning in 1944, the effects of Allied bombing. The difference in purpose was the desperate German need for high-performance interceptors beginning

in 1943, whereas the British (and Americans) by that time had little if any need for a fighter of extremely high performance attained at the cost of range.

As a result of these differences in the conditions and objectives of development, the British followed the course of developing a thoroughly reliable engine of reasonably good fuel economy, whatever the cost in time of development or in difficulty and expense of manufacture, whereas the Germans rushed into quantity production an engine which had been intended only as a preliminary stage in a longer development program, and to some extent sacrificed the performance and reliability of even this engine in order to make possible very rapid production with a minimum consumption of strategic materials.