

stayed practically the same. Continuity through employment by the victorious powers also allowed these researchers to avoid critical questions about their joint responsibility for National Socialist Germany's war.

The easy integration of German specialists into the Allies' armaments programmes leads to the question of similarity between the armaments research organization in Nazi Germany and that of its victorious opponents. A systematic comparison of Nazi and Stalinist research organization is needed and would be very fruitful. This comparison cannot be made here, particularly in view of the lack of systematic analysis in the existing literature on the Soviet Union.

The fundamental thesis of this essay is that the momentous activities of German armaments engineers under National Socialism were a continuation of a previously existing professional self-perception, of a technocratic way of working and opportunistic political accommodation. This continuity explains the applicability of these behaviour patterns to the work for the victorious powers after 1945. In other words, the exaggeration of the specific Nazi convictions in the conduct of German armaments engineers would be a mistake. The Nazis did achieve one thing: the social self-awareness of engineers grew enormously. The appreciation of German know-how through employment by the Allies continued this tradition. A feeling of surrender or of having been involved in a shameful deed could be avoided or denied. The contributions of German engineers to armaments research and technological development both under the Nazis and after the Second World War in the service of the victorious powers are impressive precisely because neither the National Socialist system nor the victorious powers demanded a break in their traditions.

### 3 *The guided missile and the Third Reich: Peenemünde and the forging of a technological revolution\**

MICHAEL J. NEUFELD

Within a decade, from late 1932 to late 1942, the technology of rocketry was transformed by a German Army team based first at Kummersdorf and then at Peenemünde. Starting with small, unreliable amateur rocket experiments in the late Weimar Republic this group created a technological revolution: the first large guided missile, the A4 or V-2. Although this missile was ultimately a poor weapon and was responsible for a massive diversion of scientific, engineering and production resources from more sensible armaments projects, at the same time it embodied spectacular advances in liquid-fuel rocket propulsion, supersonic aerodynamics and inertial guidance. Indeed, it must be considered the greatest technological achievement of the Third Reich.<sup>1</sup> Yet the scholarly literature on this topic is extremely meagre; the subject has been too long the captive of popular historians who gave myth-making a higher priority than analysis or accuracy. The only major exception is Heinz Dieter Hölsken's *Die V-Waffen*, which illuminates the internecine German struggles over the 'vengeance weapons'. Hölsken, however, shows little interest in the history of science and technology in the Third Reich.<sup>2</sup>

In fact the German Army rocket programme was one of the first examples of state mobilization of massive engineering and scientific resources for the forced invention of a radical, new military technology. It preceded by a decade and was not dramatically smaller in scale than the even more revolutionary Manhattan Project in the United States. It is thus part of the intertwined stories of the rise of 'big science' and the growth of the military-industrial complex, which might be better called the military-industrial-university complex.<sup>3</sup>

But a more useful lens for viewing the creation and growth of Peenemünde is the 'technological systems' approach of Thomas P. Hughes. Hughes has shown, in his studies of the electrical pioneers, how successful

'system builders' had to overcome social and political obstacles just as much as technical, scientific and economic ones. John Law has called this 'heterogeneous engineering' – the social must be engineered as much as the technical if new inventions are to be converted into functioning technological systems. In the growth of systems, their builders encounter 'reverse salients' – Hughes' military metaphor for difficulties that impede the smooth advance of the system. By converting reverse salients into better-understood 'critical problems', system builders can concentrate financial and human resources to solve those problems. Successful systems acquire 'momentum': the mass of their capital investment and human organizations acquire a direction and velocity, and through 'conservative' inventions perpetuate and extend the control of the system. But as Law has pointed out, system growth is far from inexorable. Systems can fail or be dismantled if they are confronted by 'radical' inventions that supersede the technology on which the system is based, or if political, technical or economic problems run out of control.<sup>4</sup>

The construction and growth of the Germany Army guided missile programme differs significantly, however, from the corporate model on which Hughes concentrates, because it was a technological system growing out of a military bureaucracy in which economic considerations were largely irrelevant. The revolutionary possibilities of a long-range missile based on liquid-fuel rocketry alone motivated the engineering officers who launched the programme. They built, over time, a viable research, development and production system for the missile that, because of the need for secrecy and the inadequate technology base in industry, centred on a large government laboratory. The growth of the Peenemünde technological system was also furthered by the 'polycratic' character of the Nazi system, divided as it was into warring bureaucratic empires. The Army, as one of the most powerful actors in the regime, at least until the early years of the war, was able to promote its rocket project in the absence of a coherent system for setting priorities.<sup>5</sup> But in order to understand why the Army succeeded where the original inventors failed, it is necessary to look first at the origins of the missile in the spaceflight movement of the Weimar Republic.

### 1 The Weimar origins of the rocket programme

The liquid-fuel rocket was, in Hughes' terms, a 'radical' invention – that is, one which potentially could initiate a whole new technological system, and thus one subject to a great deal of initial scepticism. The idea of using liquid fuel to produce a quantum leap in performance over the black-powder rocket was originated primarily by the three main pioneers of the spaceflight movement: Konstantin Tsiolkovsky, Robert Goddard and Hermann Oberth. Of the three, Oberth, a German-speaking Transylvanian, had the most impact in Europe. While Tsiolkovsky was the first,

his publications were buried in obscure Russian journals and he was virtually unknown until after Oberth's seminal 1923 work, *Die Rakete zu den Planetenräumen* (The Rocket into Interplanetary Space). Goddard, a physicist at Clark University in Massachusetts, attempted to avoid public controversy. His famous *A Method of Reaching Extreme Altitudes* (1919/20) made only opaque references to advanced rocketry. Nonetheless, Goddard's discussion of a staged powder rocket capable of hitting the moon unleashed a wave of sensationalism and ridicule in the newspapers that only furthered his reclusiveness. He waited a decade before publicly acknowledging his launch of the world's first liquid-fuel rocket in 1926, although wild rumours of his activities did circulate in the press. Goddard was anything but a system builder. Supported by funds from the Guggenheim Foundation, Goddard eventually withdrew to the New Mexico desert and worked out of the public eye. He had neither the personality to convert the technology into a viable system, nor the historical context to do so – that is, energetic military support. As a result, his technological influence on later missile development was practically nil.<sup>6</sup>

Thus it was Oberth's 1923 book that had the most enduring impact. His open discussion of how the obstacles to spaceflight might be overcome included detailed discussions of possible alcohol/liquid-oxygen and liquid-hydrogen/liquid-oxygen multi-stage vehicles. Although *Die Rakete* initially did not provoke a large reaction, Oberth's cause was soon taken up by Max Valier, a freelance writer of dubious books on cosmology and the occult, but also a tireless propagandist. Valier's campaign eventually led to a brief alliance with Fritz von Opel, heir to the car-manufacturing fortune, and to a spectacular set of rocket-car stunts in the spring of 1928 using black-powder rockets. This unleashed a popular fad for rocketry and spaceflight in the Weimar Republic. Rocket stunts with cars, rail cars, gliders and even ice sleds followed, and famed director Fritz Lang released a serious moonflight movie, *Frau im Mond* (The Woman in the Moon), in October 1929. While some ridicule accompanied this activity, it appears that Germany had the most positive public reaction to the idea of spaceflight in the world at this time. Weimar culture in the 'stabilization period' (1924–30) seems to have been particularly open to radical technological change, and there was a nationalist pride in any German accomplishments that signalled recovery from the humiliations of the war and Versailles.<sup>7</sup>

The fad naturally boosted the fortunes of the small spaceflight movement in Germany, which had already formed an organization, the *Verein für Raumschiffahrt* (The Society for Space Travel or VfR), in 1927. One of the consequences of this fad was the beginning of serious liquid-fuel experiments – in contrast to the stunts with commercial black-powder rockets which served no useful purpose except publicity. Johannes Winkler, the first president of the VfR, carried out private experiments and worked at the Junkers aircraft company in Dessau from 1929 to 1931 and from 1933

to 1938 on the application of rocketry to aircraft. Meanwhile, Max Valier made an alliance with the Berlin liquid-oxygen equipment manufacturer Paul Heylandt in late 1929, and began to build a new rocket-car engine using paraffin fuel. Valier was killed in a laboratory explosion in May 1930, but his work was carried on in the factory by his Heylandt assistants, Walter Riedel and Arthur Rudolph – both to play very important roles at Peenemünde. The rocket car that was finished in 1931 was a public-relations flop, however. As the Depression deepened the rocket fad slowly died.<sup>8</sup>

But the group of experimenters that sustained rocketry more than any other in the years of economic collapse was the VfR's own *Raketenflugplatz* (Rocketport) in Berlin. It had its origins in Oberth's attempt to build a liquid-fuel rocket in 1929, as a publicity stunt for Lang's *Frau im Mond*. The technologically naive Oberth had hired a self-proclaimed engineer and shameless con-man, Rudolf Nebel, to help him. (It is ironically appropriate that 'Nebel' means 'fog'.) After the whole thing ended as a fiasco, Nebel went on an endless search for money and resources for further experiments. In the fall of 1930 his efforts led to the setting up of a rocket experiment group on an abandoned munitions dump in northern Berlin. The group attracted a number of unemployed craftsmen and engineers, and included a student, Wernher Freiherr von Braun, who was 18 in 1930 and was enrolled at the *Technische Hochschule* Berlin in mechanical engineering. The *Raketenflugplatz* built a number of engines and staged many launches from 1931 to 1933. The group's engine technology was based on trial-and-error experimentation, with liquid oxygen and gasoline as propellants (Figure 3.1). Alcohol was later substituted as the fuel, in line with Oberth's original suggestions – it was less explosive than gasoline and had the useful property that water could be added to reduce its concentration, thereby lowering burning temperature. Burn-throughs of engines nonetheless continued, along with frozen valves, leaky lines and innumerable other failures. The problem of rocket stability in flight was solved only poorly by giving the vehicles rather baroque configurations. The whole enterprise was a lot more showmanship than science.<sup>9</sup>

Compared to what would be needed to convert liquid-fuel rocketry into a viable technological system, the resources of the rocket groups and inventors were, of course, completely inadequate. The rocket pioneers, from Oberth to Nebel, had all pinned their hopes largely on some corporation or millionaire financing development or on forming their own corporation. They seem to have been influenced by the heroic independent inventor of the late nineteenth and early twentieth centuries, such as Edison and Diesel, and they marketed as possible commercial applications intercontinental transport by rocket plane, or in the nearer future, rocket mail. Nobody could imagine how expensive this technology would be, or what kind of military-industrial-university complex would be necessary to create it.

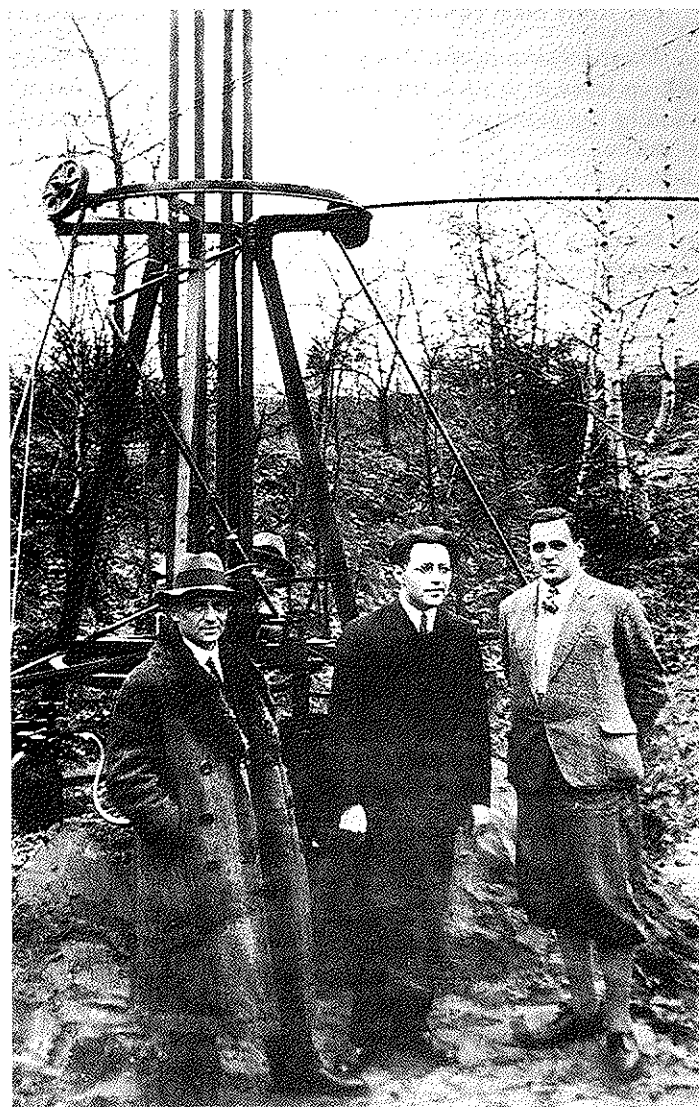


Fig. 3.1 Rudolf Nebel, at left, is shown at the *Raketenflugplatz* in April 1931, along with space popularizer Willy Ley and engineer Klaus Riedel. The engine test stand in the background was made out of the launch rail for the ill-fated Oberth *Frau im Mond* rocket of 1929.

## 2 The Army takes command – and builds a technological system

When officers in the Army Ordnance Office (*Heereswaffenamt*) first took an interest in rocketry they were no clearer on what would be required. The key figure at the beginning was Lt. Col. Dr Ing. Karl Becker, head of the ballistics and munitions section of the Weapons Testing Division. Undoubtedly as a result of the rocket fad, in 1929 Becker obtained the permission of the Reichswehr Ministry to investigate the rocket as a weapon. Because that technology had been militarily insignificant since the mid nineteenth century, there was no specific prohibition of it in the Versailles Treaty. But the lack of a clause banning rocketry has often been overrated as a cause of the programme. In fact, Becker's section was interested in using solid-fuel rockets as artillery for chemical warfare. Versailles forbade Germany the possession of poison gas, but that and other prohibitions had been continually violated by the Reichswehr in its secret rearmament programme. It is thus doubtful that the Treaty would have made much of a difference even if it had banned the rocket.<sup>10</sup>

Becker and his subordinates – of whom Capt. Walter Dornberger would later be the most important – also became interested in the long-term possibilities of liquid fuels for something much more ambitious. The ballistics and munitions section played a hidden hand in letting Nebel lease the *Raketenflugplatz* and, in 1931, as a result of Heylandt's rocket car, secretly began to give contracts to that company for engine development. Various rocketry inventors were investigated, and many turned out to be frauds. The *Raketenflugplatz* was paid to give a rocket launch demonstration in mid 1932, but the result was unimpressive, reinforcing the officers' disgust with the circus-like atmosphere surrounding Nebel. By this time it became clear that the inventors were achieving little while creating unwanted publicity, and that an in-house research-and-development group might make better progress. It took some years, however, before this became the central organizational concept of the new technological system.<sup>11</sup>

In late 1932 Wernher von Braun was hired as the first employee of the new group. He was of old Prussian Junker stock and his father was Minister of Agriculture in the reactionary Papen and Schleicher cabinets of 1932–3. This background helped the twenty-year-old von Braun overcome the officers' skepticism about his youth, but it was his technical brilliance that had most impressed Becker and Dornberger. He was put into a doctoral programme in applied physics at the University of Berlin after only two years of engineering school. His secret dissertation, defended with high honours in June 1934, amounted to a summary of the rocket development carried out under his direction at the artillery range at Kummersdorf, southwest of Berlin.<sup>12</sup> A number of assistants were brought to Kummersdorf as well – most notably Riedel, and later Rudolph, both originally from Heylandt.

Between 1932 and 1936, two factors pushed the Army Ordnance rocket group toward concentrating development in a large in-house laboratory: secrecy, and the frustrating inadequacy of the technology base in industry. Utter secrecy was an obsession with the engineering officers who supervised the rocket programme. Although the exact form of a large guided missile was unclear, the aim was to maintain Germany's 'sizable development lead' over foreign countries 'above all because of the element of surprise', Capt. Leo Zanssen stated in 1935.<sup>13</sup> The Nazi seizure of power provided the police state needed to suppress other rocket work and establish an Army near-monopoly over the technology, as well as the armaments build-up necessary to fund it. Army Ordnance worked hand in glove with counter-intelligence and the Gestapo to drive the rocket experimenters out of business in 1934; discussion of the subject was virtually banned from the press; unwanted people like Nebel were excluded from Kummersdorf while useful people like Rudolph were brought on board; and non-Germans, including the Romanian citizen Oberth, were kept at arm's length.<sup>14</sup>

The obsession with secrecy encouraged the construction of a large government laboratory. It also added to the difficulties of contracting out rocket-engine and vehicle parts to companies – something that was problematic in any case because of the lack of an adequate technology base in industry. While various firms working with aluminium did build engines, tanks and parts in the first few years, the problems involved drove the rocket group to concentrate more and more hardware fabrication in-house at Kummersdorf and to plan the new facility at Peenemünde on the Baltic coast with a complete manufacturing capability for test vehicles. Thus the heart of the nascent Army guided-missile system was the concentration of development and fabrication in one military facility, with corporate contractors playing only secondary roles. Contracting to private industry only became important when there were technological reverse salients that could not be easily attacked with in-house expertise. That was particularly the case in guidance and control; von Braun and his assistants had come out of an amateur tradition that, out of necessity, had emphasized propulsion to the neglect of all else. The crude stopgap measure of using a large rotating mass on the two A2s – the first Army liquid-fuel rockets launched in December 1934 – had to be replaced with a true three-axis guidance system based on gyroscopic principles. *Kreiselgeräte GmbH* (Gyro Devices Ltd), a research-and-development company secretly owned by the Navy, was given that task.<sup>15</sup>

The decisive breakthrough in the growth of the Army rocket programme came in 1935 through an alliance with the *Luftwaffe* (Air Force), which possessed enormous political capital in Göring's leadership. The new service's technical staff and the Army Ordnance group at Kummersdorf made an agreement to cooperate in exotic propulsion technologies. Five years of joint experiments with rocket planes and a rocket-assisted take-off system

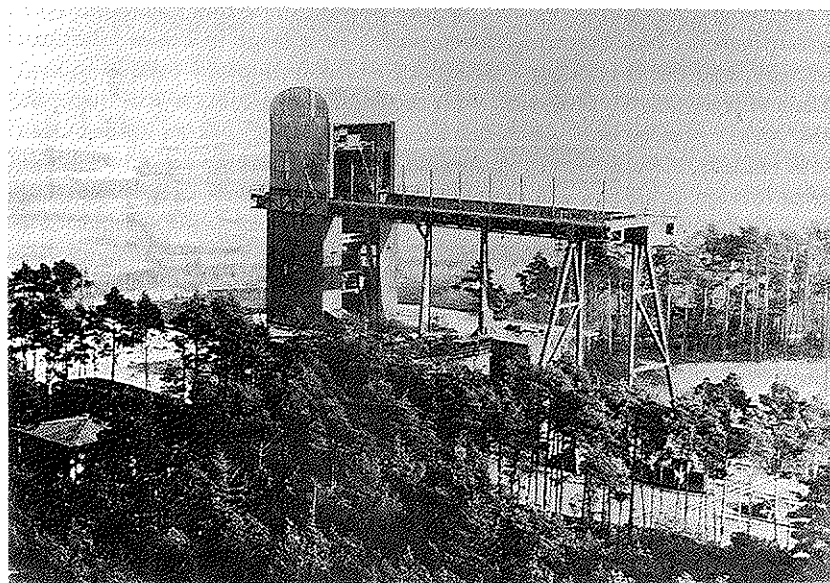


Fig. 3.2 Test stand I at Peenemünde, which could accommodate engines of up to 100 metric tons of thrust, was completed in spring 1939. Its massive size shows the huge investment made by the Army in rocketry since the *Raketenflugplatz* era.

for aircraft followed. Even more important was the decision to establish a joint research centre for the testing of missiles and other secret weapons. The Peenemünde site was purchased in early 1936, and it is clear that the *Luftwaffe's* influence and free-flowing money had much to do with the sudden acceleration in the scale of the Army rocket programme – not least because Becker, now a general and head of the Testing Division, was determined not to let the *Luftwaffe* outdo the Army in spending. Further support was received in 1936 from the Commander-in-Chief of the Army in return for the promise of a viable weapon. Out of this sprang Dornberger's idea for the A4 – a missile to deliver a one-ton warhead at twice the range of the Paris Gun of World War I – the prestige weapon of the heavy artillery, the area of specialization out of which Dornberger and Becker had come.<sup>16</sup> The *Luftwaffe* undertook construction of both halves of the Peenemünde facility and, beginning in April 1937, most of the Kummersdorf team moved to the Baltic coast. In September 1937 the Army side of Peenemünde had 349 employees. By mid 1942 it would have almost 6,000 in development alone (Figure 3.2).

### 3 The system expands – and incorporates the universities

With the growth of the new facility and with money no object, Dornberger's role as the key system builder became steadily more apparent. By 1936 he was head of an independent rocketry section and he possessed the full backing of Becker, who became head of Army Ordnance in 1938. Dornberger's ambitious concept for Peenemünde as a large in-house facility is shown by his desire to build a production line for the A4 there, rather than giving the vehicle to a corporation for quantity production. According to Arthur Rudolph, Dornberger sprang the idea of an in-house production facility on von Braun and himself during the December 1937 launches of the unsuccessful A3, a test vehicle. Rudolph and von Braun protested that they knew nothing about production, but within a year the plan had been approved by the new Army Commander-in-Chief, von Brauchitsch, and Rudolph had been named chief engineer in Peenemünde for the project.<sup>17</sup>

The second critical system builder was von Braun. His role was, first and foremost, to motivate and manage the engineers at Peenemünde – and indeed the key personnel in the project were overwhelmingly engineers or engineering professors, not scientists. Through his charismatic leadership and matchless command of difficult technical issues in all areas, von Braun kept morale high and development on track. He also played a crucial role in the integration of the universities into the research process. Contrary to many assertions in the English-language literature, the incorporation of many academic institutes into the Peenemünde system did not begin after secrecy was loosened in September 1939 to accelerate A4 development. Since 1935–6 Dr Rudolf Hermann, an assistant at the *Technische Hochschule* (Technical University) Aachen, had been involved in testing subscale rocket models in the supersonic windtunnel there. Von Braun and Dornberger attracted him to the Peenemünde team in 1937 with the promise of a new, much larger, world-class supersonic windtunnel to be built in the Army facility. Until it was completed in November 1939, however, von Braun and his development people still depended on Aachen, *Luftwaffe* facilities and the Zeppelin company for aerodynamic research. Measuring systems and other apparatus were also designed by Prof. Dr Hase at the TH Hannover. It is true, however, that the involvement of university institutes became much larger during the war; particularly important were the *Technische Hochschulen*, especially Dresden and Darmstadt.<sup>18</sup>

The reasons why institute directors were willing to accept many of Peenemünde's research problems included scientific interest, nationalist or National Socialist ideological commitment, and funding and draft exemptions for key people. More interesting is how the von Braun team incorporated the universities into the research process. Von Braun seems to have cultivated his contacts with academic scientists and engineers in part to find key personnel for the massive build-up of on-site development capability.

During the war he also assiduously promoted an academic atmosphere, including the exchange of ideas and research results among the Peenemünde laboratories and between the Baltic-coast facility and the universities. It is noteworthy that von Braun and Dornberger incorporated the university institutes by evading all centralized mechanisms like the weak Reich Research Council which, ironically, Becker headed from its founding in 1938 until his suicide in April 1940. But even Becker seems to have had little interest in the Council, and in the polycratic ruling system of the Third Reich no one was able to organize research centrally or produce a coherent scientific war effort. In this context Peenemünde was able to divert a significant percentage of German research resources into the militarily questionable guided-missile programme. It also fended off attempts later in the war to strengthen Research Council control.<sup>19</sup>

With the relentless expansion of its resources between 1935 and 1942, Peenemünde had finally entered the realm of 'big science', or better, *Grossforschung* ('big research'). This transformation both fostered dramatic breakthroughs in the three key technologies necessary for the A4 and was a result of them, since success helped ensure continued growth. In liquid-fuel rocket propulsion, Dr Walter Thiel, formerly of the Research Section of Ordnance Testing Division, produced a quantum leap in performance between 1936 and 1941. He scaled up the alcohol/liquid oxygen engine from the A3's 1.5 metric ton thrust to the 25 ton thrust needed for the A4, while drastically reducing engine size, overcoming perplexing injection and burn-through problems and increasing efficiency to near the theoretical maximum. This effort was almost entirely in-house, except for the contracts for the steam generator/turbopump combination needed to move large volumes of propellants. In aerodynamics, Hermann's group, through laborious subsonic and supersonic wind-tunnel work, drop tests and launches, was able to refine the fin and fuselage shape to produce the first fin-stabilized supersonic projectile – something some artillery specialists said was impossible.<sup>20</sup>

But it was the third key technology, guidance and control, that was the biggest technological reverse salient. Simply contracting the problem to Kreiselgeräte for the A3 proved illusory as the difficulties were far larger than the company or the Army anticipated. In the aftermath of the failure of the A3 guidance platforms, a new test vehicle (the A5) was designed, other firms, primarily from the aviation instruments sector, were given parallel contracts to those of Kreiselgeräte, and the formerly weak guidance-and-control section of Peenemünde was greatly expanded in personnel under the direction of Dr Ernst Steinhoff. This change greatly expanded the large in-house laboratory concept at the heart of the system. After the war started, university research also made significant contributions. Prof. Dr Wolman of the TH Dresden was the key figure in the design and refinement of the radio cut-off and tracking systems for the A4,

and many institutes at Darmstadt were involved in the calculation and simulation of trajectories, the design of accelerometers and the perfection of the control system.<sup>21</sup>

#### 4 The battle for priority

The attack on Poland brought an acceleration of A4/V-2 development, making possible the appropriation of greatly expanded research resources. But the war also plunged the programme into the Third Reich's internal struggles for power and priority. Although Dornberger was only a lieutenant colonel in the Army Ordnance at the start of the war, he proved to be a talented in-fighter and system-builder who cultivated contacts at the highest levels of the Army and the regime. His close alliances with Becker, and above all with von Brauchitsch, who had been his regimental commander in the Weimar Republic, were particularly important.<sup>22</sup> In the very first days of the war Dornberger secured top priority for the rocket programme from the Army Commander-in-Chief by promising field deployment of the missile in two years: a risky gamble. Another key ally was cultivated at this time – Albert Speer, Hitler's chief architect and, after 1942, Armaments Minister. Speer's organization began supervising the construction of the Army installation in 1939. He explained in his memoirs the peculiar fascination exercised by the von Braun team ('these mathematical romantics'), and with the technology ('the planning of a miracle').<sup>23</sup> The romantic appeal of the technology was not a trivial factor in the support rocketry received from leading personalities in the Third Reich – above all because of the anticipated morale effect on target populations of this exotic new weapon. The guided-missile technological system of the Army also acquired a great deal of 'momentum' through its first-rate installations and research staff. These factors made it difficult to question the logic of an enormously expensive weapon that could, as it turned out, only drop conventional explosives randomly over large urban areas.

Nonetheless, the Army rocket programme went through a number of vicissitudes between 1939 and 1943 as a result of the incoherent leadership of the war economy and because of episodes of scepticism on the part of both Hitler and Fritz Todt, who became the first Armaments Minister in 1940. Von Brauchitsch's assignment of top priority without regard to other authorities – like his approval of the production plant in 1938 – symbolized an arrogant independence on the part of the Army which could not be sustained. Hitler cut back the steel quota for Peenemünde in November 1939, and showed himself unenthusiastic for the project at times. A mythology has been constructed around this fact, however, based on the memoirs of Dornberger and von Braun. Far from Hitler withholding top priority until mid 1943, missile development was reduced to second priority only for six months in 1940–1. This temporary reduction plus other



transitory priority problems did not delay the A4 for more than a few months; the missile lagged behind because the technical difficulties were so challenging. It was production that was delayed – in the shape of the separate Peenemünde plant that was being built. But that project was mired in a morass of problems of its own making, and even if it had been built faster it would have been ready too soon – before the A4 itself. In fact in August 1941 the Army leadership succeeded in making an end run around the increasingly sceptical Todt by securing the support of Hitler, who in a meeting with Dornberger and von Braun declared the A4 ‘revolutionary for the conduct of warfare in the whole world’. He made an absurd demand for hundreds of thousands of missiles! The production plant was upgraded to top priority immediately afterward.<sup>24</sup>

This incident reveals clearly the ‘polycratic’ character of the war economy and priority system and the lack of perceptive strategic leadership in the Reich. By one estimate it cost 550 million Reichmarks to build the Army facilities at Peenemünde, and the cost of production was considerably more.<sup>25</sup> The Army was able to push the programme forward because of its substantial, though declining, influence, and because skilful manoeuvring by Dornberger and his superiors allowed them to reach the *Führer* and exploit his desire to punish Britain.

But even a *Führer* order did not end the priority battles over the Army project. During the early years of the war, relations with the *Luftwaffe* deteriorated and the rocket plane experiments were ended. After the failure of the air arm in the Battle of Britain, the Army’s long-range weapon project began to look too much like competition: ‘the Army is beginning to fly’, grumbled some Air Force officers. Eventually the *Luftwaffe* launched its own long-range weapons project in 1942, the later V-1, in part to get back at the Army, but this never proved a decisive threat to the A4/V-2. The interservice rivalry has, however, been exaggerated. In 1942 a new cooperative Army/*Luftwaffe* project was launched, an anti-aircraft missile name Wasserfall. That project has hampered not so much by interservice rivalry as by disarray in the Aviation Ministry itself, and by an underestimation on all side of its technical difficulty.<sup>26</sup>

## 5 Production, concentration-camp labour and the collapse

The Wasserfall project brought new manpower and resources to the Army side of Peenemünde, but also complicated further the immense difficulties in putting the A4 into production and deploying it in the field. Aided by the *Führer’s* support in August 1941, Dornberger accelerated planning for production, and extended his system-building to include new production sites, liquid-oxygen plants, and the fabrication of vehicles and equipment for mobile and fixed launches. But there is every sign that the technology of the A4 was rushed prematurely into production by Dornberger

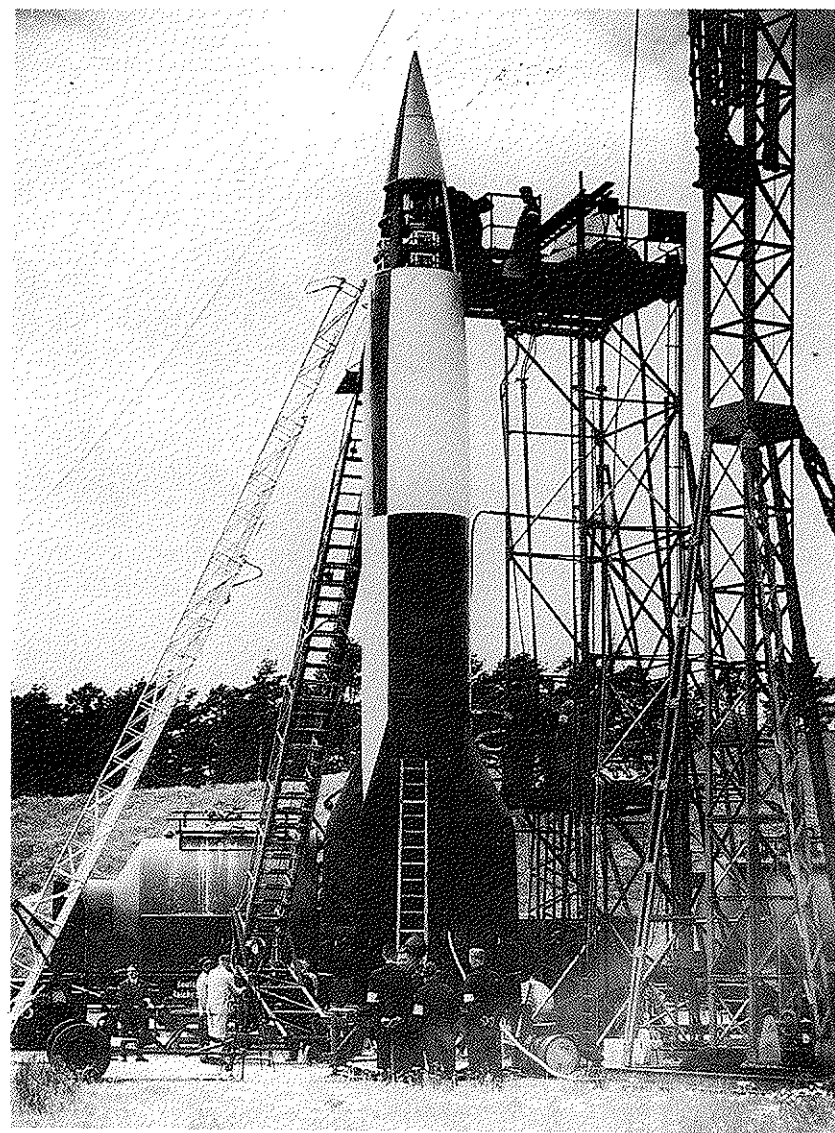


Fig. 3.3 The first successful A4 (V-2) is prepared for launch on 3 October, 1942.



Fig. 3.4 After the first successful launch, General Fellgiebel, head of the radar programme, congratulates Peenemünde-East Commander Col. Leo Zanssen, standing at centre. Third from left is Col. Walter Dornberger, followed by Dr Werner von Braun, Dr Ernst Steinhoff (in *Luftwaffe* uniform), Dr Rudolf Hermann, and Dipl.-Ing. Gerhard Reisig, head of the measurement group.

because he had 'bet the company': promising early deployment was the only way for the missile programme to grow rather than to shrink or to be cancelled. As a result, the engine was too complicated for cost-effective mass production, the guidance system too immature to deliver the accuracy promised. Von Braun's development team struggled with innumerable failures, but did achieve a successful launch on the third attempt in October 1942. However, due to the ever-changing configuration of the vehicle as it was refined, the production drawings remained in a terrible mess<sup>27</sup> (Figures 3.3 and 3.4).

The morass into which the production plans had sunk was only overcome when Speer, who had become Armaments Minister after the February 1942 death of Todt, obtained approval from Hitler for mass production in December of that year. Speer ruthlessly pushed through a speed-up and reorganization, just as he had done with the war economy. Inevitably, many of his top people collided with Dornberger, who like most officers resented the intrusion of the civilian armaments bureaucracy into his bailiwick. Dornberger even had to fend off attempts to hand over the production plant to the electrical engineering giant AEG and then to convert the whole facility into a company.<sup>28</sup> But all plans to build A4s at Peenemünde and elsewhere became irrelevant after the harmful but not decisive RAF air raid on the secret weapons centre on 17–18 August 1943. Himmler, arguing that spies must have betrayed the location, convinced Hitler to move production underground. The result was the murderous Mittelwerk factory built with concentration-camp labour by SS-General Hans Kammler and run by an Armaments Ministry corporation. It began producing A4s at the end of 1943 – at the cost of thousands of prisoner lives<sup>29</sup> (Figure 3.5).

After the war the SS provided a convenient scapegoat for all crimes connected with the rocket programme. Actually Dornberger, Rudolph and the Armaments Ministry had already arranged to have SS prisoners brought to Peenemünde and planned the same for other factories.<sup>30</sup> The desperate shortage of manpower and the relentless drive to expand the guided-missile technological system necessarily implicated the programme more and more in the Third Reich's growing system of forced and slave labour. Nonetheless, Himmler and the SS presented an even more formidable challenge to the Army's control over the system than had the Armaments Ministry. Himmler made his next move in February–March 1944 by attempting first to entice von Braun, who held honorary SS rank, to take his team into the SS, then, when he refused, by arresting him and two others as punishment. Von Braun and the others were rescued by the efforts of Speer and Dornberger.<sup>31</sup>

Only after the assassination attempt against Hitler on 20 July 1944 was Himmler able to make further strides toward his goal of absorbing the rocket programme. As new head of Army armaments, he named Kammler



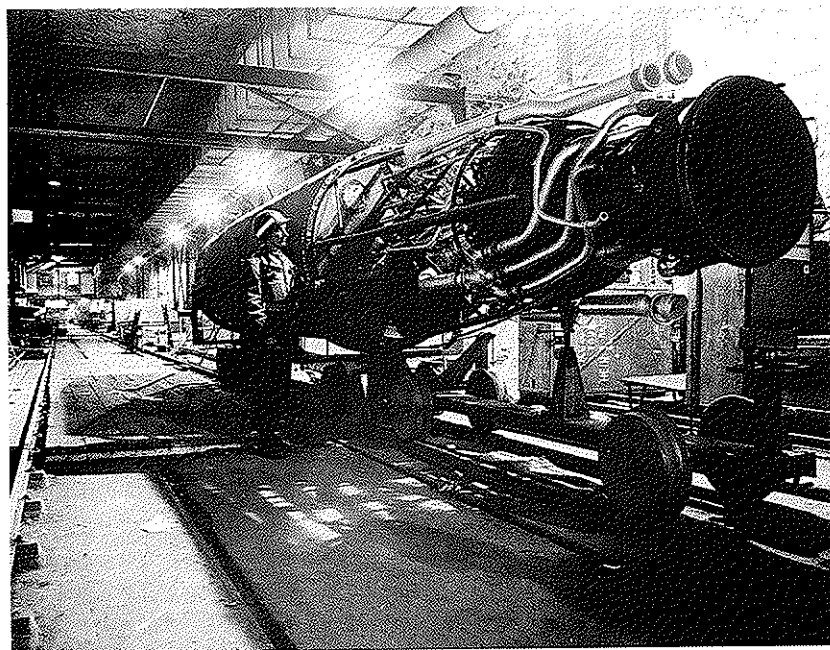


Fig. 3.5 An American soldier guards a captured and nearly completed A4 missile in the underground *Mittelwerk* facility, 1945.

'special commissioner for A4 matters'. In what may have been a counter-move, on 1 August the Army establishment at Peenemünde completed its transformation into a civilian government corporation, the *Elektromechanische Werke GmbH*, with a director from Siemens as its chief. It was a further sign of the collapse of the Army's position in the Third Reich.<sup>32</sup> In the last months of the war Kammler became the ultimate authority in a technological system run by a coalition of the SS, the Speer Ministry and the Army. While Dornberger retained an important position in the system directing the training and outfitting of the guided-missile troops, he was more and more reduced to carrying out the orders of Kammler and Speer.

On 8 September 1944 the first operational missiles – now called V-2s – were successfully fired against Paris and London. Their effect has often been greatly overrated; the total explosive load of all the V-2s fired was less than a large RAF bomber raid.<sup>33</sup> But impelled by desperation, von Braun's team at Peenemünde, Dornberger, Speer and Kammler all worked to produce as many missiles as possible without regard to the cost to the prisoners. Work also continued on Wasserfall; many test launches were made in 1944–5, but the guidance system was very incomplete. The Baltic-

coast installation was finally evacuated in February–March 1945, and the team was concentrated around the *Mittelwerk* in central Germany. Nothing much could be done there. In April Dornberger and some of the team members moved to Bavaria, where they successfully contacted the US forces on 2 May.

## 6 Transfer to the United States

Within weeks the United States had seized most of the documents and key people from the German Army missile programme, plus parts and equipment for about 100 V-2s. Much of this material was quickly evacuated from areas that were to be in the Russian and British zones of occupation. 'Project Overcast', to exploit German scientists and engineers for the war against Japan, soon became 'Project Paperclip', aimed at a broader use of German personnel in the United States. As is well known, a group of about one hundred and twenty researchers led by von Braun was assembled at Fort Bliss, near El Paso, Texas, and was involved in the Army Ordnance/General Electric *Hermes* programme for guided-missile research (Figure 3.6). V-2 launches were carried out at White Sands, New Mexico, for scientific and military purposes. But the von Braun group was underutilized and frustrated at Fort Bliss, and only in 1950 when they were moved to Redstone Arsenal in Huntsville, Alabama, did they return to accelerated missile development. They designed the Redstone missile, really an upgraded A4, and later the Jupiter and Pershing (Figure 3.7). In 1960 the Huntsville group was transferred to NASA as the Marshall Space Flight Center, along with their giant booster programme, Saturn.<sup>34</sup>

The details of these developments need not distract us here. For our purposes what is interesting is the manner in which the German Army guided-missile programme was transferred to the United States. The end of the war meant the collapse of the technological system centred at Peenemünde. But the preservation of its documents and its core personnel relatively intact, plus the transfer from German to US Army Ordnance allowed the reconstruction of the system in another country – something that may be unique. The 'arsenal system' of development and production of weapons in Army installations was an old tradition in the United States, despite the general hostility to state ownership in American ideology. At Redstone Arsenal the von Braun group was able to reconstruct the model of in-house development and manufacture of test and prototype missiles, with contracting limited to subsystems and mass production. The only functional elements missing were close university contacts – and concentration camps.

This system was in marked contrast to the Air Force, which contracted development to aerospace corporations with limited supervision/programme management by officers. In the interservice battles over missiles and space in the Sputnik era, the arsenal system was often attacked as



Fig. 3.6 Peenemünde engineers brought to the United States under 'Project Paperclip' are assembled at White Sands Proving Ground, New Mexico, in 1946. Von Braun is standing seventh from the right in the first row, with his hand in his pocket. Fourth from left is the front row, in the short white jacket, is Arthur Rudolph.



Fig. 3.7 Counterclockwise from left, at the US Army Redstone Arsenal in Huntsville, Alabama, c. 1955, are Gen. Holger Toftoy, Dr Ernst Stuhlinger, Hermann Oberth, Dr Wernher von Braun and Dr Robert Lusser.

expensive, old-fashioned and incompatible with American capitalism. Under NASA, the Marshal Space Flight Center was forced more and more to depart from the old system, due to the agency's preference for the Air Force system and the massive scale of the Saturn V project – the launch

vehicle for the Apollo lunar landings. Even so, the von Braun group retained more intense supervision, more in-house work and a more conservative technological style, which contributed to the astonishing standards of reliability of the Saturn vehicles. Only with the post-Apollo cutbacks of the early 1970s was the Huntsville system finally gutted and most of the Germans pushed into retirement.<sup>35</sup>

## 7 Conclusions

The transfer of Peenemünde's system to the United States obviously raises the question as to what, if anything, about the German guided-missile programme was specifically Nazi in character, other than slave labour. As part of the story of the rise of the military-industrial-university complex, Peenemünde had some of the features seen elsewhere, such as at Los Alamos: ultra-secrecy, massive state investment, the need to scale up exotic technologies to an industrial level, and the harnessing of university research for weapons development. For enterprises like Peenemünde and the Manhattan Project to be successful, they needed system builders who had a vision of how military, corporate and academic resources might be reorganized for the purpose of creating radical new weapons technologies almost regardless of cost. Even the feature that appears to be unique to the German missile programme – the dominance of the central military laboratory, with production as well as research-and-development capability – turns out to be fairly similar to the US arsenal system. It is possible that older German Army Ordnance traditions resembled those of the United States, since armories and arsenals had a long history in all Western armies. But such influences are not readily visible in the Peenemünde documents.

What clearly was influential for the in-house development system at Peenemünde was secrecy, plus the lack of any industrial base for rocket technology. Becker, Dornberger and other leading officers were obsessed with secrecy because they thought the revolutionary possibilities of the guided missile justified launching Germany first into a new arms race. (They were in fact convinced that they were in a race with other powers, especially the United States, until late in the war – an ironic mirror image of the assumptions behind the Manhattan programme.) Secrecy plus the Nazi police state allowed the Army to put the amateurs out of business, but also hampered the contracting out of development to corporations, which had proven frustrating in any case because of the inadequacy of the technology in industry. As a result, Peenemünde was planned with the capability to fabricate entire test rockets and Dornberger, as chief system-builder, pushed this philosophy further in 1938 with his idea for a production plant. The unanticipated need to build a large guidance-and-control laboratory only added to the trend toward extensive in-house capability as the core of the system.

Corporate contractors thus played a secondary role as extensions of the system, as did a number of university institutes which were increasingly integrated after the beginning of the war. Only with the shift to mass production and the forceful intrusion of the Speer ministry in 1942–3 was the corporate role expanded. National Socialist anti-capitalism – as fraudulent as it often was – therefore cannot be shown to have played any role in the shaping of the German guided-missile programme, and Nazi ideology in general had little effect. The desire for an aggressive military buildup and the search for decisive new weapons technologies already flourished in the old Reichswehr officer corps. Versailles, by stripping the Army of most of its men and armaments, had fuelled both revanchist attitudes and an openness to radical inventions with military potential.

We are thus left with the question: what was specifically Nazi about the German guided-missile programme? Other than the use of concentration-camp labour, the answer is, not very much. But posing the question in this way misses what is really important: the Third Reich as historical context. The leap at such an early date from small-scale rocket research to a massive technological system is difficult to imagine without National Socialism. Becker, Dornberger and von Braun's system-building flourished as a result of the rearmament drive and the Army's autonomous position in a polycratic regime of competing power blocs. The division and incoherence in the leadership of the military and war economy also contributed to the lack of a coherent weapons development policy or perceptive strategic leadership – something that was a problem in any case with dilettantes like Hitler and Göring as supreme commanders. In the end, despite episodes of disinterest on the part of the *Führer*, almost no one fundamentally questioned the wisdom of an extremely expensive weapons system that was supposed to destroy enemy morale by scattering relatively small amounts of conventional explosives over large urban areas. As a result, the rocket programme built an institution and a weapon which made little sense given the Reich's limited research resources and industrial capacity – a perfect symbol of the Nazi regime's pursuit of irrational goals with rational, technocratic means. Because of the in-fighting in the Third Reich, the guided missile came not 'too late' but, as Hölsken has suggested, too early – before electronics, computers and nuclear weapons could make it effective.<sup>36</sup> Only in other places and at other times could the technology of Peenemünde reach its logical conclusion: the ICBM.

- Germany (B.E.), Berlin B.A.O.R. (12 August 1946); all of the above-mentioned reports are in FO 1031/65 Public Record Office, London; cases of luring scientists and engineers are also reported by G. Klimow, *Berliner Kreml* (Cologne, 1951), pp. 276ff. and Lasby, *Project Paperclip*, pp. 140ff.
- 92 *Christ und Welt* (22 June 1950) and I. Gröttrup, *Die Besessenen und die Mächtigen. Im Schatten der Roten Rakete* (Stuttgart, 1958), p. 17.
- 93 'Return of Specified Specialists-Scientists to Russian zone', U.S. Group Control Council (Germany), F.I.A.T. (14 September 1945) RG 260/OMGUS/1945-46/41/16 Bundesarchiv Koblenz.
- 94 'The Employment of German Scientists and Technicians for Civil Industry in U.K.', British Intelligence Objectives Sub-Committee (B.I.O.S.) (18 December 1946) B.T. 211/60 Public Record Office, London.
- 95 Deputy chiefs of Staff Committee (D.C.O.S.), 27th meeting (11 September 1946) B.T. 211/60 Public Record Office, London.
- 96 Message from CONFOLK to BERCOMB (26 September 1946) B.T. 211/60 Public Record Office, London.
- 97 F.I.A.T. Forward Intelligence Group, Control Commission for Germany (24 May 1946) and F.I.A.T. Enemy Personnel Exploitation Section (31 May 1946), both in FO 1031/59 Public Record Office, London.
- 98 Lasby, *Project Paperclip*, pp. 151 and 180.
- 99 See H. Esche, *Die Ausplünderung des deutschen Ostens* (Munich, 1948), pp. 30ff.
- 100 H. and E. Barwich, *Das rote Atom* (Munich, 1967), pp. 19 and 21.
- 101 For example Gustav Hertz and Heinz Barwich.
- 102 See Gimbel, 'U.S. Policy', 434ff.
- 103 Gimbel, 'U.S. Policy', 437 and 445.
- 104 Gimbel, 'U.S. Policy', 446.
- 105 See Brandner, *Ein Leben*, p. 123.
- 106 See Lucius D. Clay to the Joint Chiefs of Staff, 'Removal of Scientific Equipment to U.S.', (6 December 1945) in J. E. Smith (ed.), *The Papers of General Lucius D. Clay: Germany 1945-1949*, vol. I (Bloomington, 1974), p. 129.
- 107 Gimbel, *Science*, p. 37.
- 108 This aspect is also underlined by Gimbel, 'U.S. Policy', 450.
- 109 Bower, *Paperclip Controversy*, pp. 3-8.
- 110 Bower, *Paperclip Controversy*, p. 254.
- 111 Esche, *Die Ausplünderung*, p. 31; see also 'Soviet sponsored Research Organizations currently active in Berlin', F.I.A.T. (1 March 1946) FO 1031/65 Public Record Office, London.

### 3 The guided missile and the Third Reich: Peenemünde and the forging of a technological revolution

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- 1 The only other achievement that comes close was the development of the turbojet engine and the first operational jet fighter, the Me 262. But the scale of the transformation of aircraft by the 'turbojet revolution', however impressive, does not equal the transformation of rocketry effected at Peenemünde from fireworks and amateur toys to the forerunner of the ICBM. See E. Constant II, *The Origins of the Turbojet Revolution* (Baltimore, 1980). Constant offers a model of technological revolution based on Thomas Kuhn, but he emphasizes conceptual revolutions in 'communities of technological practitioners' as a result of a 'normal technology' reaching its limitations. This seems less appropriate to my case than models of technological 'system-building'. The term 'technological revolution' is used here only informally to indicate the scale of the transformation.
- 2 *Die V-Waffen* (Stuttgart, 1984). For an earlier, unfootnoted version of the 'V' weapons struggle see D. Irving, *The Mare's Nest* (Boston, 1964), translated as *Die Geheimwaffen des Dritten Reiches* (Gutersloh, 1965). The most influential book in English, F. Ordway and M. Sharpe, *The Rocket Team* (New York, 1979), is riddled with errors, and it mythologizes the record of von Braun and his assistants.
- 3 On the military-industrial complex and its relationship to rocketry see W. McDougall, *The Heavens and the Earth. A Political History of the Space Age* (New York, 1985).
- 4 T. Hughes, *Networks of Power* (Baltimore, 1983), pp. 5-17; W. Bijker, T. Hughes and T. Pinch (eds.), *The Social Construction of Technological Systems* (Cambridge, Mass., 1987), pp. 51-82, 112-14.
- 5 For an introduction to the literature on the 'polycratic' character of the Third Reich see I. Kershaw, *The Nazi Dictatorship*, 2nd edn (London, 1989), pp. 65-81.
- 6 For details see F. Winter's *Prelude to the Space Age* (Washington, D.C., 1983), pp. 21-54.
- 7 For an elaboration of this argument see my 'Weimar Culture and Futuristic Technology: The Rocketry and Spaceflight Fad in Germany, 1923-1933', *Technology and Culture* 31 (1990), 725-52.
- 8 J. Winkler, 'Rückstoss-Arbeiten-Winkler', 8 May 1943, Deutsches Museum, Klee-Sammlung, Korrespondenzbd. 22 (1943), H. Kunze, 'Zur Zusammenarbeit von Hugo Junkers und Johannes Winkler', *NTM: Schriftenreihe für Geschichte der Naturwissenschaften, Technik und Medizin* 24 (1987), 62-82; Arthur Rudolph, oral history interview (hereafter abbreviated as OHI) with M. Neufeld, 4 August 1989, pp. 5-11, National Air and Space Museum (NASM).
- 9 Winter, *Prelude*, pp. 40-4; W. Ley, *Rockets, Missiles and Space Travel*, 2nd rev. edn (New York, 1962), chap. 6.
- 10 Lt. Gen. E. Schneider, 'Technik und Waffenentwicklung im Kriege', in

- Bilanz des Zweiten Weltkrieges* (Oldenbourg, 1953), pp. 225-47, here 236; R.-D. Müller, 'World Power Status Through the Use of Poison Gas? German Preparations for Chemical Warfare, 1919-1945', in W. Deist (ed.), *The German Military in the Age of Total War* (Leamington Spa, 1985), pp. 171-209.
11. On the relations between Army Ordnance and the rocketry pioneers see Bundesarchiv/Militärarchiv (hereafter BA/MA), RH 8/v. 1221-1226 (part of which is also available at the NASM archives on microfilm, NASM/FE 366) and with Heylandt, NASM/FE 724. Only summary descriptions of most archival sources are given here. Details will be given in my forthcoming book, *The Rocket and the Reich: Peenemünde and the German Army Guided Missile Program* (in press). See also W. Dornberger, V-2 (New York, 1954), pp. 27-32.
  12. W. von Braun, 'Konstruktive, theoretische und experimentelle Beiträge zu dem Problem der Flüssigkeitsrakete', (PhD Diss., University of Berlin, 1934), reprint, *Raketentechnik und Raumfahrtforschung*, Sonderheft 1, n.d. (c. 1960); Rudolph, OHI, NASM, 86-7.
  13. Zanssen to Wimmer (Chief, Air Ministry Technical Office), 22 May 1935, NASM/FE 746c.
  14. BA/MA RH 8/v. 1221-1226.
  15. On contracts with industry see the correspondence on microfilm in NASM/FE 724, 744, 752. On Kreiselgeräte, NASM/FE 74b and Fritz Mueller, OHI by M. Neufeld, 6-8 Nov. 1989, NASM.
  16. Correspondence with the Luftwaffe in NASM/FE 746; W. von Braun, 'Reminiscences of German Rocketry', *Journal of the British Interplanetary Society* 15 (1956), 133-4; Dornberger, V-2, pp. 38-9.
  17. Rudolph, OHI, 75-7, NASM.
  18. Hölsken, *Die V-Waffen*, pp. 19, 21; von Braun, 'Reminiscences', 137-8; Ordway and Sharpe, *The Rocket Team*, p. 35; H. Mehrrens, 'Angewandte Mathematik und Anwendungen der Mathematik im nationalsozialistischen Deutschland', *Geschichte und Gesellschaft* 12 (1986), 334; 1939 meetings at Dresden and Kummersdorf in NASM technical file 'Peenemünde #2'. On Hase see the correspondence in NASM/FE 737.
  19. von Braun, 'Reminiscences', 138-9; Dornberger to Wa F (Schumann) 19 Sept. 1939, NASM file 'Peenemünde #2'; G. Reisig, 'Das kongeniale Vermächtnis Hermann Oberth's und Wernher von Braun's für die Raumfahrt-Entwicklung', *Astronautik* (1987), no. 4, 106. On the Reich Research Council see K.-H. Ludwig, *Technik und Ingenieure im Dritten Reich* (Düsseldorf, 1974), pp. 218-70 and M. Walker, *German National Socialism and the Quest for Nuclear Power 1939-1949* (Cambridge, 1989), p. 18.
  20. G. Reisig, 'Von den Peenemünde "Aggregaten" zur amerikanischen "Mondrakete"', *Astronautik* (1986), 5-9, 44-7, 73-8, 111. My primary research confirms Reisig's main conclusions. On *Grossforschung*, see M. Szöllösi-Janze and H. Trischler (eds.), *Grossforschung in Deutschland* (Frankfurt a.M., 1990), especially pp. 13-20, 23-37.
  21. For a preliminary synthesis of the Peenemünde guidance and control story

- see D. MacKenzie, *Inventing Accuracy* (Cambridge, Mass., 1990), pp. 44-60. MacKenzie does not use the original sources, which are found in NASM/FE 23a, 23b, 74b, 119, 452, 746 and innumerable other files. For an older account which uses part of the original documents, but discusses only Siemens, see S. Karner, 'Die Steuerung der V2', *Technikgeschichte* 46 (1979), 45-66.
22. Gerhard Reisig, OHI by D. DeVorkin and M. Collins, 1985, NASM.
  23. Hölsken, *Die V-Waffen*, pp. 20-1; A. Speer, *Inside the Third Reich* (New York, 1971), p. 469.
  24. Dornberger Aktennotiz, 21 Aug. 1941, and Oberkommando der Wehrmacht [OKW] order of 15 Sept. 1941, in NASM/FE 341. For the best account of the priority battle to 1941 see Hölsken, *Die V-Waffen*, pp. 21-33, but this account contains errors. The original documents are found in the BA/MA Freiburg and on microfilm NASM/FE 341, 342 and 349. I have examined these questions in detail in 'Hitler, the V-2 and the Battle for Priority, 1939-1943', forthcoming in *The Journal of Military History* (July 1993).
  25. Hölsken, *Die V-Waffen*, p. 19. The total cost of the programme, including 6,000 V-2s, was around RM 2,000 million.
  26. 'Milch Collection' documents of Luftwaffe development meetings in US National Archives microfilm publication T-321; Hölsken, *Die V-Waffen*, 25-38; E. Klee and O. Merk, *The Birth of the Missile* (New York, 1965), pp. 64-78.
  27. Hölsken, *Die V-Waffen*, pp. 36-49; Reisig, OHI, 1985, NASM; and original documents in NASM/FE 342, 357, 358, 692f, 750.
  28. Schubert chronicle entries for 23-6 Feb., 16-19 Mar. and 30 Apr. 1943 in BA/MA RH 8/v. 1210; Hölsken, *Die V-Waffen*, pp. 40-1; Dornberger, V-2, pp. 80-6.
  29. Hölsken, *Die V-Waffen*, pp. 37, 50-1; M. Bornemann, *Geheimprojekt Mittelbau* (Munich, 1971).
  30. HAP/VW chronicle entries and documents in BA/MA RH 8/v. 1210; F. Freund and B. Perz, *Das KZ in der Serbenhalle* (Vienna, 1987), pp. 55-91.
  31. Hölsken, *Die V-Waffen*, pp. 67-9; von Braun, 'Reminiscences', 142-3; Dornberger V-2, pp. 200-7; Wernher von Braun file, Berlin Document Center.
  32. Hölsken, *Die V-Waffen*, p. 72. The conversion to a corporation was in discussion no later than June as shown by Dir. Storch?, 'Die Aufgaben der Elektromechanische Werke G.m.b.H. (EMW)', 28 June 1944, NASM/FE 692f.
  33. Hölsken, *Die V-Waffen*, p. 211.
  34. C. Lasby, *Project Paperclip* (New York, 1971); T. Bower, *The Paperclip Conspiracy* (London, 1987); L. Hunt, *Secret Agenda* (New York, 1991); J. Gimbel, 'German Scientists, United States Denazification Policy, and the "Paperclip Conspiracy"', *International History Review* 12 (Aug. 1990), 441-65. On the von Braun group under the US Army, the literature is poor. See Ordway and Sharpe, *Rocket Team*, pp. 344-404 and their bibliography.
  35. R. Bilstein, *Stages to Saturn* (Washington, D.C., 1980), pp. 81-3, 262-92;



- A. Dunar and S. Waring, draft chapters 1 and 2 of the NASA Marshall Space Flight Center history (ms., University of Alabama at Huntsville, 1989); G. Reisig, 'Das kongeniale Vermächtnis', *Astronautik* (1988), no. 1, 10–11.
- 36 Hölsken, *Die V-Waffen*, pp. 203–8. Hölsken does not mention nuclear weapons.

#### 4 Self-mobilization or resistance? Aeronautical research and National Socialism

- 1 I. Kershaw, *The Nazi Dictatorship: Problems and Perspectives of Interpretation*, 2nd edn (London, 1989), p. 151; cf. M. Broszat et al. (eds.), *Bayern in der NS-Zeit*, 6 Vols. (Munich, 1977–1983); M. Broszat and E. Fröhlich, *Alltag und Widerstand. Bayern im Nationalsozialismus* (Munich, 1987).
- 2 Broszat and Fröhlich, *Alltag*, pp. 49–52. For criticism see H. A. Winkler, 'Referat', in Institut für Zeitgeschichte (ed.), *Alltagsgeschichte der NS-Zeit: Neue Perspektive oder Trivialisierung?* (Munich, 1984), p. 31.
- 3 The term was coined by K-H. Ludwig, *Technik und Ingenieure im Dritten Reich* (Düsseldorf, 1974).
- 4 H. Möller, 'Nationalsozialistische Wissenschaftsideologie', in J. Tröger (ed.), *Hochschule und Wissenschaft im Dritten Reich* (Frankfurt a.M. 1986), pp. 65–76. This judgment has to be differentiated, if life sciences like eugenics are examined. For these sciences the historical research has detected within the last years an astonishingly powerful trend towards modernization; see, for example, P. Weindling, *Health, Race and German Politics between National Unification and Nazism, 1870–1945* (Cambridge, 1989); P. Weingart et al., *Rasse, Blut und Gene: Geschichte der Eugenik und Rassenhygiene* (Frankfurt a.M., 1988).
- 5 A. Beyerchen, *Scientists under Hitler: Politics and the Physics Community in the Third Reich* (New Haven, 1977); M. Walker, 'National Socialism and German Physics', *Journal of Contemporary History* 24 (1989), 63–89; S. Richter, 'Die "Deutsche Physik"', in H. Mehrrens and S. Richter (eds.), *Naturwissenschaft, Technik und NS-Ideologie. Beiträge zur Wissenschaftsgeschichte des Dritten Reiches* (Frankfurt a.M., 1980), pp. 116–41.
- 6 H. Trischler, 'Historische Wurzeln der Grossforschung: Die Luftfahrtforschung vor 1945', in M. Szöllösi-Janze and H. Trischler (eds.), *Grossforschung in Deutschland* (Frankfurt a.M., 1990), pp. 23–37 and H. Trischler, *Luft- und Raumfahrtforschung in Deutschland 1900–1970* (Frankfurt a.M., 1992), especially pp. 34–88; J. C. Rotta, *Die Aerodynamische Versuchsanstalt in Göttingen, ein Werk Ludwig Prandtls. Ihre Geschichte von den Anfängen bis 1925* (Göttingen, 1990); also see H. Trischler (ed.), *Dokumente zur Geschichte der Luft- und Raumfahrtforschung in Deutschland 1900–1970* (Munich, 1993).
- 7 Prandtl to Telschow/KWG (11 Feb. 1933) (Archives of the Max-Planck-Gesellschaft [MPGA], I. Abt. Rep. 1 A/1508, pp. 17f.). Cf. H. Trischler, 'Die Luftfahrtforschung im Dritten Reich, Organisation, Steuerung und Effizienz im Zeichen von Aufrüstung und Krieg', in H. Boog (ed.), *Luftkrieg und Luftkriegsführung. Ein internationaler Vergleich* (Herford, 1993).

- 8 A. Baeumker, *Zur Geschichte der deutschen Luftfahrtforschung – Ein Beitrag* (Munich, 1944), pp. 31ff. See also W. Boje and K. Stuchtey (eds.), *Beiträge zur Geschichte der deutschen Luftfahrtforschung und -technik* (Berlin, 1941); L. Simon, *German Research in World War II* (New York, 1947).
- 9 Cf. H. Albrecht and A. Hermann, 'Die Kaiser-Wilhelm-Gesellschaft im Dritten Reich', in R. Vierhaus and B. vom Brocke (eds.), *Forschung im Spannungsfeld von Politik und Gesellschaft. Geschichte und Struktur der Kaiser-Wilhelm/Max-Planck-Gesellschaft* (Göttingen, 1990), pp. 356–406.
- 10 Cf. W. Abendroth, 'Die deutschen Professoren und die Weimarer Republik', in Tröger (ed.), *Hochschule*, pp. 11–25.
- 11 I. Kershaw, *The Hitler-Myth. Image and Reality in the Third Reich* (Oxford, 1987); I. Kershaw, *Popular Opinion and Political Dissent in the Third Reich, Bavaria 1933–1945* (Oxford, 1983).
- 12 Memo of Engelbrecht/AVA (1 Jan. 1938) (Historical Archives of the German Research Establishment for Aeronautics [HA/DLR], AVA).
- 13 Betz to Ackeret/Zurich (30 Oct. 1939), (HA/DLR, AVA).
- 14 A. Busemann, 'Ludwig Prandtl 1875–1953', *Biographical Memoirs of the Royal Society*, 5 (1959), pp. 193–205.
- 15 Cf. Trischler, 'Historische Wurzeln', pp. 28ff.
- 16 C. Tollmien, 'Das Kaiser-Wilhelm-Institut für Strömungsforschung verbunden mit der Aerodynamischen Versuchsanstalt', in Heinrich Becker et al. (eds.), *Die Universität Göttingen im Nationalsozialismus. Das verdrängte Kapitel ihrer 250 jährigen Geschichte* (Munich, 1988), pp. 464–88.
- 17 Göttingen Kreisleiter to Gauamtsleitung of the Amt für Technik der NSDAP (28 May 1937) (Berlin Document Centre henceforth BDC, Prandtl); see also the characterization of Betz from the Kreisleiter of Göttingen (28 May 1937) (BDC, Prandtl). I am very much indebted to Mark Walker for pointing these sources out to me.
- 18 See: Beyerchen, *Scientists*, passim; and U. Rosenow, 'Die Göttinger Physik unter dem Nationalsozialismus', in Becker et al., *Die Universität Göttingen*, pp. 374–409.
- 19 Prandtl to Frick (27 Apr. 1933) (Archives of the Max-Planck-Institut für Strömungsforschung [MPIA]); Prandtl to Trefftz/Dresden (6 July 1933) (MPIA). Cf. H. Mehrrens, 'Angewandte Mathematik und Anwendungen der Mathematik im nationalsozialistischen Deutschland', in *Geschichte und Gesellschaft*, 12 (1986), 317–47; H. Mehrrens, 'Mathematics in the Third Reich: Resistance, Adaption and Collaboration of a Scientific Discipline', in R. P. Visser et al. (eds.), *New Trends in the History of Science* (Amsterdam 1989), pp. 151–66. As the second article by Mehrrens in this volume shows, Prandtl finally capitulated in the face of Nazi pressure.
- 20 Prandtl to Himmler (12 July 1938) (MPIA); cf. Beyerchen, *Scientists*; Walker, 'National Socialism', 66ff.
- 21 Prandtl to Milch (16 Oct. 1933) (MPIA); Milch to Preussischer Minister für Wissenschaft, Kunst und Volksbildung (9 Feb. 1934) (Zentrales Staatsarchiv Potsdam, RMI 26795/3, pp. 135ff.); Prandtl to Göring (28 Apr. 1941);