Andrew Nahum

'I believe the Americans have not yet taken them all!': the exploitation of German aeronautical science in postwar Britain

Introduction

The exploitation of Germany's scientific research and its scientists by the USA, and particularly the transfer of Wernher von Braun and the other rocket experts from the V2 programme, has received considerable attention, both at a scholarly and a popular level.

There have also been broader studies of the well-known American programmes 'Overcast' and 'Paperclip', which brought many German scientists to the USA. Of these studies the most comprehensive and analytical must be that by the American historian John Gimbel which puts 'Paperclip' into the context of the whole intelligence-gathering operation mounted in Germany at the end of the war and its translation into a kind of undeclared programme to extract 'intellectual reparations'.[1]

By contrast, the substantial British efforts after the war to utilise German science and technology have received surprisingly little study, although Tom Bower has characterised UK efforts as amateurish and piecemeal.[2] Similarly, Bill Gunston, a writer well regarded by the aircraft industry and the former Technical Editor of *Flight* magazine has asserted, quite misleadingly, that in postwar Britain designers struggled to create advanced aircraft without proper equipment because 'all the transonic windtunnels found in Germany were pinched by our allies'.[3]

Even a 1996 work on technology transfer out of Germany after 1945 largely neglects Britain. This neglect of the British efforts to exploit German science is a major gap in the study of the postwar period in Europe and the section here will focus, in particular, on the use made in Britain of German aerodynamics and aeronautical science.[4] However, there is a movement to re-evaluate these events, of which this work is a part, and Matthew Uttley has recently discussed 'Operation Surgeon' and has questioned why the achievements of German specialists who came to Britain are so much less celebrated than, for example, those in the USA.[5] It will be argued here that this resulted from the specific character of the postwar organisation of British defence research and industry and the culture of the government establishments to which the specialists largely went.

The paper suggests that the British initiatives for the utilisation of German science were actually carefully targeted, ambitious and probably at the limit of what was practical in the immediate postwar environment. The effect of this influx of German technique should certainly be analysed in the context of British postwar aviation, since it appears to have had a significant influence on both defence research in the government establishments and on the aircraft projects that were undertaken.

First impressions

As the Allied forces entered Germany, a variety of intelligence-gathering operations and missions were put in hand to investigate German technique and the apparent lead in many areas of weaponry. The initial British attitude to much of the German research that was uncovered was equivocal. The proliferation of surprising secret weapons and new kinds of aircraft had done little to slow the Allied advance and some of the projects, produced in response to the pressure for wonder weapons, would under normal conditions, 'have been considered technological charlatanism'.[6]

Sir Roy Fedden, leading one mission, contrasted this profusion of projects with 'the simple, but sound, British aeronautical programme [...] pursued with very little interruption throughout the war, but accompanied all the time by intelligent improvisation until there was really very little in the way of development to come'.[7] But if the policy directing the German effort seemed diffuse, the actual technique of production was of excellent quality in most centres, although not, in the opinion of the investigators, superior to British methods.[8]

On 7 June 1945, a month after the German surrender, Air Marshal Sir Alec Coryton at the Ministry of Aircraft Production (MAP) invited members of the aircraft industry to survey a cross-section of the corresponding German industries under the leadership of W S Farren, Director of the Royal Aircraft Establishment, Farnborough (RAE). The Farren Mission included eight industry designers and managers, the Director of Technical Development (DTD) at MAP and the economist A K Cairncross, representing the Director-General of Programmes, Planning and Statistics at MAP. It left on 9 July, returning just over two weeks later. The Mission observed that there had been no central direction of the industry in Germany and no operational research 'as we know it'. There was also no organised resident German air ministry representative at the firms equivalent to the British post of Resident Technical Officer. It also noted that 'the firms were forbidden to make contact with the Service [and] considered that the inability of the designers to obtain first-hand knowledge of [...] performance of aircraft under operational conditions was a serious hindrance. [...] This lack of direct contact with the Service may well have been one of the contributory causes of the violent changes in Air Staff requirements.' Thus the Farren Mission was able to take comfort from failures which Britain had avoided, and claimed that 'when U.K. personnel reached Germany after the war, the surveys supported a view that the MAP had been successful'.[9]

What certainly was different, in the German case, was the sophisticated level of the aeronautical research effort and the quality of the associated equipment in the firms, where – it was noted – corporate research and development departments were well organised and staffed with 'relatively young men of experience, energy, and enthusiasm'. Farren observed that although the German methods did not differ greatly from the British 'their resources were greater'.[10]

It also began to be appreciated increasingly by British investigators that jet aircraft like the Messerschmitt Me 262, which were entering service by the end of the war, would have proved a grave embarrassment if they had been made available only a little earlier and in sufficient numbers.[11] In addition there were other innovations such as rocket interceptor fighters, anti-aircraft rockets, the V1 and V2 missiles, and radio-controlled anti-shipping glider-bombs. Although, in most cases, these could scarcely be regarded as mature and practical weapons systems, they nevertheless pointed to a huge German lead in the technology of high-speed flight, propulsion, guidance and control, as well as the research facilities for the mechanical and aerodynamic analysis of aero structures in a new high-speed aerodynamic regime. As the British missions moved through the parts of Germany to which they had access, the scale and quality of the advanced research being done began to astonish them.[12] In a rider to his defence of the pragmatic British production programme, Sir Roy Fedden observed that the Allied victory had been won by 'obsolete types, from which every ounce of development had been wrung'. American commentators reached a similar conclusion, suggesting that the air war had been won with brawn, not brain: 'we choked them with the weight of our planes'.[13]

Perhaps this advanced work should not have been so surprising for, before the war, Germany had hosted many visits by British aeronautical engineers, including Roy Fedden (who went several times), Sir Harry Ricardo, the noted engine research engineer, and a delegation from Rolls-Royce which toured a range of companies and research establishments. These tours always impressed with the scale and quality of the facilities and, no doubt, were offered to persuade British opinion that to challenge Germany in the air would be fruitless.[14] Nevertheless, when revisited in 1945, the scale on which Germany's government defence research establishments had moved ahead was startling. The first challenge to British investigators appeared to be the exploitation of the plant and physical resources found in the British area of control in Germany.

The Hermann Göring Research Institute in Völkenrode

A very wide-ranging list of intelligence targets had been developed in concert by British and US investigators prior to the invasion under the Combined Intelligence Objectives Subcommittee (CIOS) programme covering almost all industries and techniques. However, it is argued here that it was in the field of aviation, and aerodynamics in particular, that Britain targeted its efforts.

Six important research facilities fell inside the British Zone of Occupation. They were:

- Luftfahrtforschungsanstalt (LFA) Völkenrode
- Aerodynamische Versuchsanstalt (AVA), Göttingen
- Kaiser Wilhelm Institut für Strömungsforschung, Göttingen
- Dispersal wind tunnels from AVA, Reyershausen
- Rocket Research Station and liquid oxygen plant, Trauen
- Focke-Wulf structural testing laboratory, Detmold.

Many of these facilities, such as the AVA at Göttingen (partly equivalent to the RAE at Farnborough), were well known before the war. However, the greatest surprise, as well as the greatest prize, was found in the LFA – the immense Deutsche Forschungsanstalt für Luftfahrt at Völkenrode, near Braunschweig (Brunswick), which had been named after Air Marshal Hermann Göring just before the war.[15] The institute had been conceived on a vast scale by British standards and was equipped particularly to deal with the new problems of high-speed flight. It was hidden in a forest and extraordinary care had been taken to conceal it from Allied photoreconnaissance flights. No large roads led there, the power lines had been buried underground, and the whole site was elaborately camouflaged.[16]

Ben Lockspeiser, as Director of Scientific Research in the MAP (DSR), went to appraise the site in May 1945 when the British army advised that there were 'some wind tunnels in a large forest' and was amazed to find 'the finest aeronautical establishment he had ever seen'.[17] His report to the Minister for Aircraft Production revealed the contemporary excitement at the discovery.

'It is concealed and dispersed in a large forest. [...] Its aerodynamic, supersonic and high speed equipment is far ahead of anything in this country, and as far as my knowledge goes, ahead of American equipment also. [...] in several directions the equipment is unsurpassed anywhere.' W S Farren, thinking clearly of his own facilities at Farnborough, observed independently that Völkenrode had 'a magnificence [...] that beggars the imagination of anyone who has seen similar institutions in the UK'.[18]

Initially the site was under the control of Colonel Donald Putt of the US Army which had discovered it shortly before, but it fell inside the British Zone and was shortly to be handed over to the British Army. Putt, in fact, was the officer in charge of the American intelligence operation 'Lusty' ('Luftwaffe secret technology') and a major proponent of the American 'Paperclip' programme to bring German scientists to the USA.[19] Lockspeiser considered that Britain ought, without delay, to put the site back into use or, in view of the possible political difficulties of allowing the installation to remain intact in Germany, transfer the most valuable equipment to the ambitious new research establishment – the National Aeronautical Establishment – which had been planned during the war and was already taking shape at Bedford. The scale and sophistication of the equipment made such an impression on Lockspeiser that he judged exploiting the Völkenrode facility meant that:

> we should bridge over the gap of some five to ten years which I see no means of doing by any other method. [...] The equipment [...] is such that we cannot expect to be able to build its parallel within a number of years and the knowledge possessed by its scientists is such that it will fill in gaps which otherwise would take us similarly many years to fill in from our own resources and researches. It would, in our view, be difficult to exaggerate the importance to this country of exploiting these facilities to the full.[20]

Lockspeiser's reports from Germany also reflected the difference in approach between the USA and Britain in acquiring this intellectual booty. The British model was that the material would be acquired by government agencies, such as that at Bedford, the RAE or other research establishments, and then be put at the disposal of firms for assistance with specific Ministry research contracts under security conditions. The American approach seemed looser and at odds with this British 'government rationing' attitude. Lockspeiser observed that 'a large part of the scientific service provided by America for this kind of investigation is in the hands of industrial representatives who have been placed in uniform and there is no doubt a great temptation in the way of individuals to profit their employers'.[21]

Lockspeiser was correct about the attitude of the Americans, although it is not clear whether the American 'industrial representatives' regarded this as a temptation or simply a normal duty. In fact, he visited Völkenrode at the same time as the noted aerodynamicist Theodore von Karman, who had arrived from CalTech as part of the 'Lusty' operation.[22] George Schairer, the head of the Boeing aerodynamics department and a member of this group, wrote home from Völkenrode to his deputy at the Boeing company within a day of Lockspeiser's own note to the MAP, giving his colleagues important details of the German research into the use of swept-back wings for high-speed flight.[23] This information was incorporated into Boeing engineering policy so quickly that the XB-47 bomber project, then under development, was delayed while this new aerodynamic theory could be incorporated. Boeing's readiness to incorporate this new thinking led, within a few years, to a generation of transport aircraft with a significant speed advantage over British (and other American) rivals.[24]

Lockspeiser also asked for a ruling to stop the records of scientific establishments being moved and for them to be microfilmed 'for the benefit of all'. In fact, some 1500 tons of documents, many of them from Völkenrode, were taken by US agencies.[25] Roy Fedden (Figure 1) told his biographer some years later that he had two loaded trucks with equipment collected for the new College of Aeronautics taken away from him by American forces at gunpoint. He also alleged that American investigators with whom he had examined wind-tunnel models of swept-wing aircraft at Völkenrode went back secretly by night and took them away.[26]

The initial report from Völkenrode by Lockspeiser was among the first to air 'the problem of the German scientists'. He mused 'what is to be done with them? They are, in my opinion, primarily scientists with an almost pathetic eagerness to continue as scientists working for us or anybody else. If they are deprived of their equipment they would inevitably drift to other countries. [...] I suggest that those who are really first class [...] should be brought over here to work under supervision.'[27]

In July 1945 Sir Frank Tribe at the MAP proposed a scheme to dismantle and remove the plant and equipment to Britain, suggesting that 'this would eventually constitute once-for-all delivery to us on reparation account'. He also noted that the plan could have the incidental result of collecting together at Völkenrode a few of the best German aeronautical scientists and technicians, observing that 'I believe the Americans have not yet taken them all!'. The most suitable could then, he suggested, be transferred to the RAE or UK aircraft design firms, 'if and when Government policy here permits'.[28]

This proposal had interesting links with earlier discussions in Britain as to how a resurgence of German air power might be prevented. Tribe observed that

> our feeling is that the UK government will eventually be driven to the conclusion that no effective plan for preventing the export of German scientists to foreign countries, or, in the long run, controlling their activities in Germany beyond a certain point, will be successfully evolved, and that therefore it would be desirable to have the best of those who might be particularly dangerous from the point of view of war potential (e.g. aeronautical scientists) under American or British control while at the same time gaining substantial advantage to our own war potential.[29]

Figure 1 The Fedden Mission to Germany, 1945, one of the earliest expert intelligence-gathering missions to visit Germany, in June 1945. Roy Fedden, the Bristol aero-engine designer (and adviser to the Minister of Aircraft Production) is supervising the unloading of a jeep from the Mission's Dakota aircraft. (Science Museum archives)

For a time the MAP considered an alternative strategy of operating and administrating the Völkenrode establishment on its existing site. RV Jones, Deputy Controller of Research and Development (DCRD) at the MAP, listed 17 aircraft projects of interest, including rocket-powered and swept-wing types and suggested that the aircraft should be completed by their designers and staff 'to the point at which the Germans fly them and prove them to be airworthy' before taking them to England for further study.[30] He also proposed that 'the maximum concentration of MAP will be in Volkenrode and we hope that we shall be able to consider that station as our MAP headquarters in Germany'.[31]

One school of thought held that allowing German scientists to continue working in advanced defence fields (whether in Germany under supervision or in the Allied nations) carried the penalty of enabling them to keep up to date with advanced technique. Set against this was the argument for a policy of 'denial' which held that the Allies should use the best scientists, both for their own benefit and to stop them gravitating to some other potentially hostile nation where they might still keep up their skills but with less chance of supervision.

However, the idea of running a defence research establishment in Germany was ultimately rejected because it was considered both politically too sensitive to utilise the site and because this would also have had the effect of preserving an element of German war potential. The problems of managing work there must also have seemed insuperable. The decision was taken, therefore, to remove the research papers and records to Britain and to dismantle the research plant and equipment for use in Britain.

Operation 'Surgeon'

The resources assembled to dismantle Völkenrode were impressive. At a meeting at the Air Ministry on 12 July 1945, Sir Charles Ellington, as Assistant Chief of Air Staff (ACAS) observed that under the government's policy for war reparations only six months were available 'in which to satisfy our requirements from places of scientific value in Germany such as Volkenrode'. The task was to be a special operation and would be run largely by the RAF as the MAP did not have the administrative or command organisation to undertake the task.[32]

This operation, code-named 'Surgeon', was assigned a commanding officer from the British Air Forces of Occupation and senior MAP officials including Major George Bulman, DCRF, Director of Construction of Research Facilities, MAP, (formerly director of aero-engine development), the aerodynamicist W J Duncan, scientific and technical officers from the MAP, a librarian and representatives from the aircraft and engine companies.

The operation consisted of two phases. Firstly, detailed information was to be collected from German scientists in the form of monographs on their research work, followed by the removal to the UK of the equipment that would be of value. Initially, some 35 British scientists came out to Germany to recommission and supervise the cleaning-up of the facility (it had become occupied by displaced persons and by troops), to run the wind tunnels and become familiar with the apparatus. This group also identified and located the former German scientific staff and brought suitable individuals back to write technical monographs summarising the wartime research in their various fields. For example, Johanna Weber of the AVA recalled that after the surrender 'we were [working] in the fields with the farmers' until the British investigators came to find them. By October 1946, 180 scientists and technicians from Völkenrode and the Göttingen institutes had been located and employed to write these reports. From the Völkenrode staff alone some 250 monographs were commissioned, translated and reproduced by a press and printing department specially established there.[33]

The work was scheduled to begin on 5 January 1946 under the supervision of Major Bulman, who had been tasked with responsibility for building the National Aeronautical Establishment at Bedford by Stafford Cripps (as Minister for Aircraft Production). This underlines the complementarity between the 'Surgeon' operation and British plans for the construction of research facilities, with the MAP noting that 'the Treasury have given approval to the special arrangements necessary for removing this valuable equipment, and they will look

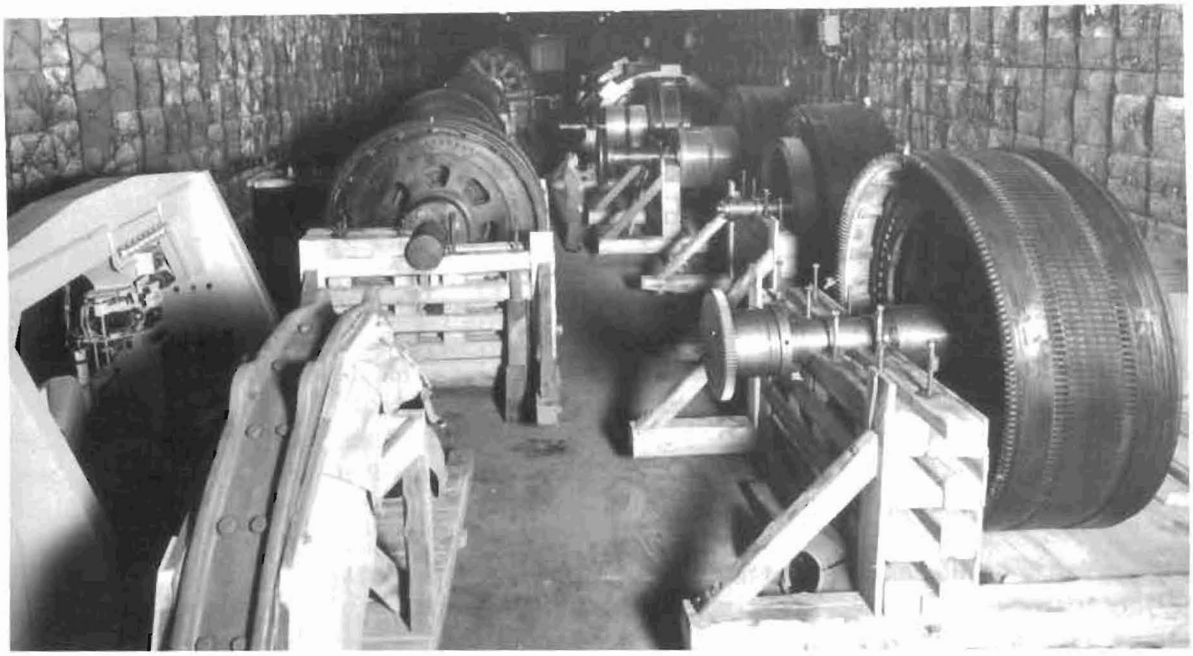


Figure 2 German heavy wind-tunnel motors from Operation 'Surgeon' in storage at Thurleigh airfield near Bedford, awaiting possible use in the new Bedford aeronautical establishment or elsewhere. (Science Museum archives)

to the use of it to save some of the very large expenditure which is planned for Bedford'.[34]

The intention to reuse the material was facilitated by the fact that the specialised dismantling team from the Ministry of Works largely consisted of the same individuals who were responsible for the erection of heavy capital plant for Bedford and other government research facilities such as the RAE, Farnborough and the National Physical Laboratory (NPL).[35]

The bulk of the structure of the large Völkenrode wind tunnels formed substantial civil engineering structures which were relatively 'low tech' and not worth transporting. However, the 6000-hp Siemens electric motors and their control gear were precious and many were shipped to England with their associated mercury arc rectifiers and compressors and were used in the construction of the '8-foot' and the '3-foot' supersonic tunnels that were built at Bedford (Figure 2). However one complete smaller supersonic tunnel was disassembled and transported to be rebuilt for projectile studies at the Armament Research Department at Fort Halstead near Sevenoaks. Also invaluable in Britain was the advanced ancillary optical equipment used for flow visualisation in the tunnels.[36]

Much of the lighter and more delicate freight was flown back to Farnborough. A Douglas DC-3 and a Junkers Ju 52 aircraft were dedicated to this, with approximately two flights per week in each direction scheduled.[37] In addition three or four Hudson aircraft brought a constant stream of personnel back and forth from England for study. These included both government and industry scientists, a considerable number of RAF and service personnel and politicians such as Arthur Woodburn (Parliamentary Secretary for the MAP), who went to see the progress of Operation 'Surgeon' in January 1946.[38]

Some idea of the scale of the operation can be gained from the provision of six road tractor units and low-loader trailers of 100-tons capacity which were used to take loads up to Hamburg for shipping. The total quantity of material identified for removal to the UK amounted to some 14,000 tons.[39] The curious emotions that must have existed in the German civilians at the time can be judged by the fact that the British team had the willing assistance of the Siemens company's chief export packer for the electrical equipment.[40] This equipment was delivered to several hangars at Great Storton airfield which marked one end of the proposed 5-mile runway at Bedford and from there delivered to the various research establishments controlled by the Ministry of Supply.[41]

Emigration from Bizonia – the employment of German scientists

In July 1946 the decision was made by the British and American governments to fuse their respective zones of occupation in Germany into a single administrative area termed the 'Bizone'. (British officials, more playfully, tended to refer to the area as 'Bizonia'). This fusion implied, or perhaps made more overt, a direct competition between the Anglo-American allies and the Soviet Union for the scientific and economic spoils of Germany; there was substantial, and exclusive, Anglo-American cooperation.[42]

However, there was inevitably rivalry between Britain and the USA, although this should not be overstated compared to that which existed in relation to the USSR and also France. Thus it is interesting to recall the claim by Bower, alluded to above, that British efforts were poorly focused and inconclusive, since the study by Lasby, written from American sources, shows that American officials considered British plans to be very effective.[43] Colonel Putt wrote in November 1946 that 'the Board of Trade handles all scientists coming here and has little interference from anyone. Once it is decided they want a man he is brought over and put to work. [...] Whether he is lily-white [does] not worry them too much. If any man can be of assistance in realigning a segment of their economy which is out of adjustment, they try to get him.'[44]

Putt had a strong personal commitment to the utilisation of German scientists for the United States and perhaps overemphasised British efforts. In fact, British policy, like that in America, was initially ambivalent over the employment of 'ex-enemy aliens'. There was less concern about the acceptability of this where pure defence research was involved and scientists could be brought to establishments like the RAE; but the question of using a wider range of personnel to assist industry at large in Britain was the subject of some debate.

However, Board of Trade officials were generally keen to utilise German developments, as were British defence personnel actually serving in Germany. Similarly American military personnel in Germany were initially more enthusiastic than State Department officials at home. Indeed, it was the value put on German science by the military of both allies that led to mutual suspicion and competition between British and American officials actually on the ground in Germany, as glimpsed from Putt's remarks above. Both groups were excited by the new technologies they had found and both considered their own governments to be irresolute in forming plans to utilise German personnel. Both groups reported to their home administrations that the other ally was being less scrupulous than themselves about former Nazi affiliations among the candidates in order to request greater urgency.[45]

In Britain the arguments for an expedient approach came quite quickly to dominate policy, while some moral doubt still was felt in American government circles over the question and it was said that German scientists often migrated back to the British zone after tiring of waiting for US employment.[46]

Thus a cipher telegram from the Cabinet Offices to the British Embassy in Washington on 14 February 1946 observed that:

> 750 Germans evacuated from the Russian zone and frozen in the American zone may be released to Russian zone if not designated. [...] We have deferred from submitting a list of Germans solely because American policy is not yet determined. It would therefore be manifestly inequitable if our scrupulous regard for the proprieties should prejudice our chance of exploiting the Germans now detained.[47]

A further telegram advised the embassy that the British list would be ready for exchange by 1 February and that 'we consider it not unreasonable to request crystallisation of American policy'. It suggested that if this were not forthcoming in a month 'we shall consider ourselves free to go ahead on a unilateral basis'.[48]

There was now growing pressure from many areas of government and particularly the Board of Trade and the firms themselves to extend the exploitation of German technique beyond the purely military sphere. This was a contentious issue and conflicted with what has been called the 'rigidly moral approach' of the postwar Labour government and the feeling that private industry and individual firms should not profit from the wartime sacrifice of Allied lives by gaining special access to the German work.

Thus Stafford Cripps (now President of the Board of Trade in the postwar Labour government) is said, initially, to have suggested that employment for the Germans in non-military industries in the UK was only tolerable if they were 'sucked dry of their knowledge in a short time'.[49] However, Arthur Woodburn argued that 'there is no possibility of getting these men to put all they have into our research if the arrangement is merely to suck them dry and throw them back into Germany'.[50] Therefore, it was proposed, scientists and technicians brought to the UK would normally work for trade associations or research establishments, since the work done there might be expected to augment the capability of a whole industrial sector, rather than enriching particular companies or groups of individuals.

These concerns were addressed by a scheme for civil industry administered by a panel chaired by Sir Horace Darwin, Director of NPL. This was announced by Stafford Cripps in parliament in December 1945, when he declared that 'it is the Government's policy to secure from Germany a knowledge of scientific and technical developments that will be of benefit to this country'. He remarked, perhaps disingenuously, that 'although we were generally ahead there are certain fields in which the Germans held a temporary lead'. The panel was to examine the requirements of British industry and to scrutinise the credentials of those whose names were put forward. Another role of the Darwin panel was 'to see fair play between the firms'.[51]

Alongside the announcement of the scheme, measures were devised to pre-empt objections from labour organisations. A brief drafted by the Board of Trade for issue by the Ministry of Labour offered arguments for employers to deploy. It suggested that 'it is evident that there must be some industrial technique in which [...] Germany has surpassed us. It is intended to bring certain German scientists, specialists and technicians [...] into civil industry [...] in order to gain the most up-to-date knowledge and perhaps save ourselves many years of research. The Americans and the Russians are exploiting the Germans in the same way'. It also stressed that the inventions and discoveries would be available to industry as a whole and that 'they will have no authority over British workpeople'.[52]

An elaborate system was set up to prepare the ground in the firms and local areas, with the Board of Trade acting as go-between for the employers and the Trades Union Council (TUC).[53] In addition, Sir Walter Citrine, as General Secretary of the TUC, was extensively briefed by the Board of Trade, which stated that 'Germans would normally work in Government Establishments and Research Associations'. Although 'exceptionally they might find their way into individual firms Germans are, however, under a contract with the British government'. It added that:

> the number of Germans who will serve in this country will not exceed one or two hundred [...] no known pro-Nazis will be admitted [...] only those Germans who have a real contribution to the national interest [...] the results of their discoveries and inventions will be available to industry as a whole.[54]

Inevitably there was some negative publicity and officials noted that 'the Beaverbrook press were running the story in a big way' with 'uninformed press criticism' and that a story in the *Daily Mail* for 5 January 1946 reported that 'a rumour-monger [sic] is sweeping Barrow [...] the shipyard workers resent the arrival of former Nazis who are still pro-Nazi'.[55]

However the British public displayed a remarkably sanguine view about the utilisation of German science and the superiority in many areas which this implied over UK technique. In December 1945 Stafford Cripps opened an exhibition of German industrial products at Millbank which showed parts of Germany's wartime advances in science and industrial technique. It also sought to promote the British Intelligence Objectives Sub-Committee (BIOS) reports on German developments for British industrial use. These amounted to 1400 reports on a great range of industries and techniques compiled by some 10,000 investigators. Cripps urged British industry 'to make the fullest and speediest use of the knowledge gathered [...] there was no time to waste'. Among the wonders promised were 'powdered white of egg which whips better than the real thing, a bath enamel you can hit with a hammer without chipping, the perfect baby food [...] and, for women of all ages "lizard" shoes and handbags, flexible, durable, dyed in rich shades and made out of haddock skin'.[56]

The *Daily Graphic* reported that 'we so often have occasion to criticise the obstructiveness of the Board of Trade that it is a considerable satisfaction to be able to compliment its President, Sir Stafford Cripps, on the apparent thoroughness of his investigations into German trade methods'. The exhibition was intended to tour Cardiff, Birmingham, Manchester, Leeds, Nottingham, Newcastle, Glasgow, Belfast and Bristol.[57]

In October and November 1945, the RAE put on a display of captured German aircraft and equipment which included not only service types like the piston-engined Focke-Wulf Fw 190 and Messerschmitt Me 109, but also the Messerschmitt Me 262 jet fighter and secret types such as the twin jet-engined Arado Ar 234 B-2 bomber which had not been used operationally before the fall of Germany. Jet engines, bombsights, communications gear, as well as V1 and V2 missiles, were also on display. A few months later three aircraft with most of the engines and other small equipment were moved to the Science Museum to form a popular exhibition entitled 'German aeronautical developments' and it is interesting to note, in the era before the Cold War, how openly this advanced German defence technology was displayed in Britain (Figure 3).

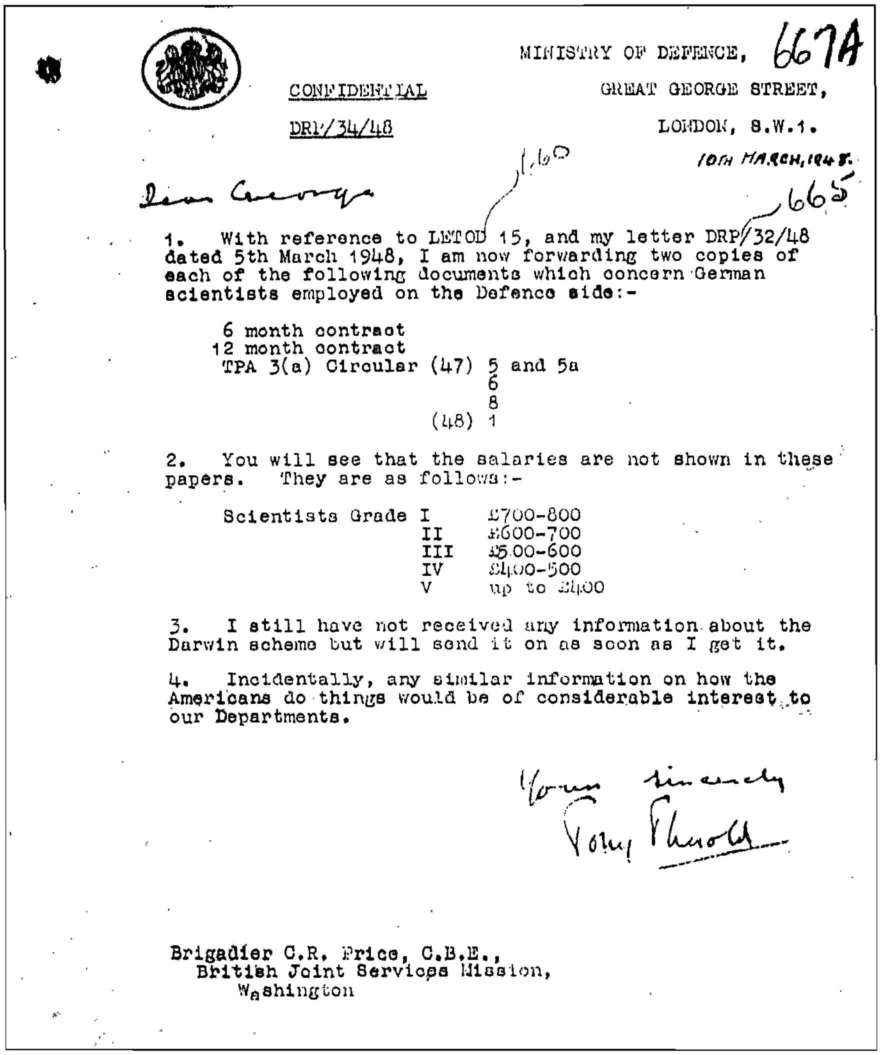
German high-speed aerodynamics and British defence science

The greatest concentration of British efforts was certainly in aeronautics. In November 1946 Arthur Woodburn, for the Ministry

Figure 3 Cover of the catalogue for the exhibition of captured German aircraft at the Science Museum in 1946. This featured jet and rocket engines, a V1 flying bomb, V2 rocket and a wide range of equipment. These displays were remarkably open, in the light of the security climate of the Cold War which was shortly to dawn. (Science Museum archives)

of Supply (MoS), had announced that German scientists were to be employed at the RAE and at the recently created Guided Projectiles Establishment at Westcott, near Aylesbury in Buckinghamshire. The press statement was careful to emphasise that the pay 'will be comparable to that of British technicians [...] but at a slightly lower figure'. Any suggestion of featherbedding former enemies was countered by the announcement that 'the men will be accommodated in Army huts'.[58] Some 124 individuals were eventually selected by the Deputy Chiefs of Staff (DCOS) committee for the DCOS or 'defence scheme' to bring in German scientists for employment. They included guided-missile experts, rocket engineers, aerodynamicists, flutter analysts, instrumentation engineers, an archivist, experts in servomechanisms, control guidance, gas turbines and, most curiously, two naval historians.[59] Of these scientists some had already been

Figure 4 Letter regarding salary scale for German scientists, 10 March 1948. (Public Record Office CAB 122/352)



667A

MINISTRY OF DEFENCE,
GREAT GEORGE STREET,
LONDON, S.W.1.

CONFIDENTIAL

DRP/34/48

10th MARCH, 1948.

Dear George

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1. With reference to LETOD 15, and my letter DRP/32/48 dated 5th March 1948, I am now forwarding two copies of each of the following documents which concern German scientists employed on the Defence side:-

6 month contract
12 month contract
TPA 3(a) Circular (47) 5 and 5a
6
8
(48) 1

2. You will see that the salaries are not shown in these papers. They are as follows:-

Scientists Grade	I	£700-800
	II	£600-700
	III	£500-600
	IV	£400-500
	V	up to £400

3. I still have not received any information about the Darwin scheme but will send it on as soon as I get it.

4. Incidentally, any similar information on how the Americans do things would be of considerable interest to our Departments.

Yours sincerely

Brigadier C.R. Price, C.B.E.,
British Joint Services Mission,
Washington

brought to Britain for interrogation, in effect as VIP prisoners of war. The aeronautical scientists were taken to the Beltane School at Wimbledon,which had been requisitioned for the purpose as part of a separate operation known as 'Inkpot'. By late 1945 about 250 of the best German scientists and engineers had been brought there for interrogation and a number of these were subsequently offered employment on a special pay scale within Civil Service terms, graded as 'German Scientist I to V' (Figure 4).[60] For example, Adolf Busemann, one of the foremost experts in the world on swept wings and supersonic flow, was retained in Britain and worked at Farnborough and at NPL, but soon left to work in the USA.[61]

However, others such as the Göttingen aerodynamicist Dietrich Küchemann were offered employment freely while they were still in Germany, writing the reports for the British investigation of their wartime work. Initially these contracts were for six months, and Küchemann's associate, Johanna Weber, who took up a similar offer to follow some months later, recalled that the short period of these initial contracts was a major factor in inducing German scientists to accept.[62]

Apart from the lucky find of Völkenrode the British search had not been hit or miss – CIOS targets even specified minor Messerschmitt dispersal factories. There was also a specific search for personnel with particular skills, such as those involved in work on flight control and stability on the new high-speed aircraft. This brought Morien Morgan of the RAE to Germany to seek out Karl Doetsch, who had been working on the directional instability of the Messerschmitt Me 262, since Britain's new jet fighter, the Gloster Meteor, was similarly afflicted with this 'snaking' problem.[63] Doetsch had unique skills, being both a highly trained research engineer and also a test pilot who had been working particularly on control and stability problems at the Deutsche Versuchsanstalt für Luftfahrt at Berlin-Adlershof, which fell inside the Russian zone, and he had, by then, taken refuge in Bavaria until other aeronautical scientists directed Morien Morgan to him.[64]

The two schemes were the official channels for the employment of German specialists and they show that 124 German scientists and technicians were formally brought into the UK under the Defence Scheme while another 257 Darwin Panel nominees were listed in 1946, although it is not clear how many of this latter group came.[65]

It also appears that other Germans did come under less formal conditions. One example, which may not have been exceptional, is that of the engineer August Stepan who had worked on the Doblhoff tip-jet-driven helicopter system in Austria. In 1947 he was given a contract by the Ministry of Supply and worked at the Fairey company on the Rotodyne passenger helicopter project until 1962. However, he does not appear on the lists of Darwin Panel scientists so far found by this author or in the separate DCOS scheme for defence scientists, and his case raises the question of how many others there may have been like him.[66]

The integration of German and British high-speed aerodynamics at the Royal Aircraft Establishment, Farnborough

The expansion of British aircraft production during rearmament and war relied largely on government finance and had produced a highly directed industry with centralised state control through the Ministry of Aircraft Production. This merged to form the new Ministry of Supply from 1945, with control over all Britain's aeronautical R&D and the responsibility for procurement and administration of all contracts for aircraft, missiles, engines and weapons on behalf of the RAF. It also had equivalent responsibility in the period for civil aircraft.[67] Thus the British pattern for the utilisation of German science was to concentrate these assets in government research establishments under

MoS control. The reports, personnel and equipment thus were located principally at Farnborough while the actual hardware initially went to the new Bedford research centre which stayed under Farnborough control.

The presence of German personnel at Farnborough, in addition to the captured documents and reports, ensured that British transonic research made striking speed in the immediate postwar period. This absorption took place partly with the assistance of intermediaries who were at home in the German language, such as the aerodynamicist T R F Nonweiler, who was the son of German-Jewish immigrants and acted as a security vetting officer for some of the German aerodynamics reports.[68] Since many British aerodynamicists were competent in scientific German, it would be tempting to cast the analysis of these events in terms of technology transfer, as it is generally understood by historians of technology, but more particularly, in terms of the transfer of 'tacit knowledge', as analysed by Collins.[69] The essential elements in such a case, it might be argued, include a body of advanced technical and theoretical knowledge, complemented by subtle practical and experimental 'know-how' (in this case wind-tunnel and modelling technique) mediated by key personnel.

However, an analysis along either of these lines would fail to capture the complexity of these events. It would also undervalue the state of British aerodynamics at the end of the Second World War and could also imply that it had developed in isolation from Continental work. In fact, RAE aerodynamicists were well informed about German research during the 1920s and early 1930s. For example, Hermann Glauert, the outstanding theoretician at the RAE in the interwar period, was at the forefront in spreading an appreciation of the work of Ludwig Prandtl and the 'Göttingen school' of aerodynamics in Britain.

These contacts disappeared as German aerodynamics became incorporated into German war planning. Probably the last open international exchange took place in Italy at the Volta High Speed Conference in 1935, and there British, American, French, Italian and German aerodynamicists gave papers on current thinking about future high-speed developments (Figure 5).[70]

Ed Constant has concluded, from a study of the papers given at the conference and the citations in them, that Germany was pre-eminent in theoretical aerodynamics in 1935, with Britain only slightly behind. By contrast, the USA (excepting the special case of Theodore von Karman who, from 1930, in essence imported German aerodynamics to CalTech) was rather backward in theoretical high-speed aerodynamics, although the National Advisory Committee on Aeronautics was 'widely recognised for the excellence of its empirical data and for little else'.[71]

At this conference the aerodynamicist Adolf Busemann presented a paper on supersonic flight which mentioned the possibility of using swept wings in the transonic region.[72] This was almost the last opportunity for international exchange, and following the Volta conference the German work became increasingly secret, while in Britain the expansion of the RAF and the introduction of new types of aircraft absorbed a great proportion of the time and energy of government scientists at the RAE.

During the war the RAE did nevertheless manage to do some advanced work in high-speed flight and in a notable investigation began flight trials with a Spitfire which was dived at an angle of 45 degrees from a height of 40,000 feet, increasing the speed attempted in each flight, until over Mach 0.9 was attained. At the same time a scale wind-tunnel model was tested in parallel in the new high-speed Farnborough tunnel. In this way an unusually good understanding for the time was developed into the interaction between the effects of compressible airflow at speeds approaching that of sound and the effects on the control and stability of the aircraft.

There was also some advanced theoretical work undertaken at the RAE during the war, including a study on a hypothetical supersonic biplane. This derived from an ingenious proposal also aired by Busemann at the 1935 Volta conference and relied on the interference between the shock waves reflected between the superimposed wings

Figure 5 The Volta High Speed Conference at Rome in 1935, the last major occasion on which German aerodynamicists met with British and American colleagues before the war. Ludwig Prandtl (with beard) is in the front row on the right, while the figure with spectacles in the second row is David Pye, soon to become Director of Scientific Research at the Air Ministry. To his left is Adolf Busemann. (By kind permission of the Royal Aeronautical Society) to cancel each other out and thus avoid the high drag (and power requirement) associated with supersonic flight.[73]

Thus although Busemann's swept-wing proposals were not explored in Britain during the war and the extent to which German research on swept wings in the transonic regime had progressed came as a surprise in 1945, these studies were not received by a naive or theoretically unsophisticated audience. British aerodynamicists realised the point of all this work as soon as they saw the reports. They had the theoretical and mathematical equipment to be able to extend it and rapidly began to incorporate the thinking into proposals for operational aircraft.

The case of the reception of German high-speed aerodynamics in Britain does not therefore fall into the generally understood categories of technology transfer or the communication of tacit knowledge that have been discussed by historians of technology. Rather, it represents a reintegration of a particular branch of theoretical aerodynamics which had been undergoing separate evolution since German science had 'gone off the air', as it were, in the late 1930s. The character of Farnborough itself was essential to the utilisation of this German expertise and, in spite of sporadic objections and newspaper reports, the absorption of German specialists into British government defence research establishments and into firms was remarkably harmonious. Karl Doetsch, as we have seen, was recruited, along with other aeronautical specialists, to come to Farnborough, initially on a six-month contract. He recalled that his Home Office immigration papers were marked 'ex-enemy alien – for exploitation only', but 'the welcome at RAE was quite different', and Morien Morgan begged him 'not to take the "ex-enemy" business too seriously'.[74]

Doetsch's view was that the RAE wished only to retain scientists who could be integrated into the existing British government research establishment system. He also had the strong impression that there was a wish at the RAE to avoid 'German language islands' which it was then believed had happened in the USA. After about two years 'it was obvious which scientists would be fully integrated' and the number reduced to a highly integrated residuum. However, in response to this desire for integration, coupled with the government policy that, in the early years, Germans not could have authority over British workers, a particular paired working structure emerged in which leading Germans were allowed a German collaborator and assistant. Thus Dietrich Küchemann worked with Johanna Weber, with whom he had previously cooperated at the AVA, Hans Multhopp with Martin Winter and Doetsch with Werner Pinsker (Figure 6).

By 1953 the whole pattern of collaboration within the RAE had become looser. Küchemann and Doetsch were promoted to Senior Principal Scientific Officers and were in the process of becoming naturalised as British subjects, while the civil service category of 'German scientist' was dropped. However, naturally enough, some

Figure 6 German scientists in Farnborough Court in 1947. In the front row, Adolf Busemann is third from the left (with cat – symbolising, to the author, a remarkable domesticity in these arrangements). To his right is Gerald Klein, Head of the Siemens autopilot group, and the penultimate figure to the right is Professor H Schlichting (Göttingen and Braunschweig). In the second row, from the left, Karl Doetsch is no. 2, Martin Winter is no. 6 with Hans Multhopp (no. 7) to his left. Dietrich Küchemann is in the rear row between Winter and Multhopp. (By kind permission of Flugbaumeister Prof. Dr.-Ing. Karl Doetsch Hon. DSc)

of the specialists did not really settle down. Kurt Tank said of Hans Multhopp (formerly his leading aerodynamicist and theoretician in the Focke-Wulf design office) that he 'had not found really satisfying work'.[75] Within RAE circles Multhopp came to be considered by some as arrogant, and eventually went as chief scientist to the Martin-Marietta aircraft company in the USA.[76] Doetsch attributes this alienation to Multhopp's outspokenness in a period when Morien Morgan and RAE aerodynamicists were impressed by the tailless German high-speed aircraft such as the Messerschmitt Me 163 rocket fighter (which appears to have inspired the ill-fated de Havilland DH 108 Swallow in which Geoffrey de Havilland was killed). He sought an opinion on a scheme from Multhopp, who replied simply 'Oh, this awful fashion'.[77]

However, in his period at RAE Multhopp had a powerful effect on the direction of advanced British aircraft work. In 1948, he and Martin Winter proposed an experimental swept-wing transonic research aircraft (Figure 7) which rested heavily on his earlier work at Focke-

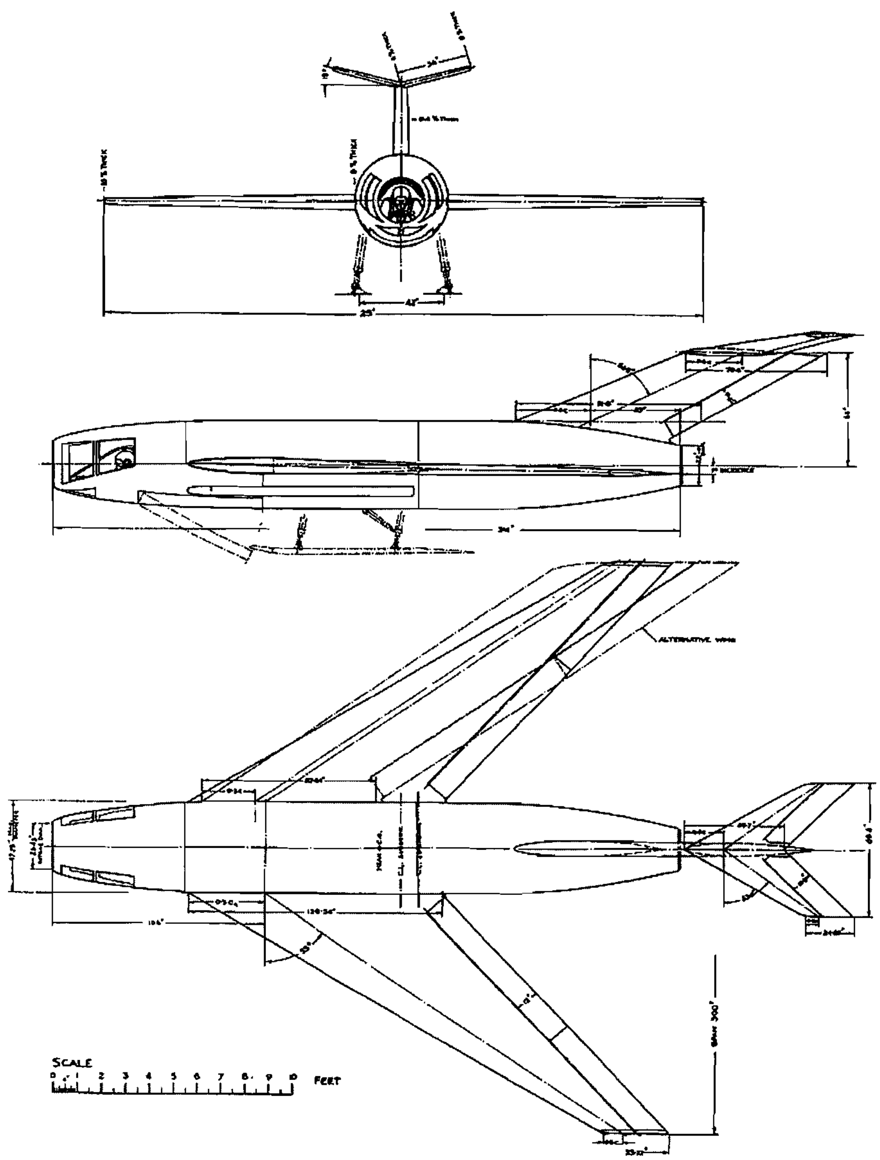

Figure 7 Swept-wing transonic research aircraft proposed at the RAE in 1948 by Hans Multhopp and Martin Winter. The concept drew on Multhopp's experience with the Focke-Wulf Ta 183 project, but also drew inspiration from the new Rolls-Royce Avon jet engine. This 'paper aeroplane' (particularly with the parallel chord alternative wing) can be viewed as the conceptual antecedent of the English Electric Lightning fighter. (Science Museum archives)

Wulf, where he was notably engaged in developing the Focke-Wulf 183 jet fighter, now considered to be an important influence on the MiG 15 and the North American Sabre.

They calculated that the new Rolls-Royce Avon engine was just sufficient to give the aircraft a supersonic performance of Mach 1.24 at 36,000 feet 'if equipment and instrumentation are restricted to only the most essential items'. The other restriction was to keep the diameter of fuselage to the absolute minimum dictated by the Avon engine and to this end the pilot was to be located in a prone position in a compartment placed, in effect, within the inlet duct. The prone pilot idea was also derived from German work and had been developed in an experimental aircraft in part by Martin Winter as a member of the Berlin Technical University *Akaflieg* group. Interestingly Doetsch had also flown this aircraft at Adlershof and encouraged the incorporation of the prone pilot feature in the RAE project. The wing was to be swept back at an angle of 55 degrees to delay compressibility effects, while the tailplane was to be mounted high on the fin to keep it clear of the transonic shock waves generated by the wings or fuselage and to avoid the loss or alteration of pitch control which had been encountered approaching transonic flight – 'a scheme which was developed some years ago for the Focke Wulf 183 fighter'.[78]

This aircraft was not built, but later, in 1948, another RAE paper by Owen, Nonweiler and Warren proposed a larger supersonic fighter which derived from it.[79] In general, layout and wing plan for the proposed fighter followed closely the Winter–Multhopp design, including a version with a prone pilot position, although an alternative layout was sketched with a conventional pilot position above the intake and a radar scanner dish faired into the centre of the intake duct. However, the Winter–Multhopp aircraft was only supersonic by dint of scrupulous streamlining and avoidance of all unnecessary structure. A practical fighter would need much more power to attain this performance, and the new feature of this June 1948 proposal was the use of multiple engines staggered so that the thickest part of one lay over the thinner part of the other – the so-called 'hip and waist' arrangement. It is significant that, in this period, Winter and Multhopp, as German scientists, were able to work on the research aircraft but not on the fighter proposal, which passed to British colleagues. However, this policy soon changed and Multhopp was to have considerable input into the English Electric P.1 Lightning which derived from this project.[80]

By November 1948 the Advanced Fighter Project Group, which had been set up at the RAE, reported on work to date, stressing the difficulty in predicting the nature of the threat (in terms of speed and altitude) for which 'the fighter which must stop the bomber' should be designed. The task, they proposed, was that of defending 'this island against the attacks of enemy bombers similar to the long-range high altitude bombers we ourselves are developing' – high-speed aircraft capable of delivering atomic bombs at 500 knots and from 50,000 feet.[81]

The group considered that, although the state of knowledge on aerodynamics, stability and control was still developing, the main uncertainty centred around the structure. The operational supersonic fighter was required to be a large and complex aircraft weighing perhaps 30,000 lbs (at a time when the relatively simple 'first generation' jet fighters such as the de Havilland Vampire and Supermarine Swift weighed only 8000 to 10,000 lbs). The gamble of estimating strength and weights closely in the absence of 'real guiding experience' or established design principles is shown by the structural challenge of providing enough stiffness to wings and tail surfaces to prevent flutter and aileron control reversal. The catch here was that the forces would be higher than those met hitherto, although the surfaces were required to be much thinner and, for geometric reasons, the high degree of sweepback also would tend to compound the problems of twist and aero-elastic distortion. However, the price of a slightly 'safer' and more conservative design, increasing the structure weight by a factor of only 3 per cent, would reduce flight endurance from 55 minutes to 29 minutes – scarcely a useful fighter.[82] German aerodynamic work had been highly influential in suggesting supersonic shapes, but it had not provided design and structural data for this new high-speed regime.[83]

But even in the light of these technical reservations the RAE took a bold and even propagandist role in weapons development policy, arguing that 'a fully operational supersonic fighter would be an immeasurably valuable asset to the defences of this country' and actively promoting work on it in spite of the many uncertainties, noting that 'the unknown factors are many and frightening but the prize may be immense'. It would be 'an appalling gamble' and 'the obvious way to achieve this prize would be to tackle the problem slowly'. But in view, implicitly, of the dawning atomic threat, the RAE proposed the 'short-cut' approach, going straight to the design of a fully operational supersonic fighter and suggesting that 'a first class design team from the Industry' be asked to proceed with the design on the lines sketched out by its scientists.[84]

In August 1948 the MoS issued Operational Requirement F.23/49 based on this RAE thinking which asked for 'a minimum top speed of Mach = 1.2 or higher' and a fantastic climb performance allowing six minutes from the moment the pilot presses 'the first button' to reaching 50,000 feet. The MoS then began to pursue discussions with English Electric as the most likely company to build the aircraft and, by March 1949, confirmed to the company that it was to develop the concept as the English Electric P.1 – the prototype that was to lead to the Lightning fighter.[85] Thus the project, it should be noted, was set in train at virtually the same time as the transonic Hawker Hunter (and long before the Hunter flew), with the intention of leapfrogging a generation of fighters.

The initial development of the Lightning took place in the context of a range of suggestions for fast-climbing manned rocket or hybrid rocket and gas turbine-powered fighters. Sir Charles Gardner (as Director of Guided Weapons Development) also gave a glimpse of a certain optimism for defence when he noted that 'the Million-fold increase in striking power of a single aircraft has transformed the defence problem from one in which an attrition of 5 or 10 percent

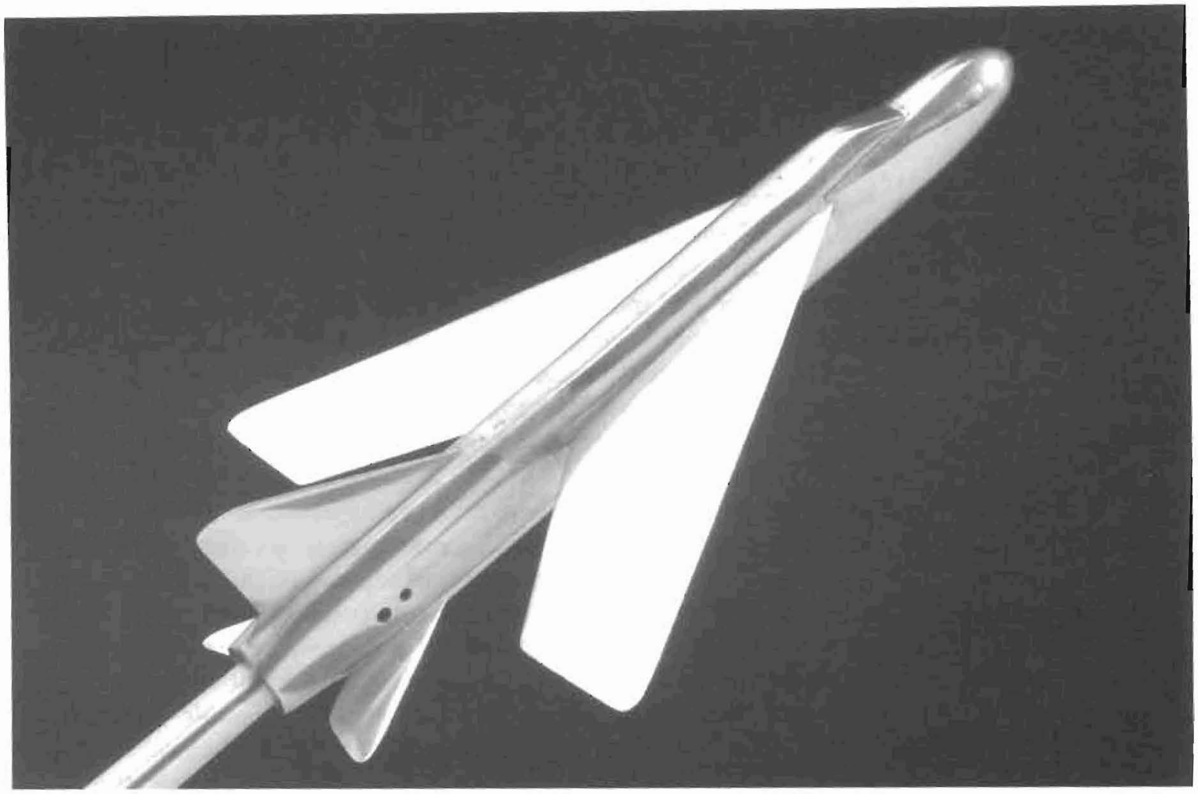

Figure 7 The English Electric company's 1/84th scale model built in 1951 for research and development of the P.1 Lightning fighter. For this programme the company acquired the first supersonic wind tunnel outside government establishments like the RAE. (Science Museum Inv. No. 1963-160) (Science & Society Picture Library)

could be worthwhile [...] to one in which it is necessary to achieve an annihilation defence in which virtually every aircraft must be destroyed'.[86]

The initial English Electric 1948 project drawings mirrored closely the planform of the RAE study, including an ingenious staggered 'hip and waist' engine arrangement. This became a distinctive and successful feature of the production aircraft, although in the case of the T-tail English Electric became convinced that RAE advice was wrong. In this they proved to be correct and the low tail position eventually adopted proved far more effective in the nose-high landing attitude (Figure 8). The Lightning, when it entered service in 1960, certainly vindicated the early RAE advocacy of the supersonic interceptor, but – although, like so many British aircraft, it arrived awfully late – the performance substantially exceeded the initial RAE predictions. It was, however, an aircraft that was predicated on the special air defence and quick reaction needs of Britain. In this role it was probably the most potent interceptor at the time in the world, but this specificity of role denied it really substantial export sales, although 40 were sold to Saudi Arabia and a further 14 to Kuwait.

Among the very many British aircraft development projects, a considerable number can be regarded as relating to, though not actually derived from, German work. For example, in the case of the V-bombers, Britain's main Cold War deterrent force, the basic aerodynamic designs were strongly influenced by German work, although the initial concepts were developed more in the firms than at the RAE. In the case of the Handley Page Victor, German aerodynamic influence was imported directly into the company, since one of its designers, G H Lee, was a member of one of the Allied technical missions in Germany.

The Avro Vulcan represents another fusion of German theoretical work with British pragmatic technique. The Avro designers accepted the need for a swept wing for the high-speed bomber requirement, but were not confident that long swept wings, as on the Victor, could be built stiff enough and conceptually reinvented the 'delta' wing planform by 'filling in the gap'. However, in this period, no major defence aircraft project could proceed without a major commitment of continuing RAE research throughout development. The RAE contributed an enormous amount of aerodynamic work to refine the Vulcan wing, with Dietrich Küchemann also providing a solution for blending the tailfin and stabiliser in the Victor.[87]

The pattern of these projects illustrates the connection between German wartime aeronautics and postwar British programmes and the process of integration of this German science and technique into UK defence research. However, the structural solutions for designing these advanced supersonic aircraft had not been imported from Germany, although they were to prove critical to success. In fact the problem of airframe distortion and oscillation in high-speed airflow became an RAE specialism. Much of the theoretical work needed to analyse these complex interactions was done at the RAE, by and under the direction of Ted Broadbent.

Thus German swept-wing work, at the end of the war, was suggestive, but it was not a complete recipe, and it was only in a place like the RAE with deep resources for theoretical and wind-tunnel aerodynamics research, combined with resources for advanced structural analysis, that it could have prospered. It is certainly suggestive that in Argentina the work on the Pulqui II fighter under a team led by Kurt Tank, the former Focke-Wulf chief designer, did eventually founder. The work was conducted by an imported German team which, though highly able, could not match the truly enormous resources then deployed at the RAE for structural testing, aero-elasticity and 'flutter' calculations, and accident or failure analysis. One Pulqui broke up in flight – a failure attributed to 'faulty welding'.[88]

Conclusions: the utility of German science

The range of aerodynamic work studied and the number of specialists brought to Britain does not support the assertion, referred to at the outset, that Britain was backward in exploiting German work in comparison to the USA. The official British total so far discovered of 381 German scientists should be compared with the declared initial total of 210 who were taken initially to America under the auspices of Project 'Paperclip'.[89] A more reasonable judgement is that the number of German scientists actually brought to Britain was probably in line with what the government and industrial research establishments could absorb. The quality and the experience of the individuals recruited also shows that Britain sought out individuals in the top rank of German aerodynamics and aeronautical science and, as we noted with the case of Karl Doetsch, the intelligence evaluation and preparation was already in place to enable British investigators to locate them.

However, it is unlikely that a quantitative judgement can ever be reached on the contribution to the British aeronautical industry of the various programmes to exploit German science. The value of the physical equipment as well as the intellectual contribution made by the personnel and the research documents brought to the UK is literally incalculable for various reasons. One could, for example, put a notional value on the R&D work from which the Winter–Multhopp transonic aircraft design sprang, but this might not represent the cost which the RAE would have had to expend to get to the same point without them. In such cases it may often be sufficient for other workers to learn of a new possibility in broad detail in order to jump to it quite rapidly by their own efforts.

In some areas of British aviation technology, postwar development was practically untouched by a knowledge of German work. This was certainly true of the gas-turbine development carried on at Rolls-Royce, de Havilland, Bristol and Armstrong-Siddeley, which built exclusively on what had been done during the war in these firms. The German jet engines were analysed at Farnborough by RAE scientists and by Power Jets (R&D) who concluded that there was little to learn from them. It is also noteworthy that only two German turbojet engineers were brought to Britain in the DCOS scheme and one of them, Max Bentele, with high-level experience of turbine blade design at Heinkel-Hirth, was not used in the British jet aero-engine programme but was despatched to a fairly low-priority project for a gas-turbine tank engine at C A Parsons, in Newcastle upon Tyne.[90] This sparing use of German turbojet personnel argues again for a purposeful and highly selective British approach to German engineering and scientific personnel.

In contrast to the UK, France, which had missed out on turbojet development during the war, considered the BMW design team to be a great prize. BMW was located in Munich, in the American zone, but the team and the chief engineer H Oestrich appear to have been 'spirited away' by French agents while awaiting travel to the USA. The team reappeared in Switzerland in a new organisation, the Atelier Technique Aéronautique Rickenbach, and the first French jet engines put into production by the nationalised SNECMA aero-engine company bore the designation ATAR.

However, the British jet-engine teams were quick to appreciate the superior quality of German test facilities and instrumentation. The de Havilland team spent several weeks at the BMW high-altitude test cell in Munich, completing over 70 hours of testing on the Goblin engine, providing information which could not then have been obtained anywhere else. The cell could be depressurised to simulate altitudes of up to 50,000 feet, while the inlet air speed could be regulated up to 550 mph and refrigerated to –70 °C.[91] The team noted that the speed at which results were obtained was much better than if flight tests only were used and the information far more complete. The BMW test facility was removed to the USA, but the practical experience of the utility of the installation certainly helped establish the need for test cells working on the same principle at the National Gas Turbine Establishment near Farnborough.

Germany was, of course, closely identified with advances in rocketry, and British liquid-fuel rocket motors certainly owed much to the V2 engine concept. Much work was done on these, for rocket-assisted takeoff applications, for the abortive rocket fighter programmes and particularly for the Blue Steel and cancelled Blue Streak nuclear weapons. The idea of the fast-climbing rocket fighter, for which prototypes were commissioned in the mid-1950s from three separate manufacturers, was clearly derived conceptually from the Messerschmitt Me 163B.

Within the British zone, at Kiel, was Helmuth Walter's Walterwerke concern which produced rocket engines for various weapons. The firm had also developed a hydrogen peroxide steam turbine for submarines which promised very high underwater speeds. The Walterwerke scientists were captured in a commando raid planned by Ian Fleming as Kiel fell to the Allies. Thus followed the adoption of concentrated ('high-test') hydrogen peroxide as the oxidiser in a wide range of British rocket engine projects, following wartime practice at Walterwerke and elsewhere and the presence of a considerable number of German specialists at the newly-formed Guided Projectiles Establishment at Westcott in Buckinghamshire. Douglas Millard, at the Science Museum, has pointed out that the 1946 British Beta rocket developed there was derived from the Walter 509 motor and has found on it a fuel valve stamped 'T-stoff – inlet'. The use of this Anglo-German hybrid term certainly seems eloquent.[92] Andrew Jeffs, a long-term Westcott scientist, has confirmed that 'thousands of captured German solenoid valves' for rocket fuel control came to Westcott without which 'we'd have been flummoxed' and that 'we were using them into the 1980s'. In the immediate postwar period, terms like T-stoff and C-stoff were routinely in use at Westcott and even some of the fuel stocks came out of Germany.[93]

Interestingly, Jeffs recalls that Westcott did not reflect the RAE working pattern of paired German scientists who were not allowed to direct British colleagues initially and that 'Dr Walder, who did the Gamma motor was very definitely the head of the team'. To Jeffs, who worked at the time with Willi Kretschmer, an engineer on the Walter 109 rocket motor for the Messerschmitt Me 163, this was probably because Westcott was new – 'we hadn't got any history at all – we were not so hidebound'.[94] The Beta and Gamma motors at Westcott demonstrated a technology which passed from there into the engine firms de Havilland, Napier and Bristol-Siddeley. Indeed the Gamma was quite closely followed by Bristol-Siddeley for the Stentor motor for the aircraft-launched nuclear standoff Blue Steel missile – the principal British nuclear weapon between 1963 and 1968.

In contrast to the liquid-fuelled motors, the solid-fuel rocket technology which was used in many anti-aircraft and air-to-air weapons was a largely home-grown and successful British technology. Thus the Bristol Bloodhound missile, which emerged as an effective ground-to-air defence system against high-altitude hostile bombers, relied largely on British technology for its solid-fuel core motor and radar guidance, and not, for example, on the German Wasserfall liquid-fuel anti-aircraft missile which had been studied with interest by Allied investigators.[95] In cases such as these the fact that Germany had done a thing, or had begun a project, was perhaps sufficient stimulus for British research engineers to accept that it could be done and to successfully attempt it, but in their own way.

Perhaps most significant, in the long term, for British aeronautics was the employment at Farnborough of the Göttingen aerodynamicist Dietrich Küchemann and his collaborator Johanna Weber. Küchemann took British nationality in 1952, becoming head of the Supersonics Division of the Aerodynamics Department in 1957 and overall head of RAE aerodynamics in 1966.[96] Both Weber and Küchemann had a major impact on the Concorde programme, but if any single person can be considered as the 'father' of the aerodynamic design of Concorde it is, in the opinion of this writer, Küchemann.

In this context Concorde is certainly an interesting case, since it represented such an enormous technological and scientific effort. It might therefore be tempting to regard the heritage of German scientific influence in both America and Britain as a kind of technological supremacism, for in some respects Concorde can be regarded as the British equivalent of the American Apollo space programme.

In this connection, one German commentator has suggested that engineers and scientists under National Socialism contributed to this through 'an aggressive cult of feasibility'.[97] While Britain had made notable use of scientific research in many areas, the new technologies and weapons systems demanded quite a new scale of expenditure and effort. Germany had been among the first to realise the returns that might be available from this intense application of science and research. Thus the effect on the Allies of their analysis of German science was as much moral as direct. Although in many cases the postwar programmes of the former allies did not build directly on the weapons and solutions that had been attempted in Germany, the scale and extent of research and the degree to which engineering science was applied to German war projects was eloquent. Nevertheless, it must be borne in mind that the Second World War had marked a step change in the application of science to weapons systems among all the combatant nations.

In conclusion, the study of Cold War aero science in the UK leads to the view that this episode really concerns the integration of German and British aeronautical science and the resurgence of the RAE as a uniquely capable research establishment with its own particular character.[98] Thus it would be unhelpful to try and consider whether Küchemann and Weber's narrow supersonic delta work should be considered as 'German' when it was conceived and nurtured within the RAE long after both had left Germany. It is simplest and most satisfactory, perhaps, to regard it simply as RAE work.

This 'integrationist analysis' also goes some way to answering the question touched on at the beginning – why was the work of the German specialists in the UK so little known? The interplay of Farnborough expertise with a firm such as English Electric in the development of the Lightning, touched on above, reveals something of the culture of government research establishments and the RAE in the period. RAE involvement was unknown in the wider community at the time – government scientists were virtually anonymous and the names even of senior figures such as the director of the RAE were unknown to the public; indeed they would have counted any kind of celebrity a grave embarrassment. In this sense, the German specialists who stayed on were completely integrated into the ethos of British defence science and behaved and were treated in exactly the same in this respect as British-born research workers.

In the rapid pace of Cold War aeronautics it quickly became meaningless to attempt to unravel what work was notionally 'German' and the term would certainly have seemed irrelevant to the participants. We should also recall that this study traverses a trajectory of 'mind-sets' about nationalism and identity, taking us from the still-fresh sensibilities of the war, in 1946, through the perceptions of the Cold War and on to the approaching entry of Britain into the European community with new and still emerging perceptions of nationalism and identity.

Appendix: a conundrum – the financial value of German defence science

In the immediate aftermath of the Allied exploitation programmes there were efforts made to assess the value of what had been taken, both from the German side and on behalf of the British and American governments of occupation. The main motivation behind this was for German trade associations, but also Allied occupation bodies such as the Bizonal Economics Administration, to estimate the value of intellectual and other properties removed from Germany in order to establish a credit figure towards the reparations account.

Of course, a major component of this material was concerned with military R&D, which could be taken as having no realisable value in a defeated and disarmed Germany, although a huge quantity of information and actual products and prototypes for civil technologies were taken, which clearly had important potential for the reviving economy of Germany. To some historians, indeed, the whole exploitation programme should be comprehended in terms of undeclared intellectual reparations.[99] Arriving at the value of this material proved extraordinarily difficult and the final assessment reached by the commission established by the administration for this purpose came up with an estimate of between $4.8 billion and $12 billion.[100]

Estimating the share of this which fell to Britain would be extraordinarily problematical and, moreover, would not represent its utility. Firstly, there is the possibility, quite strong in many cases, that British manufacturers would have in time adopted types of plant, processes and designs that were in use in Germany anyway, and that there was a process of modernisation which had been deferred by the war. Another reason to suggest that the value to the recipient is lower than the value estimated by the loser is suggested by a 'housebreaker' analogy where the burglar never obtains the full value of items taken away. In the case of German science, the utility that patents, processes, scientific knowledge and so on would have had when stripped out of the milieu in which they developed must have been vastly reduced. It seems likely that the only environments where this special knowledge could have been absorbed and transferred without high dilution could have been in defence establishments such as the RAE.

Another factor which also makes a proper assessment difficult, if not impossible, is the problem of valuing 'false starts' and dead ends in technology. Germany had been found to be so extraordinarily fertile in new technologies applicable to aviation that the Allies tended to assume that almost all these leads might prove valuable, and the German estimators certainly have echoed a high estimation of value. Thus General Electric considered that expertise with helicopters powered by tip jets at the ends of the rotor blades, acquired from the inventor, Dr Doblhoff, was worth $1 million.[101] One of Doblhoff's engineers, August Stepan (mentioned above) also brought experience of the system to Britain, where it was used for the experimental Fairey Rotodyne. The Rotodyne was intended to be a short-haul helicopter airliner linking both cities to cities and cities to international airports, but proved to be an expensive diversion. By 1957 it had consumed some £7.6 million in development money and was cancelled shortly afterwards.[102] Neither Britain nor the USA developed useful machines with jet-powered rotors and the whole concept could be viewed as an expensive 'negative dowry'.[103]

Another example where the value is highly contentious is provided by the case of BMW aero engines. The firm's report on the removal of 50 crates of reports and drawings to Wright Field by American personnel valued the material at more than 325 million Reichsmarks (about £32 million in contemporary sterling value) – the sum spent in research and development since 1937.[104] The problem with such a figure, for the purposes of economic analysis, is that it does not reflect the value of the intellectual property to either party. In the case of BMW, the special knowledge which it had acquired in aero engines was effectively made useless by the defeat of Germany, since even if there had been no Allied exploitation it no longer had a customer for military goods and was prevented from making warlike material for any other state. The value to the USA would also be grossly overstated by this figure. Much of BMW's special expertise related to air-cooled radial piston engines (such as that in the Focke-Wulf 190), but although Allied experimenters were naturally intrigued by the competing solutions developed in Germany, the USA in 1945 had two producers, Wright and Pratt & Witney, making highly developed air-cooled radials. There is no suggestion that either firm altered their designs after the war in the light of knowledge from BMW. In fact, developed versions of American Second World War service types powered the first postwar civil airliners, while for military use the piston engine was being rapidly replaced by the jet and little new development engineering on piston engines was done.[105]

Notes and references

1 Gimbel, J, *Science, Technology and Reparations; Exploitation and Plunder in Postwar Germany* (Stanford: 1990). For a critical reassessment of Gimbel's book see Judt, M and Ciesla, B (eds), *Technology Transfer out of Germany after 1945* (Amsterdam: 1996).

2 Bower, T, *The Paperclip Conspiracy* (London: 1988). Bower makes the curious judgement that the British programme was characterised by excessive scrupulousness with respect to scientists with Nazi associations, vagueness about objectives and 'lost opportunities', while at the same time he castigates the Americans for being too greedy and too ready to whitewash the record of

'desirable aliens'. See also Lasby, C G, *Project Paperclip* (New York: 1971).

3 Gunston, B, *Bombers of the West* (Hersham: 1973). This comment ignores not only the massive haul of German equipment, which this paper sets out to study, but also the substantial UK investment in government research which made the Royal Aircraft Establishment (RAE) at Farnborough the biggest research establishment in Europe in the Cold War era.

4 There is also a need for a far wider study of these events, which is beyond the scope of this study, taking in the use made of the whole range of scientific and technical material brought to Britain including German industrial chemistry, plastics and synthetic materials, textile handling, photography, film developments and much more.

5 Uttley, M, 'Operation Surgeon and Britain's post-war exploitation of Nazi German aeronautics', *Intelligence and National Security*, 17/2 (summer 2002), pp1–26

6 Heinemann-Grüder, A, 'Keinerlei Untergang: German armaments engineers during the Second World War and in the service of the victorious powers', in Renneberg, M and Walker, M (eds), *Science Technology and National Socialism* (Cambridge: 1994), pp30–50

7 Fedden, R, 'Final report – The Fedden Mission to Germany', Ministry of Aircraft Production, June 1945 (Science Museum archives). Fedden had been chief designer for Bristol aero engines but after his rift with the company board became special adviser to the Minister for Aircraft Production. In Germany his principal brief was to select equipment for the new College of Aeronautics at Cranfield.

8 Both Britain and Germany suffered, in terms of economy of scale, from generally smaller plants and shorter production runs relative to the USA, although Britain had probably gone further in training and incorporating new labour into the aircraft plants, whereas in Germany the power of the master craftsman or *Meister* in engineering shops seemed little diminished. Although in Germany much airframe manufacture was improvised and dispersed, Hans-Joachim Braun has argued that engine manufacture tended to rely on established German high-skill craft technique and multipurpose tooling. The introduction of single-purpose ('mass-production') tooling was relatively slow and where engine manufacture was dispersed, productivity was generally poor. See Braun, H-J, 'Aero-engine production in the Third Reich', *History and Technology*, 14 (1992), pp1–15.

9 Public Record Office Ref. AVIA 10/411, 'Farren Mission to Germany'. Helmuth Trischler has discussed the frustration of aerodynamicists at the lack of access to the experience gained by the fighting services – in direct contrast to the First World War – in 'Self-mobilisation or resistance? Aeronautical research and national socialism', in Renneberg, M and Walker, M (eds), note 6, pp72–87.

10 *Ibid.* Sir Alec Cairncross has also left his recollections of the mission recalling that 'the Farren Mission was greatly impressed by the lavish scale on which the German government had supported research and development, employing in 1945 5,000 workers (in a private firm) in five separate establishments, and

stressed the contrast with the parsimony of the British government in financing research and development in aviation'. Cairncross, A K, *Planning in Wartime* (Oxford: 1991), pp137–40.

11 Public Record Office Ref. AIR 8/784, minute of 24 January 1945. The threat of the new Messerschmitt jet fighters was serious enough for Lord Portal to predict that 'if Germany has not been beaten before July 1945 she will have dominance in the air over Germany and above the armies during good flying weather'.

12 Gunston, B, *By Jupiter: The Life of Sir Roy Fedden* (London: 1978), p130

13 Gunston, B, note 12; Senator Albert D Thomas, quoted in Judt, M and Ciesla, B (eds), note 1, p101.

14 The subject of these various high-level missions into Germany before the war and German intentions in facilitating them is a curious one which has not been explored. It is interesting to note that Tizard wrote to Lord Swinton, Secretary of State for Air, in 1936 about one such: 'H R Ricardo, of whom I expect you have heard, has just returned from Germany where he has been shown German engine developments. I think that it would be helpful to you if you had a talk with him. His news is very reassuring in some ways.' (Public Record Office Ref. AIR 2/1866, 'Committee for the Scientific Survey of Air Offence'). The facilities given to the Rolls-Royce mission in 1937 are particularly intriguing, since these were top-level engineers who could see the significance of what they were shown. The three Rolls-Royce men were A G Elliot, Chief Designer, H J Swift, General Manager, Production, and J Ellor, the firm's supercharger expert. They saw, among other things, the Daimler-Benz, Junkers and BMW aero-engine works and were provided with a Junkers Ju 52 aircraft. They were deeply impressed with the scale of organisation and the provision of enclosed 'silent' test-beds with instrumentation grouped outside, noting that the facilities of plant, buildings, equipment and personnel for research and development 'was superior to anything we have seen in this country'. They also noted the open layout of factory sites with buildings widely spaced 'evidently planned [to make] air attack extremely difficult'. Report reproduced in *The Archive* (journal of the Rolls-Royce Heritage Trust), 2/2 (1984) and subsequent issues.

15 Public Record Office Ref. AVIA 9/88, 'Visits to Volkenrode'. Paper on file: 'MAP interest in German research establishments', 3 January 1946. This notes 'of these, by far the most important is Volkenrode'.

16 Some authors have seemed to imply that the development of aeronautical research facilities and advanced weapons was a response to the Allied bombing campaign. The development of the LFA was part of a long-planned dispersal of aeronautical facilities which was well advanced in the mid-1930s. Thus Helmuth Trischler, note 9, pp74–6, has described the preparatory prewar work for aerodynamic facilities. In January 1946, Arthur Woodburn, Parliamentary Secretary for the MAP, visited Völkenrode and observed that 'the Herman Goering wind tunnel was covered by a special cement platform covered with tons of earth in which shrubs, grass and even trees were planted. [...] the fact that all this [...] was planned and prepared long before the war and so

carefully hidden [is] itself a silent indictment of the Nazi preparations for war' (Public Record Office Ref. AVIA 9/88).

17 Lockspeiser, B, introductory remarks as Chairman on 9 October 1946, to Smelt, R, 'A critical review of German research on high-speed air flow', *Journal of the Royal Aeronautical Society*, 50 (1946), p900

18 Public Record Office Ref. AVIA 10/113, quoted in Bower, T, note 2

19 Lasby, C G, note 2, pp28–9. According to Lasby, Putt was one of the most vocal and influential advocates for the transfer of German scientists to the USA. 'Lusty' was just one of a large number of the intelligence missions intended to investigate and exploit German science after the surrender. These also included ALSOS (the mission to investigate the state of German atomic research), CIOS (Combined Allied Intelligence Sub-Committee) and BIOS (British Intelligence Objectives Sub-Committee).

20 Public Record Office Ref. AVIA 15/2216, Hermann Goering Research Institute at Volkenrode (Luftfahrtforschungsanstalt Hermann Goering, LFA), Ben Lockspeiser, DSR to Minister (through CRD and DTD), 11 May 1945.

21 *Ibid.*

22 Irving, C, *Wide-Body, the Making of the 747*, (London: 1993), pp75–94

23 Schairer wrote 'the Germans have been doing extensive work on high speed aerodynamics. This has led to one *very* important discovery. Sweepback or sweepforward has a large effect on critical Mach No.' and he gave sample calculations to illustrate the theory. Letter, G S Schairer to Benedict Cohn, 10 May 1945, reproduced in facsimile in *50 Jahre Turbostrahlflug*, DGLR-Symposium proceedings, Munich, 26–27 October 1989. The fact that Schairer wrote 'Censored' on the cover of his letter and signed this statement himself could indicate a desire to avoid US government control, although one account attributes his action to a desire to 'avoid delay'. Schairer and Cohn would have immediately realised that the swept-back wing allows a subsonic aircraft to approach the speed of sound without suffering the effects of buffeting and trim change (pitching up or down) – the so-called compressibility phenomena which had been encountered by the increasingly powerful Allied service aircraft used in the war.

24 Irving, C, note 22.

25 Gorn, M, *The Universal Man, Theodore von Karman's Life in Aeronautics* (Washington DC: 1992), pp105–6. Much of this haul, amounting, it has been said, to 3 million documents, was air-freighted back to the USA, to form the nucleus of the Armed Services Technical Information Center.

26 Gunston, B, personal communication, 1997 (also see note 12). Gunston recalled Fedden saying 'it was the law of the jungle out there'. It is possible that Fedden had encountered in this case an American unit of the Allied army 'T-Forces' which had armoured infantry and antitank weaponry in order to gather material in target areas immediately resistance ceased. In general Anglo-American cooperation was good and apart from these intelligence-related issues, Fedden specifically noted the generosity and helpfulness to the Mission of the US Army (Fedden, R, note 7).

27 Public Record Office Ref. AVIA 15/2216. Lockspeiser to Minister, 11 May 1945.

28 *Ibid.*

29 Public Record Office Ref. AVIA 15/2216. Tribe's paper also noted 'I am sending a copy of this letter to Barlow at the Treasury because of the reparation issues involved.'

30 Public Record Office Ref. AVIA 15/2216, Jones, R V, MAP statement on Völkenrode to ACAS, Air Ministry, 6 July 1945. Jones ascribed the highest priority to a supersonic swept-wing jet-powered project, the DFS (Deutsches Forschungsintitut für Segelflug) 346. This was intended for reconnaissance and to achieve the startling performance of 1250 mph (Mach 1.9) at 60,000 feet.

31 Public Record Office Ref. AVIA 15/2216, Jones, R V, MAP statement on Völkenrode to ACAS, 6 July 1947.

32 *Ibid.*

33 Weber, J, interview with author, 1 June 1998; Public Record Office Ref. AVIA 12/82, 'Operation Surgeon – memorandum no. 2'.

34 Public Record Office Ref. AVIA 9/88, 'MAP interest in German research establishments'. It was noted to Sir Alec Coryton, Controller of Research and Development (CRD) that 'Mr Gorrell Barnes of the Treasury is therefore accompanying you [to visit Völkenrode] to obtain a general picture of the equipment involved and the scale of the operation'.

35 Fletcher, P, conversation with the author, March 1996. As 'Superintending Engineer – Heavy Research Plant' for the Ministry of Works, Fletcher was concerned with the engineering of all the large government research installations in the UK and was in overall charge of the engineering side of the dismantling of Völkenrode and the transport of its equipment. He was also involved in the planning and layout of the Bedford site and the building of the wind tunnels, spinning tunnels and engine test facilities at Bedford so that there was a close integration between these programmes. The Ministry of Works engineers in the 'Surgeon' team referred to themselves ironically as 'Operation Spanner-hammer'.

36 For example, Schlieren interferometry equipment. The superb quality of the German optical and mechanical instrumentation can be seen in the case of kinetheodolites – calibrated camera devices used on ranges for tracking the trajectory, height and speed of projectiles and aircraft. In 1965 the RAE were still using and maintaining what effectively were German Askania instruments of prewar manufacture. ('Kinetheodolite planned maintenance manual', Workshops Department in conjunction with Instrumentation and Ranges Department, July 1966, Science Museum Technical File for Inv. No. 1993-2547).

37 Public Record Office Ref. AVIA 15/2216. It was also noted that 'at Göttingen there is [...] equipment deposited by Sir Roy Fedden [for the College of Aeronautics]. This should be included in general plans.'

38 Public Record Office Ref. AVIA 9/99

39 Public Record Office Ref. AVIA 12/82, 'Operation Surgeon, memorandum no. 2'. The scale of this removal is all the more remarkable when it is recalled that this 'take' consisted of 'high-tech' research equipment rather than general industrial plant. By 1 October 1946 approximately half the identified material

had been shipped (7620 tons by sea and 144 tons of more delicate equipment by air) and it was reported that shipments were going out at a rate of 1800 tons per month. For the new College of Aeronautics at Cranfield alone, which was the junior partner in allocations, 400 tons of research equipment and machine tools were packed in Germany during October 1945 by Wing Commander Hereford. (Harrington, J, Librarian, Cranfield University, personal communication, 1996). Some equipment did still remain *in situ* at the end of the agreed period and was destroyed punitively.

40 Fletcher (note 35) recalls the attitude among the Siemens men as 'We have a good name and we want to see that it comes out tidily.'

41 Public Record Office Ref. AVIA 9/88, MAP, Ashworth, E C, 'Interest in German research establishments', note for CRD, PS 15, 3 January 1946 and paper 'Organisation of Operation Surgeon'. The Ministry of Aircraft Production was amalgamated with the Ministry of Supply during the course of this programme.

42 Public Record Office Ref. BT 211/46, 'Employment of German technicians and German reparation labour generally', March 1946. The secret and contentious nature of these arrangements is illustrated by the instruction on a telegram in the file from the British administration in Vienna to the Board of Trade: 'This message will not be distributed outside British or US government departments or HQs or re-transmitted, even in code, without being paraphrased.'

43 Bower, T, note 2; Lasby, C G, note 2

44 Note from Colonel Putt to 'Hap' Arnold, Commanding General, AAF (Army Air Force), 4 November 1946, quoted in Lasby, C G, note 2, p170.

45 Public Record Office Ref. BT 211/46, Preston, G E, minute of 27 September 1945

46 Lasby, C G, note 2

47 Public Record Office Ref. AVIA 15/3846, 'Panel to consider employment of German scientists, specialists and technicians for civil industry in the United Kingdom'.

48 Public Record Office Ref. AVIA 15/3846, telegram of 19 January 1946 to British Embassy, Washington. In fact the MAP had noted that in early January 1946 'Air Vice Marshall Jones paid a special visit a few weeks ago to Volkenrode and Göttingen to disclose the broad policy in connection with the German scientists in the UK [...] at Headquarters in London arrangements are now in hand for the preparation of the contracts and for the accommodation, programmes of work etc. for those Germans who elect to come to this country.' (Note from PRO AVIA 9/88, PS15).

49 Public Record Office Ref. BT 64/2879, quoted in Bower, T, note 2

50 Public Record Office Ref. AVIA 9/88, Woodburn, A, 15 January 1946

51 Public Record Office Ref. AVIA 15/3846, 'Panel to consider employment of German scientists, specialists and technicians for civil industry in the United Kingdom'. The Darwin Panel nominees handled by the 'German Division' at the Board of Trade formed an extremely diverse list including specialists in cameras, lenses and optics, photographic film, fuel injection, but also oddities

like the chief engineer for a fully-fashioned hosiery machine company and a designer of sugar and chocolate machinery.

52 Public Record Office Ref. BT 211/47. The press release on the Darwin scheme, released in December 1945, also made these points and added that 'during their stay the Germans will not be in any position of authority, and will, in no case, serve in any vacancy which could be filled by a British employee'.

53 *Ibid.*, minute of 25 February 1946.

54 *Ibid.*, paper of 9 January 1946.

55 The Germans referred to at Barrow-in-Furness were Helmuth Walter and his team which had produced a hydrogen peroxide submarine power plant to allow sustained high-speed underwater running. The Admiralty had managed to install the Walter team at Vickers in advance of any general resolution of the policy doubts over placing the Germans in specific companies.

56 'To brighten your life', in *Sunday Pictorial*, 24 November 1946

57 Public Record Office Ref. BT 211/47

58 *Ibid.*, cuttings in file from *The Times*, *Daily Mirror* and *Daily Telegraph*, 1 November 1946, *Daily Worker*, 8 November 1946.

59 Public Record Office Ref. CAB 122/352

60 *Ibid.*

61 Karl Doetsch attributed his desire to leave to the fact that, intellectually, Busemann felt isolated at NPL and that 'there was no one of his calibre' there. Doetsch, K, conversation with the author, 5 October 1998.

62 Weber, J, note 33

63 Doetsch, K, note 61. Doetsch was one of the German scientists offered employment at Farnborough. He and Dietrich Küchemann were the only ones offered 'German Scientist I' grade salary.

64 *Ibid.* Doetsch recalled that 'Lindner and Multhopp pointed me out'. Interestingly, Morgan has also provided an account of his encounter in Morgan, M M, Morris, D E, and Truran, W C, 'Notes on a visit to Southern Germany, July 8th–18th, 1945, to interrogate German technical staff on stability and control matters, with special reference to flight testing'. RAE Tech. Note No. Aero 1673 (Flight), August 1945.

65 Although the intention to recruit under this scheme was announced early in 1946 and many individuals appear to have come to the UK in 1946 and 1947, the details of procedure, contract terms and so on were not formally defined until March 1948, and are detailed in PRO CAB 122/352. The Ministry of Supply paid for removal expenses of Germans and their families.

66 Stepan, A, personal communication, 1990

67 Edgerton, D, 'Whatever happened to the British warfare state? The Ministry of Supply, 1945–1951', in Mercer, H, Rollings, N, and Tomlinson, J D (eds), *Labour Governments and Private Industry, The Experience of 1945–1951* (Edinburgh: 1992), pp91–116

68 Conversation with Steve Thornton, Librarian at RAE Bedford, December 1996. Nonweiler also wrote a comprehensive overview of German work for the RAE, Nonweiler, T, 'German high speed aircraft and guided missiles', Royal Aircraft Establishment Aero Reports 2070, 2071, 2072, August 1945.

The study covers aircraft, guided missiles, and engines and fuels in three parts.

69 Collins, H M, *Changing Order* (Chicago: 1992), p55. Collins argues for the importance of the human mediation of tacit knowledge in the case of the TEA carbon dioxide laser in one of his case studies by noting that 'no scientist succeeded in building a TEA-laser where their informant was a "middle man" who had not built a device himself'.

70 The Volta High Speed Conference, held under the auspices of the Italian Academy of Science, was held in Rome from 30 September to 6 October 1936. Proceedings were published as: Fondazione Alessandro Volta (ed.), *Convegno di Scienze Fisiche, Matematiche e Naturali*, 'Theme: High Speeds in Aviation' (Rome: 1935, 2nd ed. 1940).

71 Constant, E W, II, *The Origins of the Turbojet Revolution* (Baltimore, MD: 1980), p156

72 Busemann, A, 'Aerodynamischer Auftrieb bei Überschallgeschwindigkeit', in Fondazione Allessandro Volta (ed.), note 70, pp328–60

73 Lighthill, M J, 'A note on supersonic biplanes', Aeronautical Research Committee Reports and Memoranda No. 2002, 27 October 1944. W F Hilton, at NPL, also published a paper 'Further tests on a faired double wedge aerofoil' on 11 May 1944, ARC Fluid Motion Panel 693, which noted interestingly 'centre of pressure calculated by Busemann's method'.

74 Doetsch, K, personal communication, March 1997; Doetsch, K, 'Deutsche Luftfahrtforscher nach 1945 in England', in *Die Tätigkeit deutscher Luftfahrt-ingenieure und -wissenschaftler im Ausland nach 1945* (Bonn–Bad Godesberg: Deutsche Gesellschaft für Luft- und Raumfahrt eV, 1992). A translation of this paper has recently been deposited in the library of the Royal Aeronautical Society.

75 Conradis, H, *Design for Flight: the Kurt Tank Story* (London: 1960), p154

76 Kervell, B, formerly Curator of the RAE Museum, personal communication, November 1995

77 We can perhaps see in Multhopp's response the view of a 'classical' aerodynamicist (his background was Göttingen and Focke-Wulf) to the 'maverick aerodynamics' of Alexander Lippisch, creator of the Me 163, and the continuation of a disagreement which was already in existence in wartime Germany. Doetsch recalls 'people thought he was arrogant which was untrue – but he was so outspoken in giving an answer. He was actually a very nice person.' Doetsch, K, personal communication, note 74.

78 Winter, M, and Multhopp, H, 'Transonic research aircraft with "Avon" turbine jet engine (A.J.65)', RAE Technical Note Aero 1928, February 1948; Doetsch, K, 'Deutsche Luftfahrtforscher nach 1945 in England', note 74

79 Owen, P R, Nonweiler, T R F, and Warren, C H E, 'Preliminary note on the design and performance of a possible supersonic fighter aircraft', RAE Technical Note Aero 1960, June 1948

80 Doetsch recalled that 'English Electric worked hard to keep Multhopp' when he was in the process of deciding to leave for the USA. Doetsch, K, personal communication, note 74.

81 'Report of R.A.E. Advanced Fighter Project Group', RAE Report Aero 2300,

November 1948
82 *Ibid.*, p11
83 It is possible that the problems of aero-elasticity and structural integrity were beginning to be addressed in Germany during the war but, if so, this work or appropriate specialists do not seem to have reached England.
84 Note 81
85 An 'experimental requirement', ER 103, issued in late 1947, preceded this. The advantages of English Electric were an industrial management that was more solid than that usually found in the aircraft companies and a design team led by Teddy Petter that had, largely through its own initiative, launched the Canberra jet bomber.
86 Gardner, C, 'The future of military aviation', lecture to the Imperial Defence College, 19 June 1957 (Science Museum archives). The hybrid rocket/gas turbine interceptors developed to prototype stage as the Saunders-Roe SR.53 and Avro 177 were cancelled in the aftermath of the Sandys 1957 Defence White Paper. However it was by then becoming clear that the gas turbine engine, with reheat, as in the Lightning, could give impressive climb performance without the complication of mixed power plants and dangerous chemical fuels.
87 Nahum, A, 'The Royal Aircraft Establishment from 1945 to Concorde', in Bud, R, and Gummett, P (eds), *Cold War, Hot Science* (London: 1999), pp29–58. This chapter analyses the relationship between the RAE and the firms in this period, and also teases out something of the internal culture of the RAE.
88 Conradis, H, note 75, pp185–8
89 Bower, T, note 2
90 Bentele, M, *Engine Revolutions* (Warrendale, PA: 1991), pp16–103
91 Moult, E S, 'The development of the Goblin engine', *Journal of the Royal Aeronautical Society*, 51 (1947), pp655–85
92 Millard, D, *The Black Arrow Rocket: a history of a satellite launch vehicle and its engines* (London: 2001)
93 Jeffs, A, former Westcott engineering scientist, conversation with the author, 19 February 2003. Westcott was one of the unloading fields for Operation 'Surgeon' and Jeffs remembers a huge haul of parts, including V2 parts, accumulating there for cannibalisation in experiments. Also 'the odd VW [Beetle] came through – and disappeared'. He recalled that there were British attempts to make solenoid (electrically commanded) valves but alongside the German version 'they were like a donkey compared to a racehorse'.
94 *Ibid.* Heinz Walder was one of the rocket experts brought over under the 'defence scheme'.
95 The AVIA 40 class at the Public Record Office contains more than 5000 drawings on the Wasserfall missile and the V2 which were collected in Germany for the Westcott rocket research establishment.
96 Owen, P R, and Maskell, E C, 'Dietrich Küchemann', *Biographical Memoirs of Fellows of the Royal Society*, Vol. 26, December 1980, pp305–26
97 Heinemann-Grüder, A, note 6, p42. Although Apollo and Concorde were not weapons systems they can certainly be regarded as first cousins to them and

could not have been remotely possible, at the time they were created, without defence expenditure.

98 Nahum, A, note 87

99 Gimbel, J, note 1. Gimbel is particularly concerned to analyse the tensions between exploitation and German reconstruction between the various agencies of the occupying American authority. See also Farquarson, J, 'Governed or exploited? The British acquisition of German technology, 1945–48', *Journal of Contemporary History*, 32/1 (1997), pp23–42.

100 Gimbel, J, note 1, pp153–66

101 Bolling Airforce Base Historical Office, Microfilm A2056, Scientists Program, frame 0117, quoted in Gimbel, J, note 1, p51

102 Public Record Office Ref. AVIA 65/738, Aircraft Research and Development Programme 1956–57

103 The tip-jet concept was made possible by the power of the new gas turbine engine which was used in this application as a gas generator to pump its high-pressure exhaust air through hollow rotor blades where it exited rearwards at the tip. The attraction of the system was that it powered the rotor without the torque reaction resulting from shaft drive. This made piloting simpler and removed the need for a powered and adjustable tail rotor.

104 Gimbel, J, note 1, p164

105 The case of the design for the BMW car, taken up in Britain by the Bristol company, is certainly in a different category, for in that case there was clearly a sizeable commercial gain for the British company as well as a commercial opportunity for the German manufacturer, although the home market for fast cars of the type made by BMW prewar had disappeared and the company re-entered the market with small economy types.