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Exploitation of German tech

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Research Article

The transfer and exploitation of German air-to-air rocket and guided missile technology by the Western Allies after World War II

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Abstract

During World War II, the German military-industrial complex under the national socialist regime made pioneering strides in the development of aircraft armaments

for the *Luftwaffe*. Through the application of scientific knowledge in the fields of mechanical and electrical engineering, ballistics, aerodynamics, and rocket propulsion, German armaments manufacturers evolved aircraft cannon technology to the automatic revolving aircraft cannon, to small unguided solid propellant rockets, and by 1945 Germany was on the threshold of starting series production of the world's first guided air-to-air missile system. Towards the conclusion of the war in Europe and in the months afterwards, the four occupying powers produced scientific and technical intelligence on these developments for the purpose of exploitation. This article provides previously unpublished details about these activities by the Western Allies – the United States, United Kingdom and France – historical events which have traditionally been overshadowed by the Allies' transfer and exploitation of other German guided weapons, such as the V-1 and the V-2.

Keywords:

World War II | aircraft armaments | technology transfer

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Notes

1 The wide scope of this article required an archival synthesis of a broad range of primary sources that are held by American, British and French repositories. These sources include American, British and French intelligence reports on German guided missile research and development during World War II; British technical reports on the examination and evaluation of captured German artefacts; bureaucratic correspondence and minutes from meetings by personnel in British government departments; contracts that were awarded by the French government to industrial firms to study and reverse engineer the technology in the X-4; progress reports by

American defence contractors who were engaged on guided missile research projects after World War II; and the US War Department foreign scientist personnel dossier of Kramer (who was recruited by the US Navy after the war), which was declassified by the National Archives and Records Administration upon my request in 2018. Data on Kramer was also acquired from a technical report that is held by the Defense Technical Information Center online repository. The report was produced in 1980 by a US Navy contractor for the Office of Naval Research, and summarises the results of 19 years of experimental research that Kramer did on a topic in the field of hydrodynamics called 'compliant coatings', from 1957 to 1975. See the bibliography.

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The transfer and exploitation of German air-to-air rocket and guided missile technology by the Western Allies after World War II

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During World War II, the German military-industrial complex under the national socialist regime made pioneering strides in the development of aircraft armaments for the *Luftwaffe*. Through the application of scientific knowledge in the fields of mechanical and electrical engineering, ballistics, aerodynamics, and rocket propulsion, German armaments manufacturers evolved aircraft cannon technology to the automatic revolving aircraft cannon, to small unguided solid propellant rockets, and by 1945 Germany was on the threshold of starting series production of the world's first guided air-to-air missile system. Towards the conclusion of the war in Europe and in the months afterwards, the four occupying powers produced scientific and technical intelligence on these developments for the purpose of exploitation. This article provides previously unpublished details about these activities by the Western Allies – the United States, United Kingdom and France – historical events which have traditionally been overshadowed by the Allies' transfer and exploitation of other German guided weapons, such as the V-1 and the V-2.

KEYWORDS World War II, aircraft armaments, technology transfer

Introduction

During World War II, Germany led the world in the development of unguided air-to-air rocket and guided air-to-air missile (AAM) technologies. The pioneering development of these new anti-aircraft armaments in the Third Reich originated from scientific and technical advances in several fields including radio, rocket propulsion and aerodynamics. The German efforts were largely stimulated

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by the Anglo-American strategic bombing campaign – by mid-1943, the *Luftwaffe* required more sophisticated ground- and air-launched anti-aircraft weapons to increase the rate of attrition of British and American four-engine heavy bombers. By 1944, the *Reichsluftfahrtministerium* (Reich Air Ministry, RLM) had initiated four experimental guided AAM projects. Three missiles were developed by the aircraft and guided missile manufacturer *Henschel Flugzeug-Werke AG,* the company that designed the world's first operational guided missile, the air-to-surface missile Hs 293. The fourth – and most successful missile – was developed by *Ruhrstahl AG Presswerke,* the firm that manufactured the world's first precision-guided bomb, the PC 1400 X, also referred to as the X-1 or by its codename 'Fritz X'.

This article will show that after World War II, the scientific and technical intelligence on German air-to-air rocket and guided missile technology that was acquired by American, British and French experts, and the knowledge of the German specialists who developed the weapons, was chiefly exploited by the defence industries in the United States and France, and to a lesser extent by the British – collectively referred to as the Western Allies – for the benefit of their indigenous guided weapon and rocket programmes. To illuminate how the German knowledge was specifically exploited in each country, four key examples are provided in this article. Of importance to this study was the exploitation of Germany's most advanced operational air-to-air rocket, the R4M, and most sophisticated experimental guided AAM in development during the war, the *Ruhrstahl* X-4, and its chief designer, Dr.-Ing. Max Kramer.

Numerous unpublished and published primary[1] and secondary sources of relevance to the subject of this article have appeared in the 75 years since the conclusion of World War II. Hierarchically, of background and contextual interest is the literature about the Allies' extraction of war booty and reparations from Germany, and the recruitment of German scientists, engineers and technicians for employment in each victor country and other nations, for instance in the British Commonwealth.[2] The story of the Allies' transfer and exploitation of the *Fieseler* Fi-103/V-1 flying bomb, the world's first cruise missile, and the Peenemünde A-4/V-2 rocket, the world's first ballistic missile, and the scientists and engineers who developed these weapons, has overshadowed the transfer and exploitation of other German guided weapon technologies by the Allies.[3] In the literature about the early development of guided weapon and rocket technologies, the German World War II guided AAMs and rockets have been fairly well documented, but there is a lack of research about the transfer and exploitation of the German knowledge after 1945.[4]

This article comprises seven parts. After the Introduction, the second part is a brief comparative analysis of air-to-air rocket and guided missile development by Germany and the Western Allies during World War II. Germany's technological lead over the Western Allies (and the Soviet Union) was considerable, although towards the end of the war the Americans and the British had begun research into radio-controlled, rocket-propelled AAMs. The third part details the discoveries of German AAM development that were made by technical intelligence officers from the Western Allies during the race with the Soviet Union to acquire

intelligence on German secret weapons. Despite the means at the disposal of the leviathan of an intelligence-gathering apparatus that was the Anglo-American Combined Intelligence Objectives Subcommittee of the Combined Intelligence Committee, French intelligence knew about the X-4 project at least six months before Britain and the United States, a very important fact which has been entirely overlooked until now.

The next three parts are concerned with the transfer and exploitation of the German knowledge by the three respective powers. Discussed in these parts are four key examples of how the German knowledge was exploited in each country within the broader transfer and exploitation activities. This is done in order to demonstrate the different methods that were used to derive advantages from the German science and engineering. Part four features the British examination and evaluation of the German R4M air-to-air rocket, the first of its type in the world, by technical intelligence officers from the British Air Ministry and by personnel at Ministry of Supply research and experimental establishments in the United Kingdom (UK). Part five features the reverse engineering of the X-4 by French firms under contract to the *Direction Technique et Industrielle de l'Aéronautique*, a French government department. Part six features two examples of exploitation on the Americans side – the recruitment and employment of Max Kramer by the US Navy Bureau of Aeronautics, and the incorporation by American engineers of technology from the X-4 into a post-war theoretical study of a guided missile system. The Conclusion recapitulates the central thesis of the article with a final note.

Comparative analysis of air-to-air rocket and guided missile development by Germany and the Western allies during World War II

Germany

In Germany during World War II, the rationale behind the development of more advanced aircraft armaments for the *Luftwaffe* was to increase the lethal efficiency of fighter aircraft during the short time of engagements, and at longer ranges to counter the expected development of the defensive armaments of American and British bombers. An important step in this direction was the design by *Mauser-Werke AG* of the world's first automatic revolving aircraft cannon, the 20 mm MG213C, and a more lethal variant for jet aircraft, the 30 mm MG213/30. However, these weapons did not enter service by the conclusion of the war. Aircraft rockets fuelled with solid propellants were also developed, but to increase the lethal efficiency of attacks at greater ranges, a rocket powered, radio-controlled AAM with a target seeker was required. Every known method of homing was explored in Germany during the war – radar, infra-red, and acoustic techniques. Investigations into proximity fuses using the same techniques were concomitantly explored. The realisation of such sophisticated technology, which in some respects was still theoretical, and the increasing demands of the air war necessitated a short-term solution in which the scientific and technical

problems could be rapidly solved. The immediate approach therefore, was the development of guided missiles with rudimentary control systems.[5]

The research and development of new aircraft armaments for the *Luftwaffe* involved co-ordination between the RLM, aeronautical research establishments, armaments manufacturers, and experimental and testing establishments (*Erprobungsstellen, E-Stellen*). Flight testing and pre-operational trials of guided weapons and rocket-powered aircraft were carried out at the *E-Stelle Karlshagen* (Peenemünde-West), one half of the inter-service installation at Peenemünde on the Baltic coast in Pomerania, which was situated adjacent to the Army Ordnance Office (*Heereswaffenamt*) establishment at Peenemünde-East, where the A-4/V-2 and the *Wasserfall* and *Taifun* surface-to-air missiles (SAMs) underwent development.

Between 1943 and 1945, the RLM had four guided AAM projects in development for the *Luftwaffe*. Three projects were by a subsidiary of the large *Henschel* industrial complex, the aircraft and guided missile manufacturer *Henschel Flugzeug-Werke* (HFW), which was based at Schönefeld in Berlin. The missiles were designed, developed and manufactured in the HFW guided missile development department by a team of specialists led by Professor Dr.-Ing. Herbert Wagner. Two missiles were air-to-air variants of other HFW guided missile designs – the Hs 293H (the H indicated an air-to-air variant), which was based on the Hs 293 air-to-surface guided missile, the world's first operational guided missile, which entered service with the *Luftwaffe* in the summer of 1943; and the Hs 117H, an almost identical variant of the Hs 297/Hs 117 SAM which was developed between 1941 and 1945. The third HFW project was the Hs 298, which was fitted with the electrical equipment in the Hs 117.[6] The fourth project, the *Ruhrstahl* X-4, was developed in parallel with the Hs 298 and was the fourth in the series of seven so-called 'X-weapons' that were designed by Dr.-Ing Max Kramer (Figure 1). The first of the series was the X-1, also known as the PC 1400 X or 'Fritz X', the world's first precision-guided bomb, which also entered service with the *Luftwaffe* in 1943.

These four guided weapon projects were conceived as potential countermeasures against the Anglo-American strategic bombing campaign, one element of a plan to develop more sophisticated anti-aircraft armament technology using rocket propulsion and radio remote control techniques. The engineers at both prime contractors applied their expertise and experience from the research and development of the technology in the Hs 293 and the X-1. All four projects reached the experimental development stage, including flight testing at the *E-Stelle Karlshagen*, but the war ended before the RLM could initiate series production (Table 1).

In addition to these armaments, there was a proliferation of solid propellant air-to-air rockets of much simpler designs in development for the *Luftwaffe*, but most of these projects did not progress beyond the experimental stage. According to Gatland, starting in 1941 the RLM converted an army artillery rocket to an air-to-air application, a 73 mm calibre projectile designated RZ.73 and code named *Föhn*.[7] A spin-stabilised rocket of either 65 mm or 73 mm calibre, designated RZ.65, was being developed by *Deutsche Waffen-und Munitions-Fabriken*

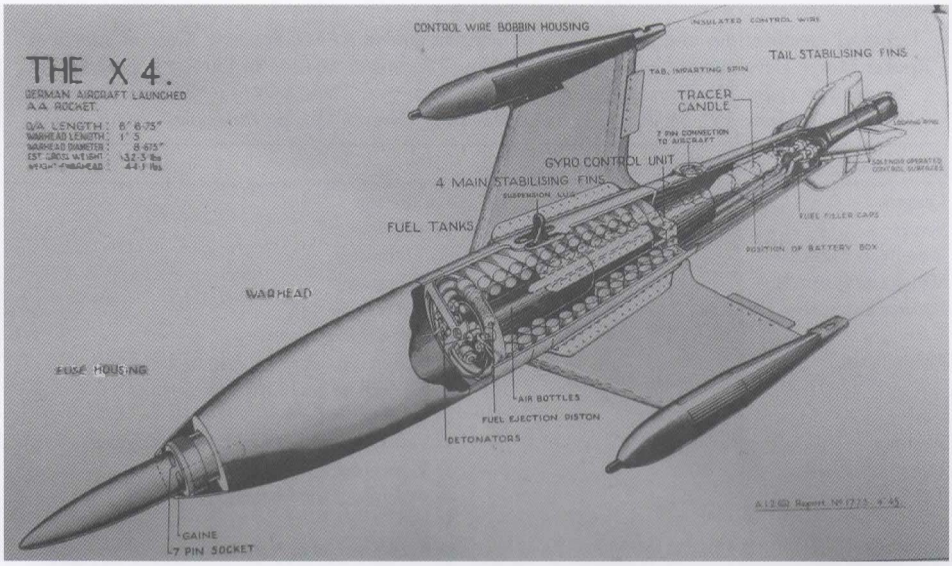


FIGURE 1 The *Ruhrstahl* X-4 guided air-to-air missile. Source: TNA, AIR 40/2162, G. Proctor, 'The X4 – German Air-launched A.A. Rocket', AI2(g) Report No. 1773, 3 May 1945.

(DWM) at Lübeck in Schleswig-Holstein.[8] *Rheinmetall-Borsig AG*, one of Germany's great armaments manufacturers, had two fin-stabilised, 210 mm calibre rockets in development, the R 100 M and the R 100 BS, which were designed to be fitted to the *Messerschmitt* Me 262.[9] There was also an 80 mm calibre projectile under development which resembled a Russian ground-launched anti-aircraft rocket.[10] At least two air-to-air rockets did enter service with *Luftwaffe* fighters during the war. One was the spin-stabilised 21 cm Wgr 42, a derivative of the German Army's 210 mm *Nebelwerfer* artillery rocket, of which four were fitted in tubes under the wings of the *Messerschmitt* Me 110, and possibly two in tubes fitted to the Me 109 G and *Focke-Wulf* Fw 190.[11] According to Zaloga, Allied bomber pilots first encountered this weapon over Wilhelmshaven on 21 May 1943.[12] In 1944, work began on Germany's best known World War II aircraft rocket, the 55 mm calibre R4M, which was developed by a group of firms including DWM. This inexpensive armament entered service in the last weeks of the war, and Me 262s fitted with the weapon reportedly shot down several Allied aircraft.[13]

United Kingdom, United States and France

No air-to-air guided missiles or rockets entered service with the air forces and naval aviation branches of the Western Allies during World War II. The UK was the first of the three powers to enter into the air-to-air rocket field, although abortively. In July 1940, the month the Battle of Britain commenced, the Air Ministry considered the possibility of using rockets fitted to fighter aircraft to

TABLE 1

Technical specifications and performance of German guided AAMs. Sources: 'General Survey of Rocket Motor Development in Germany', US Naval Technical Mission in Europe Report 236-45, September 1945; *The Story of Peenemünde*, pp. 527–531; TNA, 20/8772, 'German Guided Projectiles, Volume IV', MAP, 1945; AVIA 6/25699, 'German Guided Projectiles', MAP, 1945.

Ruhrstahl AG X-4 (RLM designation 8-344)	
Length:	1.9 metres
Span:	58 centimetres
Weight at launch:	70 kilograms
Weight at burnout:	60 kilograms
Rocket engine:	a) BMW 109-548 b) *Schmidding* 109-603
Propellants:	a) *Tonka 250* (57% crude m-xylidine/43% triethylamine) + 98–100% nitric acid. b) solid propellant
Thrust:	a) 140 kilograms down to 30 kilograms
Exhaust velocity:	a) 5,000 feet/second
Total impulse:	a) 636 kilograms/second
Specific impulse:	a) 156
Velocity:	a) Mach 0.7 at 6,500 metres
Stabilisation:	four large and four small fins in cruciform configurations and a gyroscope.
Control system:	wire-link by two x six-kilometre spools of 0.2 millimetre insulated wire.
Proximity fuse:	acoustic '*Kranich*' fuse designed by Dr.-Ing. Max Kramer
Seeker:	acoustic
Wind-tunnel testing:	DVL
Carrier aircraft:	*Focke Wulf* Fw 190, *Messerschmitt* Me 262, *Junkers* Ju 88 and Ju 388
Range:	2.5 kilometres

Henschel Flugzeug-Werke AG			
	Hs 293H	Hs 298 (8-298)	Hs 117H (8-117H)
Length:	3.82 metres	2.54 metres	4.29 metres
Span:	3.10 metres	1.25 metres	2 metres
Diameter:	–	25 centimetres	35 centimetres
Weight at launch:	980 kilograms	120 kilograms	320 kilograms
Rocket engine:	*Schmidding* 109-513	*Schmidding* 109-543	BMW 109-558
Propellants:	methanol/oxygen gas	diethylene glycol dinitrate R6M	*Tonka*/nitric acid
Thrust:	669 kilograms	150 kgs (5 secs) 50 kgs (20 secs)	60 kgs to 380 kgs
Exhaust velocity:	5,600 feet/second	5,100 feet/second	5,600 feet/second
Total impulse:	7,360 kgs/second	5,100 kgs/second	12,500 kgs/second
Specific impulse:	175	160	175
Velocity:	Mach 0.72	Mach 0.71	Mach 0.71
Stabilisation:	wings + gyroscope	swept-wings + gyroscope	swept-wings + gyro.
Control system:	radio or wire link	radio link	radio link
Proximity fuse:	yes	yes	yes
Seeker:	no	yes	yes
Wind-tunnel testing:	DVL	DVL	DVL
Carrier aircraft:	Dornier Do 217	fighters or bombers	Junkers Ju 188
Range:	0.5–4 kilometres	0.6–3.5 kilometres	7–12 kilometres

break up large formations of *Luftwaffe* bombers. The intended plan was to fit tubes 10 feet long and 12 inches in diameter in the cannon bay (where there were four 20 mm cannons) of the Bristol 156 Beaufighter, to fire 3-inch (76 mm) calibre unrotated projectile (UP) solid propellant anti-aircraft rockets. In tests, two rockets were successfully fired from such a tube, but the investigation did not proceed any further. Aircraft rocket development in Britain was subsequently continued by the Ministry of Aircraft Production (MAP). For the remainder of the war, the UK led the Allies in the development of solid propellant aircraft rockets for use in air-to-surface, anti-tank, anti-ship and anti-submarine roles, with demonstrable success. These projectiles evolved from the 3-inch rocket to the higher-velocity 5-inch (127 mm) calibre light alloy/plastic (LAP) rocket (designed for assisted take-off), to the armour-busting 10.25-inch (260.35 mm) calibre 'Uncle Tom' anti-shipping rocket.[14]

The MAP did not proceed with research and development of air-to-air rocket and guided missile technology with any seriousness until the last year of the war. One project was a spin-stabilised rocket of 2.36-inch (60 mm) calibre that was designed for firing from an automatic projector. There were three options as to the design of this particular weapon – a spinning rocket with or without fins, the latter of which was advantageous over the finned rocket as the diameter of the launching tube only had to be slightly greater than the rocket, which reduced drag; or an unrotated rocket with retractable fins, a more complicated undertaking. By the end of the war, many questions remained unanswered with little progress.[15]

Another MAP project was the 'Little Ben' air-to-air guided missile. The provenance of this project was an informal meeting held at the MAP on 27 October 1944 to discuss a homing AAM. At this meeting, representatives from the Royal Aircraft Establishment (RAE) at Farnborough proposed a missile powered by three 3-inch rockets, based on an opening range of 6,000 feet, with three possible control techniques – visual control with a radio link (as with the HFW and *Ruhrstahl* missiles), radar beam guidance, or semi-active guidance, where the target aircraft is illuminated by radar and the missile homes in on the reflections. Proposals put forward by the RAE provided a valuable basis for research work to meet the requirement, and industrial firms and government research and experimental establishments were brought into the project. In January 1945, the RAE produced specifications of a guided AAM for possible use also in air-to-surface and surface-to-air roles (the Naval Air Staff had their own requirement for an air-to-air guided missile). After the war, the project evolved into an experimental AAM development called 'Long Shot'. Generally speaking, the status of British guided AAM development in 1945 was where Germany was in mid-1943.[16]

American research and development on aircraft rockets began before the US entered the war in December 1941, and was largely built upon British dry-extruded double-based solid propellant rocket technology that was passed to the Americans in 1940. The US Army, with some support from the US Navy, had a 4.5-inch folding-fin air-to-air rocket in development that was fired from a three-tube jettisonable launcher, but disappointing results led the Americans to produce

their own versions of the British 3-inch rocket and Mk. I launching installation. US Navy research and development with aircraft rockets was predominately directed towards anti-shipping and anti-submarine weapons, with considerable success from 1943 onwards. As a result of these efforts, by 1945 the US was beginning to surpass the UK in aircraft rocket development, but no air-to-air rockets entered service during the war. In the guided AAM field, the US Navy Bureau of Aeronautics (BuAer) initiated two projects, both planned to be powered by liquid propellant rocket engines (LPREs) – an air-to-air version of a SAM called the 'Lark'; and the 'Gorgon IIA', which became a test vehicle after the war.[17]

The orthodox historical narrative of the German superiority in guided weapon and rocket development during World War II was the case with AAM technology. The Germans successfully designed and integrated all the different sub-systems – the rocket propulsion, radio control system, fusing, and aerodynamics – into functional experimental weapons. The RLM, the armaments manufacturers and *Luftwaffe* pilots were more familiar with the problems of small solid propellant air-to-air rockets from experimental development and operational experience than the Americans and the British. Also, the Germans were the first to realise that guided AAMs were the future and to evolve the technology from aircraft cannons to rockets and to guided weapons.

Nevertheless, there were some scientific and technical shortcomings in the nascent German technology. The Anglo-Americans had a considerable lead in electronic warfare and microwave radio research, which had ramifications for German guided AAM development – the designers of the X-4 were forced to use a wire-link control system to prevent jamming of the radio frequencies. Also, the British plastic rocket propellants that were in development towards the end of the war (the propellant in the 5-inch LAP rocket was one such example) were superior in performance to German double-based solid propellants which consisted of nitrocellulose and diethylene glycol dinitrate as the principal constituents. But in the US and the UK, the technological evolution from aircraft cannons to rockets to guided missiles still had to be achieved. After the war, the American and British leap forward towards guided missile technology – with the aid of scientific and technical intelligence from Nazi Germany – became more complex as jet aircraft with greater performance and manoeuvrability were developed to reach and break the sound barrier.

Investigations of German air-to-air guided missile and rocket development by American, British and French scientific and technical intelligence personnel in Germany

In the wake (on occasions in advance) of the Allies' march towards Germany after D-Day, technical intelligence officers gathered much information about Nazi Germany's secret military projects. On the Anglo-American side, these activities operated under the aegis of the Combined Intelligence Objectives Subcommittee (CIOS), whose creation was authorised by the Combined Chiefs

of Staff in August 1944. The American scientific and technical missions that were sent to Europe included two from the AAF – the Air Technical Intelligence Operation 'Lusty' (an acronym for *Luftwaffe* Secret Technology), and a civilian Army Air Forces Scientific Advisory Group. In addition, there was the US Naval Technical Mission in Europe, and the US Army's 'Special Mission V-2', which was tasked with seizing V-2 technology for removal to the US, and 'Project Hermes', which produced scientific and technical intelligence on German guided missile research and development. The British missions were dispatched by government ministries and departments, such as the MAP and the Air Ministry, and by research and experimental establishments, such as RAE Farnborough; and there was a special commando unit, the Royal Navy/Royal Marines 30 Assault Unit, which was set up to capture and remove enemy technology of technical intelligence value.

On the French side, besides the military intelligence branches of the armed services (*Deuxième Bureau,* Second Bureau), there were service-specific technical intelligence-gathering missions. For example, the *Ministère de l'Air,* the government department which was responsible for the French Air Force (*Armée de l'Air*), dispatched the *Service Central d'Information Technique* to track discoveries of German hardware behind the front lines; and the *Bureau Scientifique de l'Armée* (BSA) sent the *Mission d'Information Technique.* There were also technology-specific missions, for instance the *Groupe Opérationnel des Projectiles Autopropulsés* (GOPA), also within the BSA, which worked with French and Allied agencies to acquire information on German guided weapons in occupied Germany, principally concerning the A-4/V-2 ballistic missile.[18]

When the Western Allies invaded Germany in March 1945, American and British intelligence organisations had reliable intelligence on the Hs 293, PC 1400 X, Fi-103/V-1 and the A-4/V-2, and the organisations that designed these guided weapons, but practically nothing on German guided AAM development. Astonishingly, French intelligence had information about the *Ruhrstahl* X-4 from as early as September 1944, and likely earlier, at least six months before American and British intelligence organisations. A French intelligence report produced that month[19] related to plans by BMW to manufacture an anti-tank or an anti-aircraft weapon – which according to the report had not yet commenced – at a factory in Bitschwiller-lès-Thann in Alsace-Lorraine. Although the information was inaccurate, the report was of secondary interest, and contained summary data that was very incomplete despite an attached drawing, the author of the report was confident – and as it turned out rightly so – that the information concerned the propulsion system in the X-4. The references to BMW and the X-4 undoubtedly indicate prior French knowledge of the missile project, and inevitably leads to the conclusion that French intelligence – for reasons unknown – did not pass the report on to American or British agencies.

The Anglo-Americans did not discover hard evidence of German guided AAM development until after the facilities of the rocket engine manufacturer *Wilhelm Schmidding AG* in Cologne were captured on 5 or 6 March 1945. A British Air Intelligence, Technical (AI2(g)) report dated 29 March 1945[20] states that documents which were discovered at the firm contained information about rocket

engines that the company supplied for the HFW guided AAM projects, plus the BMW LPRE in the X-4. The same report mentions that since the *Luftwaffe* first used the Hs 293 operationally against Allied shipping in the Mediterranean in the late summer of 1943, German POWs had made unsubstantiated references about the development of an air-to-air variant of the missile.

Indeed, what is interesting about the AI2(g) report were unverified sightings by Allied flying personnel of guided AAMs fired by *Luftwaffe* planes against their bomber aircraft:

> Although it is not possible to draw a definite conclusion from the *Schmidding* documents as to whether any of the above missiles [Hs 293H, Hs 117H, Hs 298 and X-4] have yet been used operationally, reports from night bomber aircrews, over the past months, have frequently referred to supposed winged missiles which could well have been the Hs 298, X-4 or Hs 117. Some of these reports have noted especially the tendency of the missiles to follow the bomber during evasive action, strongly suggesting the use of remote control and/or homing devices. It seems reasonable to conclude therefore that these controlled missiles have to some extent been put into operation and that an increasing use will be made of them in the near future.[21]

It is certainly possible that a small number of experimental trials of the technology were carried out in 1944 or in January and February 1945. The most likely missile would have been the X-4, which had reached the threshold of series production by late December 1944/early January 1945.[22] If so, the *Luftwaffe* would have dared test only a limited number in order not to reveal the weapon's functionality to the Anglo-Americans, lest the RAF and the AAF bomb the industrial contractors. Alternatively, the objects could have been the so- called 'foo fighters', the atmospheric phenomenon witnessed by Allied pilots in the skies over Europe where strange balls of light seemed to shadow their aircraft.

By the third week of April 1945, enough information on the X-4 had come to hand to enable British and American intelligence officers to understand the basic dimensions of the missile and method of operation. An AI2(g) report dated 21 April 1945[23] stated that the *Ruhrstahl AG Presswerke* at Bielefeld 'were in some way connected with manufacture.' The culmination of the AI2(g) investigation into the X-4 was described in a report dated 3 May 1945,[24] in which is stated that technical intelligence officers, presumably both British and American, had located and investigated the *Ruhrstahl Presswerke* plant at Brackwede, near Bielefeld, and an associated firm, *Brinkmann & Co. Geha Fabrik* at nearby Hövelhof. Though no documents were recovered, several prototype X-4 missiles were found in good condition but missing certain components. At least one of the artefacts was unearthed in the grounds of *Ruhrstahl* after being buried. Of perhaps the greatest import to the investigation was the capture of Max Kramer. Kramer – who successfully rose through the German aeronautical engineering profession without joining any Nazi political organisations – was evacuated to England and interrogated by British officers from the Assistant Directorate of Intelligence, Prisoner Interrogation (ADI (K)) in the Air Ministry, and American officers from AAF Air Intelligence on 4 May 1945.[25]

In north-western Germany, a four-man British CIOS team also discovered evidence of the X-4 and other guided weapon projects at the *Seefliegerhorst Wesermünde*, a seaplane base where Peenemünde-West was evacuated to during March and April 1945 as the Red Army approached from the east. The investigators remarked in their report that almost all of the documentation at the site had been burnt. However, at least part of the establishment's archives had actually been buried near Wesermünde, and would not be unearthed until March 1947 during a joint Anglo-American intelligence operation called project 'Abstract'. In April, the first specimens of the R4M were recovered from a *Luftwaffe* ammunition store by a RAF bomb disposal unit in the Twenty-First Army Group area of operations in north-west Europe. British troops also captured the DWM facilities at Lübeck.[26]

In Bavaria, CIOS investigators reached the facilities of BMW *Flugmotorenbau GmbH* (BMW Aircraft Engine Construction) around Munich towards the end of April. The designer of the LPREs in the X-4 (109-548) and the Hs 117H (109-558), Hans Ziegler, was located at the firm's Bruckmühl plant, and was instructed by American and British investigators to build samples of each engine. By 30 May 1945, samples of both engines had been despatched to the UK for evaluation, plus ten 109-548 engines (plus one mock-up) which were sent to America by US Naval Technical Mission in Europe personnel.[27]

Another significant prize for the Anglo-Americans was the capture in Upper Bavaria in early May of Professor Dr.-Ing. Herbert Wagner, the chief designer of the HFW guided missiles, also by US Naval Technical Mission in Europe personnel. Wagner – an Austrian by birth who had been an engineering professor before the war, head of aircraft development at *Junkers,* and spent five years designing guided weapons at HFW – soon produced for the officers seven large cases containing blueprints and models. He was also interrogated by British and American intelligence officers in the UK, two weeks later on 18 May 1945.[28]

French intelligence organisations and scientific and technical missions were, like their American and British contemporaries, naturally very eager to gather information on German guided missile technology. Ironically, the French armed forces in Germany failed to capture any of the facilities that were connected to the X-4 project. However, the *Ministère de l'Air* did receive from AI2(g) the report on the examination of the X-4, and the ADI(K) report on the interrogation of Kramer in England (as did the *Deuxième Bureau*). French scientists and engineers also acquired intelligence through contacts in the MoS – during a visit to London in September 1945, GOPA personnel obtained a number of ADI(K) reports, very likely including those on the interrogations of Kramer and Wagner in the UK in May 1945.[29]

The *Marine Nationale* was arguably the most involved of the French armed services in acquiring technical intelligence on German air-launched guided weapons in occupied Germany. The service's *Deuxième Bureau* obtained intelligence on all the tactical guided weapons, and around the time of the Allies' transition to the four zones of occupation zones in July 1945, a ministerial decree

authorised the naval aviation branch of the *Marine Nationale*, the *Aéronautique Navale* (*Aéronavale*), to create a special organisation to exploit intelligence on German air-launched guided weapons of interest to French naval aviation. The operation, located at Hechingen in the *Zone Française d'Occupation* (ZFO), was called *Groupe d'Aéronautique Navale d'Engins Spéciaux* (Naval Aviation Guided Weapons Group, GANES). The commanding officer of GANES was *Lieutenant de vaisseau* Patrice Decaix, who had previously commanded the *6ème flottille d'exploration,* a French fleet of American Lockheed Ventura maritime patrol aircraft based at Agadir in the French protectorate of Morocco.[30]

Decaix headed an organisation which employed around 400 men in 1945, including Kramer (whom the British had returned to Germany) and some of his former staff. According to a British document, Kramer was in possession of plans and blueprints of his work when he agreed to work for the French. He was appointed technical director of GANES – effectively Decaix's deputy. GANES comprised four factories – in three, parts for guided weapons were assembled, and high frequency transmitters and receivers were produced in the other. There was also a building with administrative offices, and an airfield for test flights, presumably for French or ex-*Luftwaffe* aircraft fitted with guided weapons and remote control equipment.[31]

To summarise the results of the Western Allies' search for scientific and technical intelligence on German AAM research and development, there were more positive than negative outcomes. On the positive side, British and American investigators acquired missile artefacts, documentation, and captured Wagner and Kramer. From these two chief missile designers, intelligence about the development histories of each missile project, the current status of development, and projected thinking for future research and development was produced. French investigators probably recovered the archives of the *Ruhrstahl AG Presswerke* which eluded the Anglo-Americans, and the *Aéronavale* was temporarily in an advantageous position to exploit the knowledge of Kramer.

There was perhaps one negative outcome. Kramer's former place of employment, the *Deutsche Versuchsanstalt für Luftfahrt* (German Experimental Station for Aviation, DVL) at Adlershof in Berlin, where research and development work on HFW and *Ruhrstahl* guided weapons was carried out (aerodynamics research in the establishment's subsonic wind-tunnels was one important area), fell into the hands of the Soviet Union after Berlin was captured by the Red Army in early May 1945. The DVL archives were seized and removed to the Soviet Union and translated into Russian for exploitation. For all three Western Allies, to have not captured the DVL archives would have represented a setback, although copies of some scientific and technical reports were distributed to other scientists and engineers in Germany. It would have therefore been possible, to a certain extent, to reconstruct the records of the work at the DVL on the basis of copies of those reports, with the assistance of Wagner, Kramer, and their staffs. Overall, by March 1947 the three Western Allies were in a position to fully exploit the German wartime advances in AAM research and development.

The transfer and exploitation of German air-to-air rocket and guided missile technology by the United Kingdom after World War II

The scientific and technical intelligence on German air-to-air rocket and guided missile technology that was acquired by the Western Allies was exploited by their respective military-industrial complexes. The knowledge was contained in three main forms – captured artefacts, ranging from subassemblies and components to practically entire missiles and rockets; documentation including books, technical reports, scholarly articles in science and engineering journals, patents, and engineering drawings; and the German scientists, engineers and technicians who had various roles in research and development.

One method that was used by the Allies to derive information from these sources in the technology transfer process from Germany was the examination and evaluation, by technical experts, of artefacts that were captured in the field. In the damaged, disorganised and dispersed German armaments industry, initially there were limitations on how much technology could be easily recovered in the field and evacuated for inspection, and what investigators could learn about it. For example, the two X-4 specimens that were recovered at Brackwede by American and British technical intelligence officers were believed to be partly-assembled production models missing certain key components, namely the warhead, fuses and parts of the control system.[32] Fortunately, parts of the control system were found elsewhere.[33] It was information that was derived from the examination of the captured samples of the X-4 and extracted from Kramer that enabled AI2(g) officers to produce the report for distribution to American, British and French agencies dated 3 May 1945. British technical specialists also examined captured R4M air-to-air rockets, which is the first of four examples of how scientific and technical intelligence pertaining to German air-to-air rockets and guided missiles was exploited by the Western Allies after World War II.

Exploitation example number one: the British examination and evaluation of the R4M air-to-air rocket

In the field, AI2(g) officers had the opportunity to examine captured R4M rounds before they were transferred to the UK for more detailed examination and evaluation. In an AI2(g) report on one such examination during June 1945, the officers who conducted the examination recognised the rocket's importance, as the author of the report remarked:

> It represents one of the latest examples of enemy aircraft rocket design and deserves special attention since it was intended to be used on the newest jet fighters.[34]

The officers did not evaluate the rocket's performance or do an analysis of the warhead filling or propellant; these tasks were undertaken at MoS establishments in the UK.[35]

From July 1945, war material that was captured in the field by investigators from the British inter-departmental committee which inherited the functions of

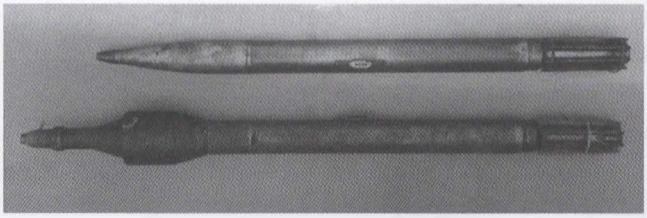


FIGURE 2 A photograph of the R4M air-to-air rocket with a high explosive warhead (above) and the *Panzerschreck* (anti-tank) variant (below) that were sent to the PDE for analysis. Source: TNA, AVIA 41/318.

CIOS in the British Zone of Occupation, the British Intelligence Objectives Subcommittee (BIOS) of the Joint Intelligence Subcommittee (JIC), first had to be sent to a specially-created MoS clearing house. This was the Halstead Exploiting Centre (HEC) at the MoS Armament Design Department establishment at Fort Halstead near Sevenoaks in Kent.[36]

Complete R4M rounds, associated documents, and samples of the propellants were forwarded from the HEC to the Projectile Development Establishment (PDE) at Aberporth in southern Wales for detailed examination (Figure 2). Before the rounds were examined, two types of propellant charges that were used in the R4M underwent quantitative chemical analysis at the PDE. The tentative results (over 99% accurate) found that the propellant 'Type A' was an extruded double-based propellant which consisted of cellulose nitrate (nitrocellulose) and diethylene glycol dinitrate (DGDN) as the two primary constituents – common in German solid propellants in guided missiles, assisted take-off units and artillery rocket applications – with various minor constituents. A 'Type B' consisted of slightly less nitrocellulose but around 18.6% trinitrotoluene (TNT) and 17% DGDN as the other primary constituents.[37]

What stands out in the subsequent PDE report on the examination of the captured rounds are the author's highly negative comments about the rocket's design. The author noted that the method of charge preparation and igniter designs were extremely crude because substitute materials were used. In the former case, strips of wood and brown paper, nails and adhesive tape were used to position the propellant charge in the tube; in the latter case, cotton wool was used to plug a hole through which an electric fuse passed into the gunpowder housing. In a critical discussion of the overall design, the author wrote:

> From all accepted standards of sound ammunition design, this weapon is appalling. Of twenty rounds broken down, the gunpowder from five of the igniters was loose in the tube. This and the method of charge preparation are sufficient to reveal the crudeness of the design.[38]

The substitute materials used by the manufacturers, and the shoddy construction, indicate that by 1945 there was a critical shortage of sealants and adhesives in the German war economy which were essential for solid propellant and powder rocket production. These shortages can almost certainly be attributed to the

damage that was inflicted upon German industry by Anglo-American bombing raids, which resulted in the destruction of factories, dispersion of manufacturing, and supply chain disruption.

A comparison of the ballistics of the R4M with current British rockets also showed that the German rocket did not have very much to offer. The author commented:

> From the results of a few static firings at charge temperatures of 35° to 55°F. [1.66° to 12.77° Celsius] it is apparent that the performance of this projectile is very similar to that of the British 2 in[ch]. rocket with tubular charge ... The major difference between the two rockets [in comparative estimates at 40°F. to 50°, 8° to 10° Celsius] ... is in the pressure level [lb/square inch], and was presumably necessitated by the slower rate of burning of the German propellant.[39]

At charge temperatures between 40° to 50° Fahrenheit the British 2-inch rocket, which was originally designed as a ground- or ship-based anti-aircraft weapon, and later used as an aircraft rocket, fitted with a high explosive (HE) warhead had a burning time of one second and a maximum velocity of 1,580 feet per second. By comparison, the R4M, also fitted with a HE warhead and fuelled with either propellant Type A or Type B, had a burning time of 0.9 seconds to one second, and a maximum velocity of 1,660 feet per second.[40]

Shoddy manufacturing and comparable ballistics aside, the destructive force of the R4M was effective. Tests to determine that aspect of the rocket's performance were carried out at the Orford Ness Research Station on the Suffolk coast. The targets used for the tests were sections of the fuselage and principal wings of the four-engine Handley Page Halifax heavy bomber and the twin-engine Vickers Warwick transport/reconnaissance aircraft.[41] The R4M's were fired from an American Bazooka tube or inserted into holes in the sections.[42] It was concluded from the tests that a single fair hit about the centre of any section of an aircraft of the Halifax type would generally be structurally lethal. A strike around half way between the leading edge and trailing edge of the principal wing of a Halifax type was considered to be aerodynamically lethal and very probably lethal by fire as well.[43] A single hit on the fuselage of an aircraft like the Warwick (of geodetic lattice construction) would generally not have been lethal structurally or aerodynamically, but a serious fire may have developed from the ignition of the fast-burning doped fabric that was stretched over the airframe (which had a tautening medium applied, usually a lacquer based on nitrocellulose).[44] These tests fully demonstrated the rocket's greater effectiveness than aircraft cannons, and confirmed its lethality as was shown in the skies over Germany in the final weeks of the war in Europe.

Examinations and evaluations of the HFW guided weapons would have also been carried out by AI2(g) and/or MoS personnel. At least one prototype Hs 298 was transferred to the UK, but where it was examined is not known to the author; the most likely locations were in London or RAE Farnborough. By 1947 the captured X-4 and Hs 298 prototypes, and other German guided weapons, were being kept in a hangar (which served as a museum) at the

RAE Rocket Propulsion Department at Westcott near Aylesbury in Buckinghamshire.[45]

There remains unanswered the very difficult question about precisely how much of the German scientific and technical knowledge was actually exploited by the British scientists and engineers who were working on air-to-air rocket and guided missile projects after the war. The masses of documentation that were recovered in Germany had to be translated, analysed and evaluated at the HEC, an undertaking that continued well into 1947. What also has to be taken into consideration was that the UK did not possess any supersonic wind-tunnels in 1945, and time was required to re-install German supersonic wind-tunnels in the UK, such as those at the *Luftfahrtforschungsanstalt Hermann Göring* (Hermann Göring Aeronautical Research Institute) near Völkenrode in the British zone. The storage of the missiles in a museum-like setting indicates that the exploitation of the German technology was essentially over by August 1947, but the work of German and Austrian specialists who were recruited through the post-war British government recruitment programme for the UK defence sector, the Deputy Chiefs of Staff (DCOS) scheme, continued into the 1950s and 1960s.

The transfer and exploitation of German air-to-air rocket and guided missile technology by France after World War II

The French approach to exploiting scientific and technical intelligence on German guided weapon technology was to reverse engineer components for testing and evaluation, and then improve the designs with French and German know-how. In France, the intelligence on AAMs was, for the most part, exploited for the profit of the *Armée de l'Air*. The exploitation was directed by the *Direction Technique et Industrielle de l'Aéronautique* (DTIA), a French government department[46] that was responsible for co-ordinating the development of new armaments for the *Armée de l'Air*. The technical service of the DTIA, the *Service Technique Aéronautique* (STAé), contracted French state- and privately-owned firms to manufacture the German missile components. At least one of the contractors, as will be shown later in this part, employed German specialists to assist in the work.

The exploitation of the German technology was executed on behalf of the *Armée de l'Air* General Staff guided weapon development programme, which was instituted on 1 July 1946 with specifications for all four categories of the new armaments: air-to-air, air-to-surface, surface-to-air, and surface-to-surface. The general specifications were set out by Carpentier in 2004; those for guided AAMs were as follows. Programme AA 10 called for an experimental, subsonic missile of the X-4 type, with a LPRE and control through wire-link. The objective of the programme was to analyse and assimilate the techniques of a guided AAM which rotated around its longitudinal axis (the X-4 was stabilised by a gyroscope and control surfaces). Programme AA 20 called for an operational missile faster than the AA 10, initially guided by remote-control and eventually

with a homing device, and designed to intercept aircraft as well as cruise missiles evolved from the German Fi-103/V-1.[47]

Exploitation example number two: the French reverse engineering of the Ruhrstahl X-4

The exploitation of German guided AAM technology in France was focused primarily on the X-4 design. There is no evidence to indicate that the *Armée de l'Air* or the DTIA had much interest in the HFW AAMs, although the department that co-ordinated the development of armaments for the *Marine Nationale,* the *Direction Centrale des Constructions et Armes Navales* (DCCAN), reverse engineered the Hs 293 (renamed *Palombe,* ringdove) and the X-1 (renamed *Pluvier,* plover) for the *Aéronavale.*[48]

Before the General Staff programme was established, in early 1946 a decision had been made in the DTIA to begin exploiting the X-4's BMW 109-548 LPRE. On 16 March 1946, the DTIA awarded a contract to the state-owned firm *Société Civile d'Étude de la Propulsion par Réaction* (SCEPR) to study the 109-548 and build 25 engines of the type.[49] SCEPR had previously been awarded contracts by the DTIA to examine and evaluate two other German LPREs, namely the *H. Walter KG* (HWK) 109-500A assisted take-off (ATO) unit and the 109-509 for the *Messerschmitt* Me 163 *Komet* rocket-powered interceptor. Under the conditions of the contract, the first five engines were built for systematic testing and evaluation by the firm, and the further 20 were to be delivered to the STAé along with the manufacturing tools and assemblies, a descriptive record and reports on the tests.[50] The 109-548 LPRE not only drew interest from French engineers because of its design and original purpose, but in a uniquely French innovation, because it could be adapted to an experimental SAM application. In this work, French engineers were assisted by at least three specialists from BMW: Dipl.-Ing. Helmuth von Zborowski, the former head of the firm's rocket engine development department, and two assistants, Dr.-Ing. Hans Schneider and Elmar Mucha.

In response to the requirements in the General Staff programme, the DTIA awarded prime contracts to two companies to design experimental AAMs according to the AA 10 specifications. One contract was awarded to *Arsenal de l'Aéronautique* at Châtillon in Paris, a state-owned company that was controlled by the DTIA; the other was awarded to a private firm, *Société Générale de Mécanique Aviation Traction* (MATRA). The *Service Historique de la Défense* (SHD) archives at Châtellerault in France[51] does not hold the prime contracts that the DTIA awarded to these firms, but a clue to the date was mentioned by Carpentier in 2004 – in the autumn of 1946, the STAé entrusted several captured German missiles to the recently-formed *Section des Engins Spéciaux*[52] at *Arsenal de l'Aéronautique* for the purpose of examination, which included at least one sample of the X-4.[53] The other missiles deposited with the firm were a Fi-103/V-1, possibly a *Ruhrstahl* X-7 anti-tank missile, a *Messerschmitt Enzian* SAM, parts of an A-4/V-2, and accompanying documentation.[54] *Arsenal de*

l'Aéronautique subsequently designated the missile that was based on the X-4 the Ars 5101, and in concert with numerous subcontractors and assisted by parts recovered from Germany, the firm successfully reverse engineered the design.

The MATRA missile, meanwhile, was designated the M.04. The engineers at the firm would design a missile that was more the product of French ideas than the Ars 5101, but aspects of the technology were nevertheless strongly influenced by German engineering. For example, the DTIA contracted the now-renamed *Société d'Étude de la Propulsion par Réaction* (SEPR, formerly SCEPR) to also manufacture the prototype propulsion system for the M.04, called the SEPR 12, which used the same propellant combination as the BMW 109-548, namely nitric acid as the oxidiser and *Tonka 250* (xylidine and triethylamine).[55]

Over the next 18 months until early 1948, the DTIA awarded at least six more contracts to French companies to reverse engineer or manufacture derivatives of the components in the X-4. These contracts were to *Société Sadir-Carpentier* on 21 October 1946 to study and produce an acoustic proximity fuse based on the *Kranich* proximity fuse that was designed by Max Kramer; to SEPR on 10 July 1947 to furnish an additional 200 LPREs derived from the 109-548 LPRE, which indicates the firm's successful execution of the first contract; another to *Société Sadir-Carpentier* on 8 October 1947 to furnish 10 *Siemens* relays (an electromagnetic device used for remote control); and to the same firm on 7 January 1948 to study and produce 210 remote control distributors (also used in the control system) in the X-4; and two contracts to the firm *Société Alkan & Compagnie* to supply control and guidance equipment (see below).[56]

The number of prototype airframes which *Arsenal de l'Aéronautique* had to build in fulfillment of the prime contract can be deduced from the information in the *Société Alkan & Compagnie* contracts – the total was 280. Concomitantly with the contract awarded to *Société Sadir-Carpentier* to produce and supply the 210 remote control distributors – 200 of which were for installation in the missiles – the DTIA contracted *Société Alkan & Compagnie* on 5 January 1948 to furnish 60 gyroscopes with housings (but not the gyroscope spinning wheels and motors, as these components were salvaged in Germany) and four spoilers and bobbins (for the control wire) per missile. The same firm was awarded another contract to build 20 more assemblies, in addition to three remote terminal (or remote telecontrol) units for installation in the parent aircraft (for the pilot to control the missile in-flight). Evidently, the 80 assemblies built by *Société Alkan & Compagnie* were for the X-4 wire-link version, whilst the 200 assemblies fabricated by *Société Sadir-Carpentier* were for a wireless version.[57]

The exploitation of the X-4 by *Arsenal de l'Aéronautique* concluded in 1950 after the firm terminated the experimental development of the Ars 5101 and abandoned the liquid propellant AAM design concept along with it. Carpentier mentioned in 2004 that the decision to terminate the project (unknown as to made by whom, either by the firm or the DTIA) was made after pilots of the parent aircraft experienced difficulties and a number of explosions, which rendered the liquid propellant missiles prohibitively dangerous. The outcome of the Ars 5101 project appears to be a case of *déjà vu* in a repetition of the circumstances experienced by the Germans on the X-4 project during the war. When Kramer

was being interrogated in the UK in 1945, he stated that although the X-4 was a success after the development trials, due to the inherent danger in the 109-548 LPRE the missile was not considered a practical proposition for operational use by the *Luftwaffe*, and thus a solid propulsion engine was considered. In 1951, the engineers at *Arsenal de l'Aéronautique* focused their efforts on the development of a supersonic solid propellant AAM in response to the AA 20 specifications, the Ars 5103, which was derived from an unrealised SAM design.[58]

The transfer and exploitation of German air-to-air rocket and guided missile technology by the United States after World War II

The transfer and exploitation of the German air-to-air rocket and guided missile technology for the benefit of the American armed forces was also multi-faceted. One key aspect was the exchange of intelligence with British government and military organisations. Captured documents that pertained to German guided weapon research and development were assessed and placed on accession lists (or bibliographies) for distribution to interested organisations for further analysis and exploitation. Captured technology was sent to military installations and universities for testing and evaluation. German and Austrian scientists and engineers were recruited – sometimes through co-operation with the British, sometimes not – and sent to military bases in the US to be 'put on ice' away from the Soviets, to further document their wartime work.

A collection of captured German guided missiles, documents pertaining to aeronautical subjects, and numerous German and Austrian specialists were sent to the AAF Air Technical Service Command (from March 1946 the Air Materiel Command, AMC) at Wright Field in Dayton, Ohio. The documents that were listed in the first *Bibliography on German Guided Missiles* which was issued by AMC Air Technical Intelligence in July 1946 reflected the many successes, but also some failures, of the Anglo-American intelligence-gathering effort in Germany as it related to AAMs. Listed were about a dozen documents from BMW which concerned the development of the 109-548 LPRE. These documents, plus numerous others from the firm, were cited several years later in a USAF analysis of German LPRE technology. There was only one document from *Ruhrstahl* concerning the X-4, which was a report about Kramer's *Kranich* proximity fuse, plus some unidentified blueprints of the X-4, which were probably also from *Ruhrstahl*. In addition, there were listed two documents about the *Wilhelm Schmidding* 109-513 LPRE for the Hs 293H (probably seized at Cologne in March 1945), a small number of documents appertaining to the *Rheinmetall-Borsig* R 100 BS air-to-air rocket, and one about the R4M. No documents were from the DVL in Berlin.[59]

The US Navy also acquired its fair share of German artefacts. One X-4 prototype was sent to the Applied Physics Laboratory at Johns Hopkins University in Baltimore, Maryland (which was under contract to the US Navy Bureau of Ordnance (BuOrd) to carry out research and development of SAM technology) for analysis; parts of the missile were also analysed at a number of other

laboratories around the country.[60] The US Navy Bureau of Aeronautics (BuAer) set up a project at the Naval Air Missiles Test Center at Point Mugu in California to test German LPREs that were brought back by the US Naval Technical Mission in Europe, primarily for familiarisation and educational purposes.[61] Progress in testing the German technology was slow however; by the end of June 1947 no German LPREs had been tested because a lack of staff delayed the work.[62] Eventually, three BMW nitric acid LPREs plus two HWK hydrogen peroxide LPREs were tested at the installation.

Concerning the recruitment and employment in the US of German and Austrian specialists with expertise from the research and development of air-to-air rockets and guided missiles, the War Department initially authorised the technical branches of the armed forces, which broadly speaking were responsible for research and development of new weapons, to hire a limited number on short-term contracts. Under the auspices of the US government recruitment programme, project 'Overcast', which was authorised by the War Department in July 1945, the number of German and Austrian specialists was limited to 350, but the number was subsequently increased through an expanded programme to include the American civil sector, project 'Paperclip', in March 1946. Largely through the efforts of an AAF technical intelligence officer, Colonel Donald Putt, the AAF/USAF secured the services of a number of Germany's top scientists and engineers in the field of aeronautics.

The US Navy BuAer and BuOrd also recruited German and Austrian guided missile and rocket specialists for employment at their research and experimental establishments, the former of which secured the services of Wagner and later also Kramer. After Wagner was interrogated in England in May 1945, he and two assistants from HFW, Dipl.-Ing. Reinhard Lahde and Wilfried Hell, were transported across the Atlantic to Washington DC on 19 May 1945 following a request from the Director of Naval Intelligence, Rear Admiral Leo H. Thebaud, to the War Department, before a policy on the employment of former enemy specialists in the US was created. The Japanese kamikaze attacks were causing a lot of damage to US Navy ships in the Pacific theatre, and the service was interested in the Hs 117 SAM, which had been scheduled to go into series production in March 1945. The HFW guided AAMs would not have offered much prospect in further development, however.[63]

A number of other German and Austrian specialists who were central figures in the early progress in guided AAM development were also recruited by the BuAer. They included Dr. Theodor Sturm, a physicist, formerly of *Stassfurter Rundfunk GmbH,* who directed and co-ordinated the development of radio remote control technology for guided weapon projects in German industry; and Dr. Edgar Kutzscher, the former director of infra-red research at *Electroacustic AG* (ELAC) in Kiel, whose work with lead sulphide cell technology for homing devices showed much promise.

In the next two sections of this part are two key examples of how German knowledge in the field of AAMs was exploited in the US after the war. The first example was the recruitment and employment of Max Kramer by the BuAer, and

the second how technology from the X-4 was incorporated into an American theoretical guided missile research project.

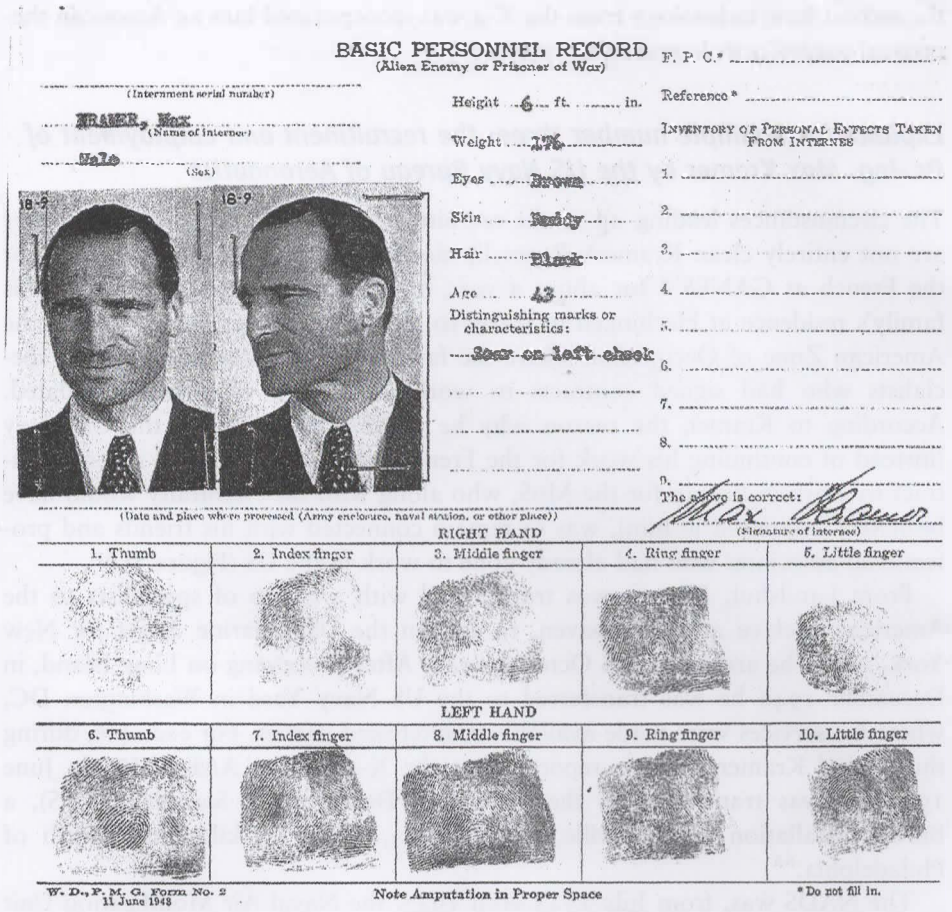
Exploitation example number three: the recruitment and employment of Dr.-Ing. Max Kramer by the US Navy Bureau of Aeronautics

The circumstances leading up to the recruitment of Max Kramer by the BuAer are not entirely clear. Kramer's Paperclip dossier records that after working for the French at GANES[64] for about a year, on 5 October 1946 he departed his family's residence at Hechingen to travel to the Landshut housing project in the American Zone of Occupation where the families of German and Austrian specialists who had signed contracts to work in the US were accommodated. According to Kramer, the reason why he decided to work for the US Navy (instead of continuing his work for the French, or signing a DCOS scheme contract to work in Britain for the MoS, who along with the Admiralty would have been very interested in him), was to remain connected with his friends and professional associates who had already gone to work in the US (Figure 3).[65]

From Landshut, Kramer was transported with a group of specialists to the American enclave at Bremerhaven, to sail on the USS Marine Angel for New York, where he arrived on 26 October 1946. After processing on Long Island, in December 1946 he was transferred to the US Navy Yard in Washington DC, where his services were made available to interested parties. For example, during this period Kramer wrote a report about the X-4 for the AAF AMC. In June 1947, he was transferred to the Naval Air Development Station (NADS), a BuAer installation in Johnsville, Pennsylvania, about 30 kilometres north of Philadelphia.[66]

The NADS was, from July 1944 until 1947, the Naval Air Modification Unit (NAMU), which was part of the BuAer. In the first fourteen months of the NAMU's existence until the end of World War II, the NAMU carried out modifications to production aircraft, in addition to work in the field of guided weapons. The guided weapon projects included the 'Glomb' and 'Pelican' precision-guided munitions, the 'Gargoyle' air-to-surface missile, and the 'Little Joe', a short-range SAM. The end of World War II saw the NAMU cease to do aircraft modification, and in the first eighteen or so months after the war, the activities at the NAMU were transitioned to research and development. During this period, German guided weapons were studied at the NAMU, including the A-4/V-2, the X-1, and the X-4. As the functions and purpose of the installation had changed, the BuAer renamed the NAMU the Naval Air Development Station (NADS) in 1947; on 1 August 1949 the establishment underwent another name change, to the Naval Air Development Center (NADC). The NADS/NADC became the centre of research and development for the BuAer.[67]

In March 1950, Kramer is recorded as being employed in the Aeronautical Electronics and Electrical Laboratory (AEEL) at the NADC, one of the three original laboratories at the NADS (a number of others were established between 1947 and 1950) along with the Aircraft Armament Laboratory and the Pilotless


BASIC PERSONNEL RECORD
(Alien Enemy or Prisoner of War)

F. P. C.* .....

(Internment serial number)

KRAMER, Max
(Name of interno)

Male
(Sex)

Height 6 ft. ... in.

Weight 176

Eyes Brown

Skin Ruddy

Hair Black

Age 43

Distinguishing marks or characteristics:
Scar on left cheek

Reference* .....

INVENTORY OF PERSONAL EFFECTS TAKEN FROM INTERNEE

1. .....
2. .....
3. .....
4. .....
5. .....
6. .....
7. .....
8. .....
9. .....

The above is correct:
Max Kramer
(Signature of internee)

(Date and place where processed (Army enclosure, naval station, or other place))

RIGHT HAND

1. Thumb	2. Index finger	3. Middle finger	4. Ring finger	5. Little finger

LEFT HAND

6. Thumb	7. Index finger	8. Middle finger	9. Ring finger	10. Little finger

W. D., P. M. G. Form No. 2
11 June 1948

Note Amputation in Proper Space

* Do not fill in.

FIGURE 3 US War Department Basic Personnel Record of Max Kramer, 1946. Source: Foreign Scientist Case Files, Max Kramer, Record Group 330; National Archives at College Park, College Park, MD.

Aircraft Design Laboratory. The wide scope of the AEEL's activities during the period which Kramer was employed there was reflected in the Laboratory's six divisions – undersea warfare, control and guidance, radar, electrical, radio, and technical services. Evidently, Kramer's employment at the NADS was connected with the exploitation of the X-1 and X-4 and possibly other German guided weapons for the BuAer. He continued his research on an acoustic homing device for an air-launched guided missile (the *Kranich* for the X-4 was one example) in a preliminary investigation of a supersonic acoustic homing device for the terminal guidance of small air-launched rockets fired from fighter aircraft. Kramer was also consulted on several American guided weapon projects. His work at the NADC concluded in June 1952, when he went to work in private industry for an American defence contractor. The following year Kramer acquired US citizenship, and remained in the US with his family.[68]

Exploitation example number four: the incorporation of technology from the Ruhrstahl X-4 into an American theoretical guided missile research project

In order to illustrate how the German AAM scientific and technical intelligence was exploited for the benefit of individual AAF guided missile projects, in the following pages is an example of where an American defence contractor examined the *Ruhrstahl* X-4 during a study of a theoretical guided missile system, and incorporated one of the German missile's components into the design. Beginning in 1946, engineers working on 'Project Wizard' (MX- 794) in the Department of Engineering Research at the University of Michigan carried out two theoretical studies for the AAF to determine the characteristics of a ground-to-air pilotless aircraft (essentially a long-range SAM for area defence) capable of intercepting enemy aircraft at altitudes up to 500,000 feet and ranges up to 880 kilometres. Curiously, in 1946 the engineers on the project became interested in the design of the combustion chamber in the 109-548 LPRE. In a December 1946 progress report for one of three preliminary design studies to fulfil the MX- 794 requirement, the researchers envisaged a three-stage missile with a solid propellant first stage, a ramjet second stage, and a liquid propellant rocket fitted onto the front of the ramjet for the third stage using the 109-548 combustion chamber. The researchers analysed the chamber, as noted in the report:

> The German X-4 guided missile has been returned to the Applied Physics Laboratory, Johns Hopkins University. Other laboratories have analysed all components of this missile with the exception of the burner [combustion chamber]. In an effort to determine the type of construction and principles of operation of the burner, several X-ray photographs were taken.[69]

The design of the combustion chamber in the 109-548 seemed to serve the purpose for the third stage and would, based on the specific impulse (thrust generated per unit volume of propellant) of the BMW *Tonka 250* rocket fuel (xylidine/triethylamine), burn at partial thrust for 120 seconds and full thrust for six seconds prior to impact. The 109-548 was, of course, not designed to burn for 126 seconds, and so the American engineers proposed the use of a thrust regulator for the first 120 seconds, a technique which the German engineers at BMW built into their rocket engines to maintain missile velocity. The example provided above is a classic post-war case of American rocket engineers innovating with World War II German rocket technology by applying the technology to a theoretical design which was well beyond the projected thinking in Germany by 1945. Although the three-stage design concept was later shelved, the MX-794 eventually became the nuclear-capable BOMARC (Boeing /Michigan Aeronautical Research Centre) area defence SAM system, the most formidable of its type to appear during the Cold War.[70]

Conclusion

The most important sources of scientific and technical intelligence about German AAM development during World War II for the Western Allies were the chief

designers of the missiles themselves, Herbert Wagner and Max Kramer. The recruitment of these and other German and Austrian specialists with scientific and/or engineering experience and expertise with the embryonic technology represented an intelligence windfall for the Western Allies at the expense of the Soviet Union. In the first ten years of the Cold War from 1945 to 1955, the specialists who went to work in the United States, United Kingdom and France, and the products of German wartime scientific and technical advances with AAMs – primarily in the designs of the R4M and X-4 – assisted the defence industries in each country to evolve the technology from aircraft cannons to solid propellant rockets, and to guided missiles. The German technology underwent further experimental development and evolution in the three countries, and so by the mid- to late 1950s the weapons became standard armaments on the jet fighter and bomber aircraft that were entering service in the three countries' armed forces.

On a final note, the US Navy was the first armed service of the Western Allies to introduce both an air-to-air rocket and a guided air-to-air missile into service, namely the 2.75-inch Folding Fin Aircraft Rocket (FFAR, nicknamed the 'Mighty Mouse') in 1952, and the supersonic Sperry 'Sparrow I' in 1956, respectively. The first British guided AAM to enter service was the Fairey Aviation 'Fireflash', with the RAF in 1957, while the first French guided AAM, the 'Nord 5103', was definitively accepted by the *Armée de l'Air* in mid-1958.[71] Both of these armaments were also necessarily supersonic. When the US Department of Defense publicly announced the successful development of the FFAR in February 1950, the new weapon, fin-stabilised with greater range and speed than World War II aircraft rockets, was described by the department as the 'first successful air-to-air rocket.'[72] It seems the department overlooked the fact that the first successful air-to-air rocket was actually the German R4M – also with folding-fins and claimed to have influenced the design of the FFAR – which was introduced into service by the *Luftwaffe* in the last weeks of World War II in Europe.[73]

Acknowledgements

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Notes

[1] The wide scope of this article required an archival synthesis of a broad range of primary sources that are held by American, British and French repositories. These sources include American, British and French intelligence reports on German guided missile research and development during World War II; British technical reports on the examination and evaluation of captured German artefacts; bureaucratic correspondence and minutes from meetings by personnel in British government departments; contracts that were awarded by the French government to industrial firms to study and reverse engineer the technology in the X-4; progress reports by American defence contractors who were engaged on guided missile research projects after World War II; and the US War Department foreign scientist

personnel dossier of Kramer (who was recruited by the US Navy after the war), which was declassified by the National Archives and Records Administration upon my request in 2018. Data on Kramer was also acquired from a technical report that is held by the Defense Technical Information Center online repository. The report was produced in 1980 by a US Navy contractor for the Office of Naval Research, and summarises the results of 19 years of experimental research that Kramer did on a topic in the field of hydrodynamics called 'compliant coatings', from 1957 to 1975. See the bibliography.

2. The publications of note are: *La Chasse aux Savants Allemands (1944–1960)* by Bar-Zohar in 1965, published in English as *The Hunt for German Scientists 1944–1960* in 1967; *Project Paperclip: German Scientists and the Cold War* by Lasby in 1971; 'Un aspect de la chasse aux cerveaux: les transferts de techniciens allemands en France: 1945–1949' by Ludmann-Obier in 1986; *The Paperclip Conspiracy* by Bower in 1987; *Science, Technology and Reparations: Exploitation and Plunder in Postwar Germany* by Gimbel in 1990; *Secret Agenda: The United States Government, Nazi Scientists, and Project Paperclip, 1945 to 1990* by Hunt in 1991; *Operation Paperclip: The Secret Intelligence Program that Brought Nazi Scientists to America* by Jacobsen in 2014; *Our Germans: Project Paperclip and the National Security State* by Crim in 2018; and *British Exploitation of German Science and Technology, 1943–1949* by Hall in 2019.

3. See *Peenemünde to Canaveral* by Huzel in 1962; *Crossbow and Overcast* by McGovern in 1964; *The Rocket Team* by Ordway and Sharpe in 1979; "Operation 'Surgeon' and Britain's Post-War Exploitation of Nazi German Aeronautics' by Uttley in 2002; and *Du V2 à Véronique. La naissance des fusées françaises* by Huwart in 2005.

4. For example, see a series of five articles by Burgess that were published in Volume 184 of the British journal *The Engineer* in October 1947; *Development of the Guided Missile* by Gatland, first published in 1952; *History of German Guided Missiles Development* by Quick and Benecke, eds., in 1957; *German Guided Missiles of the Second World War* by Pocock in 1967; and *German Secret Weapons of World War II: The Missiles, Rockets, Weapons, and New Technology of the Third Reich* by Hogg, originally published in 2002.

5. TNA, AIR 40/1310, 'Section IV – Part 4 – Controlled Missiles', MAP, 7.8.1945; Davis, 'Historical Development Summary of Automatic Cannon Caliber Ammunition: 20–30 Millimeter', Air Force Armament Laboratory, 1984, p. 15.

6. TNA, DSIR 23/15145, CIOS report XXXII-125, 'German Guided Missile Research', 1945, p. 52.

7. Gatland, *Development of the Guided Missile*, pp. 122–123.

8. TNA, AIR 40/2874, 'Development of Rotation-Stabilised Rockets in Aircraft', ADI (K) Report No. 288/1945, 20.4.1945.

9. TNA, AIR 40/2162, 'New German fighter rocket armament and "Oberon" automatic range-finding and firing procedure', AI2(g) Report No. 1774, 28.4.1945.

10. 'La Fusée Aérienne Allemande de 80mm', *France d'abord – SHD, Châtellerault, AA 396 4H2 5*. The date of the article is unknown, although it could have been published as late as the early 1950s.

11. TNA, AVIA 40/2168, 'Employment of Rocket Projectiles for Air-to-Air Attack by the GAF', AI2(g) Report No. 3003, 17.7.1943; Zaloga, *Operation Pointblank: Defeating the Luftwaffe*, p. 16.

12. Zaloga, op cit, p. 39.

13. Simon and US Army Ordnance Department, *German Scientific Establishments*, p. 61; Gatland, op cit, p. 27; Boog, Krebs, and Vogel, *Germany and the Second World War, Volume VII: The Strategic Air War in Europe and the War in the West and East Asia 1943–1944/5*, pp. 319–320.

14. TNA, DSIR 23/17581, F. Bisby, 'The Development of British Airborne Rockets', RAE Report No. Arm. 208, March 1946, pp. 7 and 15–16.

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18. Carpentier, *Les Missiles Tactiques de 1945 à 1995*, p. 19; Huwart, *Du V2 à Véronique. La naissance des fusées françaises*, pp. 56–59.

19. Centre d'Étude des Projectiles autopropulsés, 'Note Mensuelle d'Information à l'Usage des Sections du C.E.P.A.', 1.2.1946 – *SHD, Châtellerault, AA 396 4H2 227*. On page 18 there is a summary of the report under the heading '*Usine B.M.W. de Bitschwiller et Projectiles à Reaction*' (Bitschwiller BMW Factory and Rocket Projectiles).

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29. 'Projectiles Commandes à Distance (RUHRSTAHL – AG – BIELEFELD)' – *SHD, Châtellerault, AA 396 4H2 227*; 'Projectiles Commandes à Distance' – *SHD, Châtellerault, AA 396 4H2 55*; Huwart, p. 62.

30. Marine Nationale, État-Major Générale, 2ème Bureau, Liaison Recherches, 'État des notes de renseignements remises par E.M.G./2 L.R. du 24 Octobre 1944 au 10 Janvier 1946, Janvier 1946 – *SHD, Châtellerault, AA 396 4H2 206*; Desgouttes, *Les Commandements de l'Aéronautique Navale (1912–2013)*.

31. War Department Intelligence Division. Basic Personnel Record, Max Otto KRAMER. Foreign Scientist Case Files, RG 330; TNA, DEFE 43/9, FO and MoD: STIB and related bodies: Record Cards of German and other Scientists and Technicians, 1946–1964, KI.O-KY, 'KRAMER, Dr. Max Otto'. The French practice of appointing a German technical director under a French official was instituted at other technical intelligence-gathering enterprises in the ZFO. For example, in April 1946, Dr. Hermann Oestrich, the former head of jet engine development at BMW, was appointed technical director of a group of Germans ('*Groupe O*') under a French *Directeur General* to study German jet engines at the *Aéronautique de Rickenbach*. Contract between the DTIA and Hermann Oestrich (*Groupe 'O'*), 25.4.1946 – *SHD, Châtellerault, AA 254 1K1 607*.

32. TNA, AIR 40/2162, 'The X4 – German Air-launched A.A. Rocket', AI2(g) Report No. 1773, 3.5.1945.

33. Ibid.

34. TNA, AIR 40/2162, 'R4M German Aircraft Rocket', AI2(g) Report No. 1787, 23.6.1945.

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43. Ibid.

44. Ibid.

45. 'Rocketry at Westcott. A Visit to the Ministry of Supply Rocket-propulsion Establishment', *Flight*, 21.8.1947, 190 and 205; Burgess, 'German Guided and Rocket Missiles' No. II, *The Engineer*, 10.10.1947, 332–333, and No. III, 17.10.1947, 356–358.

46. During the turbulent early period of the Fourth Republic in the 1940s, the DTIA was successively within the *Ministère de l'Air* (1944–1946), *Ministère de l'Armement* (1946–1947), *Ministère de l'Air* (1947–1948), and the *Ministère des Forces Armées Secrétariat d'État aux Forces Armées (Air)* (1948-).

47. Carpentier, op cit, pp. 19–22 and 36.

48. Ibid, p. 32.

49. SCEPR, 'Étude du propulseur Allemand BMW 548 et la fabrication de 25 réacteurs de ce type', marché no. 5067/46, 16.3.1946 – *SHD, Châtellerault, AA 711 1K1 741.*

50. Ibid.

51. Inventory 711 1K1, 'Marchés passes par la Direction des Constructions Aéronautiques', 1945–1963.

52. *Engins spéciaux* was a generic French term used at the time to describe all guided weapons.

53. Carpentier and Huwart disagree on the number of X-4 missiles that were deposited with *L'Arsenal*. Carpentier claims there were several, whilst Huwart claims one. The lists of these missiles are found in Carpentier, p. 35, and Huwart, p. 86.

54. Huwart, p. 86. It is recorded in a contract that the STAé awarded to the firm *Société Anonyme d'Enterprises Aéronautiques* in October 1946 to reconstruct the X-7 that the reconstruction was to be based on the memories of two French engineers who had been deported to Germany and had information about the projectile. The two may have been from a group of three French engineers who made a statement about the X-7 to French military intelligence in December 1944. If the STAé did acquire a prototype of the X-7, that artefact would have served the purpose of exploitation. See 'Note Mensuelle d'Information à l'Usage des Sections du C.E.P.A.', 1.2.1946 – SHD, Châtellerault, AA 396 4H2 227; and Société d'Entreprises Aéronautiques, 'Reconstitution de l'engin Allemand X 7', marché no. 5209/46, 29.10.1946 – *SHD, Châtellerault, AA 711 1K1 745.*

55. SEPR, 'Fourniture de 100 moteurs fusées prototype SEPR 4 de décollage d'engins spéciaux, 20 moteurs fusées prototype SEPR 2 pour engins spéciaux NC 3500 & 3501, 20 moteurs fusées prototype SEPR 12 pour engins spéciaux M 04', marché no. 2257/48, 14.12.1948 – *SHD, Châtellerault, AA 711 1K1 765.*

56. Société Sadir-Carpentier, 'Étude et realisation d'une fusée acoustique de proximité analogue en matériel Allemand KRANICH', marché no. 5164/46, 21.10.1946 – *SHD, Châtellerault, AA 711 1K1 744;* SEPR, 'Fourniture de 200 fusées type BMW 548 et dérivés', marché no. 3129/47, 10.7.1947 – *SHD, Châtellerault, AA 711 1K1 751*; Société Sadir-Carpentier, 'Fourniture de 10 relais SIEMENS pour engins spéciaux', marché no. 3253/47, 8.10.1947 – *SHD, Châtellerault, AA 711 1K1 755*; Société Sadir-Carpentier, 'Étude et realisation de 210 distributeurs de commande pour engins X.4., marché no. 3305/47, 7.1.1948 – *SHD, Châtellerault, AA 711 1K1 756.*

57. Société Alkan & Cie, Fourniture de 60 ensembles d'équipement pour engins AA10, marché 3252/47, 5.1.1948 – *SHD, Châtellerault, AA 711 1K1 755*; Société Alkan & Cie, Réalisation et fourniture de 20 ensembles d'equipement d'engin AA 10 et 3 postes de télécommande sur avion, marché no. 3087/47 – *SHD, Châtellerault, AA 711 1K1 750.*

58. TNA, AIR 40/2162, 'The X4 – German Air-launched A.A. Rocket', AI2(g) Report No. 1773, 3.5.1945; Carpentier, p. 36.

59. *Bibliography on German Guided Missiles,* Headquarters USAAF Air Materiel Command, Dayton, Ohio, July 1946; American Power Jet Company, 'Analysis and Evaluation of German Attainments and Research in the Liquid Rocket Engine Field', Central Air Documents Office (Army-Navy-Air Force), Dayton, Ohio, Volume IV, 'Propellant Injectors', and Volume VII, 'Thrust Control', February 1952.

60. Conlon, 'Project "Wizard" Progress Report No. 4 (October 1–December 1, 1946)', University of Michigan, Department of Engineering Research, December 1946.

61. House, 'Project Squid. Liquid Propellant Rockets. Field Survey Report Volume II, Part 2', Princeton University, 30.6.1947'.

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63. Lasby, *Project Paperclip: German Scientists and the Cold War*, pp. 4 and 66–67.

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65. Signal from Major E.C. Davies, Assistant Adjutant General, to Kramer, 8.10.1946; JIOA, 'Biographical and Professional Data. Exploitation of German and Austrian Scientists', Max Kramer, 17.2.1948; in Foreign Scientist Case Files, Max Kramer, Record Group 330, National Archives at College Park, College Park, MD.

66. US Department of Justice, Immigration and Naturalisation Service, General Information Form, Foreign Scientist Case Files, Max Kramer, Record Group 330, National Archives at College Park, College Park, MD. The report that Kramer wrote for the AAF was: F.E. Patton, 'The German Guided Missile X-4', Project No. NTE-63 – Max Kramer, Summary Report No. F-SU-2131-ND, Headquarters AMC, Wright Field, Dayton, Ohio, June 1947. Abstract: 'Summarises available data on German guided missile X-4 with details of control, radio, airframe, propulsion, production, laboratory calculations and experiments. It was considered Germany's most effective air-to-air controlled missile, especially against bomber formations. History of Dr.-Ing. Max Kramer, chief designer, is recorded as well as other personnel connected with the X-4 project. Report covers specifications, performance data, warhead and fuse and launching devices in considerable detail. Profusely illustrated and with adequate bibliography, report is of value in guided missile research'. Johnson, 'Review of Compliant Coating Research of M.O. Kramer', RPJ Associates, 17.10.1980.

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