Department of the Environment
Industry Profile

Engineering works

aircraft manufacturing works

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The Department's Contaminated Land Research Report series deals with information needed to assess risks; procedures for categorising and assessing risks; and evaluation and selection of remedial measures.

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DOE Industry Profile

Engineering works: aircraft manufacturing works

This profile is based on work by W S Atkins Environment and was prepared for publication by the Building Research Establishment.

Preface

DOE Industry Profiles provide developers, local authorities and anyone else interested in contaminated land, with information on the processes, materials and wastes associated with individual industries. They are not definitive studies but they introduce some of the technical considerations that need to be borne in mind at the start of an investigation for possible contamination.

Every site is unique. Investigation of a site should begin with documentary research to establish past uses. Information on the site's history helps to focus a more detailed investigation. This knowledge needs to be supplemented by information on the type of contamination that may be present and where on site it may be found. Profiles give information on the contamination which might be associated with specific industries, factors that affect the likely presence of contamination, the effect of mobility of contaminants and guidance on potential contaminants.

The date when industrial practices first commenced on a site and its location are important clues in establishing the types of operations that may have taken place, so each profile provides a summary of the history of the industry and its likely geographical spread within the United Kingdom.

Profiles should be read with the following reservations in mind:

individual sites will not necessarily have all of the characteristics described in the profile of that industry;

practices can vary between sites and change over time;

as practices change, problems of possible contamination may also change;

the profile may refer to practices which are no longer followed, and may omit current practices which avoid contamination.

The risks presented by contaminated sites depend on the nature of the contaminants, the targets to which they are a potential threat (such as humans or groundwater) and the routes or pathways by which they reach these targets. The current or proposed use of a site and its environmental setting are crucial in deciding whether treatment is necessary and if so, the methods to be used. Some sites may not need treatment.

The information in profiles may help in carrying out Control of Substances Hazardous to Health (COSHH) assessments for work on contaminated land - see Health and Safety Guidance Note HS(G) 66 *Protection of workers and the general public during the development of contaminated land,* Health and Safety Executive, 1991, and *A guide to safe working practices for contaminated sites,* Construction Industry Research and Information Association, 1995.

Note: the chemical names given to substances in this profile are often not the modern chemical nomenclature, but the names used historically for those substances.

Engineering works: aircraft manufacturing works

1. Background

This profile covers the manufacture of the airframe and mechanical systems, and aircraft assembly. Engine design and manufacture have traditionally been carried out by specialist companies who supply complete units to an assembly line and these activities are not included in this profile. Information relevant to aircraft engine manufacture can be found in the Industry Profile covering mechanical engineering works (see Section 4). Other specialist services carried out away from the assembly site are also excluded from this profile.

1.1 History and location

In the United Kingdom, early experiments with balloon and airship manufacture were carried out by the War Office at various sites, notably at Farnborough, but also at Woolwich Arsenal, Chatham and Aldershot. The Farnborough site was used for aeroplane manufacturing for a short time but later became a research and development facility and was renamed the Royal Aircraft Establishment (RAE).

The British aircraft industry began in about 1909, when a biplane was built by Shorts Brothers. Other companies were founded soon afterwards and some, like Shorts Brothers, subsequently evolved into large-scale enterprises. Early aircraft were wood-based biplanes with struts or wires between the wings.

Economic and technical development was greatly accelerated by the First World War. The Society for British Aircraft Companies (SBAC) was founded in 1916 with 48 members; by 1918, membership had risen to 80 and the annual rate of aircraft production had reached some 10 000 units. A number of airships were also manufactured for military purposes. During the First World War most of them were constructed at the Naval Airship Station at Kingsnorth, but certain designs were contracted out to private companies, for example Vickers and Shorts.

Whilst most aeroplanes were manufactured by private companies, three National Aircraft Factories were established in 1918, at Croydon, Liverpool and Manchester. After the First World War, a number of companies switched to the manufacture of civil aeroplanes but by the early 1920s SBAC membership had fallen to 18, as a result of the post-war reduction in demand.

Between the two World Wars, companies tended to specialise in certain types of military aircraft, for example Gloster, Hawker and Bristol concentrated on fighters, while Blackburn, Shorts and Supermarine manufactured flying boats and Fairey produced light bombers. A number of mergers occurred during this period, most notably Hawker acquired Armstrong Siddeley, AV Roe and Gloster to form the Hawker Siddeley Group. In 1935, there were 27 companies producing both civil and military aircraft and a number of companies producing aero-engines. The main airframe companies are listed in Table 1.

Table 1 Main United Kingdom airframe manufacturers in 1935

Area	Company	Location
South	Hawker Aircraft Fairey Aviation de Havilland Handley Page Vickers Aircraft Shorts Brothers	Kingston-upon-Thames, Surrey Hayes, Middlesex Hatfield, Hertfordshire Cricklewood, London Weybridge, Surrey Rochester, Kent
South West	Supermarine Aviation Westland Aircraft Bristol Aeroplane Company Gloster Aircraft	Southampton Yeovil, Somerset Bristol, Avon Hucclecote, Gloucestershire
Midlands and North	Armstrong Whitworth Aircraft AV Roe and Company Blackburn Aeroplane and Motor Company	Coventry, Warwickshire Manchester Brough, Yorkshire
East	Boulton & Paul Aircraft	Norwich, Norfolk

The twenty years from 1919 to 1939 saw an increase in the reliability of aero engines, a change in design from the biplane to the monoplane and the gradual replacement of fabric-covered wood or tubular steel structures by all-metal construction. The production of rigid airships ceased in 1937 following a series of disasters. The most notable of these were the British *R101* in 1930, which had been built at the Airship Works, Cardington, Bedford, and the German *Hindenburg* in 1937.

Rearmament prior to the Second World War caused a rapid expansion in the military aircraft manufacturing industry. The Air Ministry introduced the 'shadow factory' scheme, contracting out airframe and engine production to other suitable manufacturing companies, particularly the motor industry, to enable their requirements to be met. In 1938 there were 4.9 million square feet of floor space available for aircraft and engine production; by October 1941 it had risen to 22.15 million square feet. The wartime production of aircraft was directed by the government but all manufacturing was carried out by the private sector.

During the Second World War, the size and power of combat aircraft grew markedly, for example the speed of conventionally powered fighters such as the *Spitfire* rose by over 100 mph. The improvements in engine design were accompanied by developments in materials and the design of aircraft. The advent of airborne radar, navigation aids and electronics-based equipment increased the complexity of aircraft. This resulted in the growth of specialist companies to produce large sub-systems which had previously been built by the main contractor. Jet engines were developed and produced towards the end of the war. By its end, over 126 000 aircraft had been delivered and there were 27 airframe manufacturers and eight aero-engine companies in the United Kingdom.

In the early post-war period, piston-engined commercial aircraft were manufactured on a substantial scale. From 1948 onwards, manufacturers concentrated on gas-turbine powered civil aircraft. In 1952, the *Comet* became the first commercial jet aircraft to enter passenger service.

After the Second World War there were a number of mergers and closures of companies. In the mid 1950s, there were 31 members of the SBAC (Table 2), although six firms (Vickers, English Electric, Hawker Siddeley, Rolls Royce, Bristol and de Havilland) accounted for 80% of the resources and production capacity.

Table 2 Main United Kingdom airframe manufacturers in 1958

Area	Company	Location
South	Hawker Aircraft	Kingston-upon-Thames, Surrey
	Fairey Aviation	Hayes, Middlesex Southampton, Hamshire White Waltham, Berkshire
	de Havilland	Hatfield, Hertfordshire Portsmouth, Hampshire Christchurch, Hampshire
	Handley Page	Cricklewood, London Reading, Berkshire
	Vickers-Armstrong Aircraft	Weybridge, Surrey Winchester, Hampshire
	Elliotts of Newbury	Newbury, Berkshire
	Folland Aircraft	Hamble, Hampshire
	Saunders-Roe	Cowes, Isle of Wight Eastleigh, Hampshire
	Hunting aircraft	Luton, Bedfordshire
South West	Westland Aircraft	Yeovil, Somerset
	Bristol Aeroplane Company	Bristol, Avon
	Gloster Aircraft	Hucclecote, Gloucestershire
Midlands and North	Sir W C Armstrong Whitworth Aircraft	Coventry, Warwickshire
	AV Roe and Company	Manchester
	Blackburn and General Aircraft	Brough, Yorkshire
	Boulton and Paul Aircraft	Wolverhampton, West Midlands
	Auster Aircraft	Rearsby, Leicester
	de Havilland Aircraft	Chester, Cheshire
	English Electric	Preston, Lancashire
	Fairey Aviation	Stockport, Cheshire
	Hawker Aircraft	Blackpool, Lancashire
	Slingsby Sailplanes	Kirbymoorshire, Yorkshire
Northern Ireland	Shorts Brothers and Harland	Belfast
Scotland	Scottish Aviation	Prestwick, Ayrshire

In 1960, a government-induced process of industrial rationalisation occurred. The industry was reorganised into two main airframe groups. These were Hawker Siddeley Aviation (HSA) based in Kingston-upon-Thames, Surrey and British Aircraft Corporation (BAC) based in Weybridge, Surrey. A few companies remained outside of these large groupings, ie Scottish Aviation in Prestwick, Shorts in Belfast and Westland Aircraft in Yeovil, the latter manufacturing helicopters. At this time European co-operation on aviation projects became increasingly common. For example, in 1962 a joint programme was agreed between France and the United Kingdom to design and manufacture *Concorde*, a long range supersonic civil aircraft. During the 1960s, the ratio of production of military to civil aircraft was three to one.

The government nationalised BAC and HSA to form British Aerospace (BAe) in the late 1970s; it was subsequently re-privatised between 1981 and 1985. The re-organisation of the industry and the formation of BAe saw the closure of a number of sites, particularly those involved in civil aircraft manufacturing. In 1986, the Military Aircraft Division of BAe operated at Weybridge, Kingston, Brough, Hamble, Warton, Preston and Salmlesbury. The Civil Aircraft Division operated at Hatfield (now closed), Chester, Filton, Chadderton, Woodford and Prestwick.

2. Production processes

2.1 Raw materials

2.1.1 Wood and fabric

The first generation of aircraft were made from a wooden and bamboo framework held together with piano wire or steel cables and covered with cotton or linen. Spruce and birch were the most commonly used timbers, although balsa, fir and ash were also used. Certain species were favoured for aircraft manufacture because of their high strength to weight ratio. The fabric used for the skins was made taut and airtight by a doping procedure. Cotton and flax were used as reinforcing tape, rib lacing cord and sewing thread. Plywood was subsequently used for the aeroplane skins in stress-skinned designs (ie designs where the structural load is carried by the skin rather than a rigid internal frame). Although metal-based aircraft were increasingly produced during the Second World War, 17% of the United Kingdom aircraft output in 1945 was still of a mainly wooden design. The continued use of wood in construction was largely due to rapid improvements from 1935 onwards in the adhesives used in bonding the veneers in plywood and for making joints in structures.

Balloons were originally constructed from goldbeater's skin, which consisted of a number of the large intestines of oxen attached together. Airships were constructed from a light metal framework covered with fabric.

2.1.2 Dope

This was a film-base made originally from cellulose, nitric acid and sulphuric acid, with added plasticisers, such as castor oil, tricresyl phosphate or vinyl resins. A thinner was added which evaporated to leave an airtight film on the surface of the fabric to which it was applied. Cellulose nitrate was the most commonly used doping mixture. It is highly flammable and closely related to guncotton, an explosive used to manufacture smokeless gunpowder. During the Second World

War, cellulose acetate butyrate dopes replaced the nitrate dopes. These were made from cellulose, acetic anhydride, butyric anhydride and sulphuric acid.

2.1.3 Aluminium

With the introduction of aluminium alloys and high tensile steels in the 1930s, precision rig-assembled all-metal aircraft became possible. Aluminium alloy is the raw material used for making fuselage and wing panels. The alloys used are over 90% aluminium, with varying levels of other metals such as copper, zinc and magnesium which improve certain mechanical properties. *Duralumin* was one of the first aluminium alloys to be used in the manufacture of aircraft (and also for later designs of airships).

2.1.4 Other metals and alloys

High tensile steels were used to manufacture aircraft skins during the 1920s and 1930s but were soon replaced by aluminium alloys. Fasteners and fittings are still made from steel, but are generally manufactured by specialist contractors. Magnesium panels were used on some early aircraft, but were discontinued because of corrosion problems. Nickel and titanium alloys also have widespread applications in aircraft engines and for structures where temperature or material compatibility requirements preclude the use of aluminium. Copper, brass and other specialist alloys are used in mechanical and hydraulic systems.

2.1.5 Reinforced plastics

Higher aircraft performance requirements and the availability of new materials have resulted in the extensive use of plastics and reinforced plastics (composites) since the 1970s.

The plastics used are usually quite inert, insoluble materials and include acrylics, polyesters, phenolics and epoxy resins. Various components are used in the manufacture of the reinforced plastics: the base resin, the fibre and sizing agent, fillers, accelerators and curing agents, as appropriate for the system being used.

Fibreglass has been used for the reinforcement of plastics since the 1950s. More recently, carbon and aromatic polyamide fibres and carbon reinforced material such as *Kevlar* have replaced fibreglass because of their increased tensile strength per unit weight.

2.1.6 Non-structural materials

A variety of other raw materials are used in the manufacture of aircraft. These are briefly outlined below and discussed in more detail in subsequent sections of this profile:

- primer, lacquer and enamel paints
- natural and synthetic rubbers in, for example, lining materials, hoses, gaskets, and sealants
- natural and synthetic oils in engines, hydraulic systems and machine tools
- solvents in cleaning operations, paints, adhesives and sealants
- acids and alkalis in cleaning and treatment techniques
- asbestos in insulating materials, gaskets and inert fillers
- petroleum-based hydrocarbon derivatives used as fuels.

2.2 Manufacturing process

2.2.1 Material cutting and forming

Wooden components were produced by conventional joinery techniques.

Metal components are usually produced from sheet, tube or bar materials by cutting, machining or forming (the latter by pressing or panel beating); cast components may also be machined. Specialist materials, such as asbestos or composites, are either machined on site or purchased from subcontractors.

Chemical milling has been used since the 1960s. This is a sculpturing process in which metal parts are dipped or sprayed with etchant solution and the portions not to be machined are protected with resistant materials. The etchants used include sodium hydroxide and polysulphides for aluminium alloys, and hydrofluoric and nitric acid for titanium alloys.

Electrochemical machining, a technique which has been introduced relatively recently, utilises preferential removal of material by anodic dissolution. The electrolytes used are mainly aqueous solutions of inorganic compounds. For example, to machine steel or nickel alloys, a 25% solution of sodium chloride in sulphuric or hydrochloric acid is used as the electrolyte. Salts or hydroxides of the workpiece metal are removed by chemical precipitation.

Heat treatment and annealing processes are carried out on steel and aluminium alloys, either to alter the physical properties of the metal (ie modify the strength, ductility, toughness and hardness) or to soften the alloy as a prelude to cold-forming operations. Annealing and heat treatment can be carried out in an electrically or gas-heated furnace, but in the aircraft industry it is more commonly carried out in a heated salt bath.

Aluminium articles are immersed in a heated bath of sodium and potassium nitrate salts. For heat treating steel articles, mixtures of barium or sodium chloride are used. The temperature and length of exposure depends on the required effect. The articles are then placed in quenching and washing tanks. The quenching medium is usually water, although oil is sometimes used.

2.2.2 Manufacture of composites

Thermoplastics and thermosetting resins reinforced with fibrous materials are increasingly used in the manufacture of aircraft owing to their very high strength to weight ratio.

Originally, *Fibreglass* was used with components formed by injection moulding or, more commonly, by contact moulding, where a mould is repeatedly coated with layers of glass fibres and a fast curing polyester resin (for more information on fibreglass manufacture, see the relevant Industry Profile, Section 4).

In modern manufacturing processes, the fibres and resins are combined to form a tape; the sheets of tape are cut to the desired shape and stacked in a specified orientation, and the resultant laminate is cured in an oven. By forming the composites in the desired shape no working of the materials is required and machining is kept to a minimum.

2.2.3 Surface coatings, protective and cleaning treatments

A wide range of coatings and treatments are used in the production of aircraft. The earliest of these was the doping of fabric on early aeroplanes and airships. With the introduction of metal alloys, different techniques were introduced.

Treatments may be applied for the following reasons:

- as an aid to manufacture, for example as masking or release agents
- as simple exterior coatings or for temporary and semi-permanent corrosion protection
- to impart specific engineering requirements by surface modification
- to clean off surface contaminants prior to a further engineering process or coating application.

Treatments may be applied to individual components, such as nuts and bolts, or to larger fabricated assemblies.

Surface coatings or protective treatments are typically applied in a three-stage process:

- preparation stage (or stages) to remove contamination such as grease or previous surface coating
- the coating operation which may involve one or more treatments
- polishing to achieve the desired finish.

Case hardening

This technique is used on steel to impart a hard surface layer which improves wear resistance whilst retaining a soft ductile core. In the past, metals were case hardened by dipping in baths of molten salts such as sodium or potassium cyanide. Cyanide present in the spent bath solution may have been stabilised/neutralised by the addition of hypochlorite prior to discharge. Modern techniques, such as bright nitriding, do not use cyanide as a process component.

Chemical cleaning and degreasing

Acid pickling is used to remove oxide and heat treatment scale from ferrous and non-ferrous metals. Cold pickling for steel usually involves immersion in a sulphuric and/or hydrochloric acid inhibitor bath, followed by rinsing.

Alkaline cleaners comprising sodium hydroxide, sodium carbonate, trisodium phosphate or sodium metasilicate are also used.

Solvent degreasing is widely carried out in engineering industries, as dedicated processes, or by manual wiping. Larger scale processes include ultrasonic baths and vapour degreasing, in which the solvents are distilled and reused. Historically, thinners and tetrachloroethane were widely used for degreasing. Materials currently used for degreasing include trichloroethylene, trichloroethane, perchloroethylene, ketones, alcohols and esters. The current trend is to use water-based cleaning systems instead of organic solvents.

Physical cleaning and surface preparation

A variety of physical abrasion techniques are used for cleaning or surface preparation including dry honing, abrasive blasting and shot peening. They are commonly used to remove paint and oxides prior to re-treatment. The abrasives used in these techniques include aluminium oxide, garnet, glass beads, nut shells, plastic pellets and steel shot. The dust and debris from the process are separated from the abrasive which is subsequently reused.

Anodising
The natural film of oxide that forms on aluminium or titanium from exposure to the atmosphere can be thickened by a process known as anodic oxidising, or anodising. The fine adhering film of oxide provides good corrosion resistance and an excellent bond for paints and adhesives. Aluminium or titanium components are placed in a bath of electrolyte and oxidation occurs by electrolysis. The electrolytes used include chromic acid (the most common), sulphuric acid and oxalic acid in distilled water. After anodising, the metal is washed thoroughly in hot water.

The Alocrom process
The Alocrom process is used extensively in the aircraft industry as a less costly, alternative process to anodising where corrosion protection requirements are not as great. The process involves immersion in a bath of the nitric acid/dichromate Alocrom solution and subsequent rinsing. Swab Alocrom is frequently used in assembly areas and rinsing is required as part of the repair/post-assembly treatment.

Electroplating
Metallic coatings are often applied to metals or other conductive surfaces by electroplating in order to modify surface characteristics such as corrosion resistance, lubricity and wear resistance. Electroplating involves immersing the components in a series of baths to deposit elemental metal. Several metals are used as surface coatings, including cadmium, copper, chromium, nickel and silver. Multiple rinsing is required between baths on a plating line and post deposition treatment may be used, such as passivation.

For more information on electroplating, consult the relevant Industry Profile (see Section 4).

Painting
In the painting process, various paints, enamels and lacquers may be applied, depending on the final finish required. Paint strippers, mainly blends of chlorinated solvents with phenolic compounds, are also used. Between applications of separate coats, various cleaning, plating and pickling processes may be required. It is usual to assemble parts after priming and apply the finishing coats after assembly.

Paints, enamels and lacquers are generally applied using a conventional spray gun, an airless spray gun or a pressurised roller. In most instances, spray booths are used, where a water curtain separates the paint from the air, allowing paint solids to be collected in a tank at the base of the booth. In some plants, a venturi cone provides continual agitation which releases solvents and additives from the paint solids. In the past, surface coatings were applied by paint brush.

More information on surface coatings is given in the profile on coatings (paints and printing inks) manufacture (see Section 4).

2.2.4 Assembly

Prior to the 1930s, assembly was carried out using standard joinery techniques. From 1930 until 1960, aircraft were made of many aluminium alloy sheet metal parts, joined together by rivets and fasteners, with high tensile steel used for rolled strip spars and end fittings. Since 1960, there has been an increasing use of machined plates of wrought aluminium alloy, together with bonded reinforced plastics. This has reduced the number of assembled parts and fasteners and has led to an increasing use of adhesives and sealants during the assembly process. Welding operations were important in the past in the assembly process but now have a more limited application, such as in the preparation of pipework.

Separate sections of the plane (sub-assemblies) are manufactured and then assembled into sub-structures and final structures using steel assembly jigs. Wooden jigs were used historically for certain purposes. The jigs enable parts to be held firmly in their correct position relative to one another whilst being fixed. During the assembly process, components produced off site, for example wheels, fittings, undercarriages, electrical equipment and engines, are installed. Throughout the assembly procedures, surfaces are cleaned to allow the application of fixing techniques.

Various sealants are used, including those listed below:

polysulphide synthetic rubber
fluoroelastomer sealant
nitrile synthetic rubber
silicone rubber.

The sealants generally contain small amounts of solvents and other compounds. Historically, seaplane manufacture used a mixture of soya oil, ester gum, wood oil and turpentine as a sealant, as well as neoprene tape.

The adhesives used on the early wooden aircraft were casein glues which often contained petroleum solvent. From about 1935 onwards, improvements were made in the adhesives used for the bonding of veneers in plywood and for securing joints in wooden structures. These adhesives resulted from the development of synthetic thermosetting resin systems which initially included urea formaldehyde and phenol formaldehyde. Improved wood-to-wood bonds and acceptable wood-to-metal and metal-to-metal bonds were achieved by the introduction of *Redux* adhesives. These are composite adhesives based on a mixture of phenol formaldehyde (a thermosetting resin) and a polyvinyl thermoplastic resin. In the early metal-based planes, riveting and welding techniques were predominant.

Adhesives currently used include the following:

modified types of tough acrylic which are supplied in two parts as resin and catalyst
epoxies available in one-part, two-part or film form, consisting of a resin and a hardener
polyurethanes
modified phenolics.

These adhesives contain various organic solvents, for example benzene, chlorinated solvents and carbon disulphide; polyurethane adhesives contain isocyanates. The adhesives are used to bond metals and non-metals. They may be used in conjunction with other methods such as riveting or spot welding.

Hydraulic systems can be extensive in large aircraft. The hydraulic fluids used are based on mineral oil, vegetable oil or phosphate ester and are installed into the system during the assembly process. Oils used on modern aircraft are required to be fire resistant. Other liquid systems which are charged during assembly include the cooling and lubrication systems. Limited quantities of these materials may have been deposited during charging and discharging operations.

2.2.5 Miscellaneous activities

The majority of components are now manufactured off site by specialist contractors. However in the past, aircraft manufacturing facilities commonly had associated activities such as rubber manufacturing, foundries and toolmaking. In addition, asbestos components are known to have been manufactured on site up until the late 1970s. In some instances, military installations will have had an associated munitions manufacturing or storage capability (see the profile on explosives manufacturing works, Section 4).

Research and development facilities may be, or may have been, associated with the aircraft manufacturing site. A wider range of activities than those described in this profile, including experimental techniques, may have been carried out.

Aircraft manufacturing works may have incorporated electricity transformers and capacitors which possibly contained polychlorinated biphenyls (PCBs) in dielectric fluids. Fuel oil storage tanks and aviation fuel tanks (for tank pressure testing purposes and engine testing) may also have been present.

Testing facilities use various pieces of equipment to ensure that the components used and the assembled aircraft meet specifications and statutory regulations. Fluorescent penetrants are of particular concern as they use solvents, surface active agents and fluorescent dyes.

Radioactive isotopes are used in testing equipment, notably in X-ray fluoroscopy. Historically, radioactive materials, for example tritium and radium, have been used in aircraft instrumentation and for the illumination of dials.

2.3 Waste management

2.3.1 Wood and fabric

When wooden frames and fabric skins were used in aircraft manufacture the main wastes from cutting operations were offcuts, shavings and sawdust. These are likely to have been burnt, reused elsewhere on or off site, or deposited on site.

2.3.2 Metal working

Conventional metal cutting, grinding and drilling techniques produce large quantities of swarf and cutting fluid. Cutting fluids are usually water soluble oils, although in the past animal oils were used. These are collected and separated prior to disposal or reclamation and recycling. Swarf and offcuts from metal working are usually accumulated and sold as scrap.

Powder produced from titanium cutting is inflammable and, with swarf from machining, is stored outside in sealed containers before disposal off site.

Aluminium and magnesium powder from finishing processes can pose a severe fire and dust explosion risk.

Waste electrolyte from electrochemical machining is treated prior to disposal. Treatment generally involves neutralisation of the residual alkalinity or acidity to precipitate out the metals from solution. The sludge of precipitated solids is disposed of off site and the effluent is discharged to sewer.

The waste from chemical milling comprises spent acid or alkali with metals in solution. The waste is either disposed of off site or treated using a neutralisation and precipitation technique prior to discharge to sewer, with the sludge being disposed of off site.

The wastes produced from heat treatment and annealing comprise spent quenching media (water or oil) and waste salt residues.

Historically, solid wastes may have been deposited on site and liquid wastes disposed of either directly to sewer or to soakaway.

2.3.3 Surface coatings and treatments

Some waste may have resulted from using dope; there may have been residues in containers and discarded doped fabrics.

The main waste from case hardening is rinse water and limited quantities of spent bath solution.

Spent pickling baths are neutralised and discharged to sewer and the sediment disposed of off site.

The spent solvents used in chemical cleaning and degreasing are usually recycled or disposed of off site.

The waste materials from physical cleaning and surface preparation processes comprise dust and debris, the nature of which depends upon the material and abrasive used. These wastes are disposed of off site.

Wastes from the anodising process comprise spent electrolyte and rinse water. The rinse water is neutralised and released to sewer. Spent electrolyte is disposed of off site.

In all electroplating techniques, large quantities of rinse water and lesser quantities of spent electrolyte are generated. Metal, acid, alkali or cyanide bearing liquids are typically chemically treated prior to discharge to sewer. Sludges from the treatment plant are disposed of off site by specialist contractors.

Waste materials generated by the application of paints, lacquers and enamels comprise sludges from booths, waste solvents, containers and packaging (some with residues) and filters from the scrubbing plant. These wastes are now disposed of off site.

In the past, waste disposal operations were less controlled and the above wastes may have been deposited on site, or if liquid, discharged to a sewer or soakaway.

2.3.4 Other wastes

Waste from cutting plastics is collected and disposed of off site.

The machining of asbestos components on site generally ceased during the 1950s and sub-contracting firms took over supply. However, in some instances asbestos components were manufactured on site until the late 1970s; asbestos off-cuts may have been deposited on site.

Limited quantities of waste are generated during the assembly process. These include packaging materials for the sealants and adhesives, some of which may contain residues, and waste solvent from cleaning activities. These wastes are disposed of off site. Carbide residue may be generated as a result of on-site acetylene production for the welding process. Apart from this, there is little residual waste associated with riveting and welding. Natural and synthetic oils are used in hydraulic fluids, lubricants and cooling fluids. Waste may be generated during testing operations, but the quantities are likely to be limited.

Wastes are also associated with research and development facilities but the quantities concerned are likely to be small. The filter media or effluent produced from testing components is disposed of off site.

Radioactive sources are enclosed, and disposal of damaged equipment containing radioactive components is strictly regulated. However, historically, disposal practices are likely to have been less rigorous and limited quantities of radioactive materials may have been deposited on site.

3. Contamination

The contaminants on a site will largely depend on the history of the site and on the range of materials used there. Potential contaminants are listed in the Annex and the probable locations on site of the main groups of contaminants are shown in Table 3. It is most unlikely that any one site will contain all of the contaminants listed. It is recommended that an appropriate site investigation be carried out to determine the exact nature of the contamination associated with individual sites.

3.1 Factors affecting contamination

Contamination of aircraft manufacturing sites could result from leaks, spillages or on-site disposal of waste materials. On-site disposal of wastes, which is more likely to have occurred in the past, may have included burning, burial or the release of untreated effluents to the drainage system.

Releases to the drainage system could have resulted in ground and/or groundwater contamination if the integrity of the system was compromised, either by age or the corrosive action of the released effluents. Releases to soakaways are likely to have resulted in direct ground and groundwater contamination.

The areas where contamination is most likely to be found are the surface treatment workshops where cleaning, treating and painting operations are carried out. The most likely contaminants in the machine and press shops and final assembly areas are oils.

3.1.1 Organic solvents

A wide range of solvents has been used in paints and for cleaning and degreasing.

Areas likely to be affected by solvent contamination include storage areas for virgin and waste solvents, particularly around the cleaning and degreasing plant, and the paint shop where large volumes of solvents are held, and to a lesser extent the assembly plant.

Releases may occur during the filling and emptying of storage tanks and as a result of leaks from storage tanks and drums, accidental spillages and the on-site disposal of cleaning solvents or paint sludges.

3.1.2 Metals and metal compounds

Structural materials used in the manufacture of aircraft include steel, aluminium, titanium and nickel. These metals will be present in swarf and scrap from cutting and metal working operations. The storage of offcuts and swarf on site prior to removal as scrap may have resulted in surface contamination.

Metal salts are present in effluents from various treatment processes. Contamination could have arisen from spillages of the effluent in process areas or from disposal of untreated effluent either to the drainage system or directly to the ground.

3.1.3 Fuel and other oils

The most likely areas of oil contamination are:

storage areas for oils, hydraulic fluids and cutting fluids around the machine shop and the assembly plant

areas where oily sludges from the paint shop and spent cutting fluids or cutting fluid sludges from the machine shop may have been temporarily stored or disposed of

areas where machining swarf has been temporarily stored prior to its removal from the site.

Releases may occur during the filling and emptying of storage tanks, as a result of leaks from storage tanks, drums and skips containing oily sludges or machining swarf and as a result of spillages in production and storage areas.

Contamination by fuels may be found in the area of fuel storage tanks which supply oil to boilers or generators, and aviation fuel tanks for tank pressure testing and engine testing purposes. The hydrocarbons may be released from leaking storage tanks, particularly if these were located underground, and from spillages during the filling of storage tanks.

3.1.4 Other materials

Where wooden aircraft were manufactured, contamination may have arisen from doping operations, either by spillage of the doping liquid or burial of waste doping solids or liquids. The residues may present a combustion hazard.

Other potentially significant contaminating materials which may be encountered include acids and alkalis used in pre-treatment processes and cyanide-bearing waste effluents from electroplating and case hardening processes. Contamination may have arisen from spillages of effluent from process areas or from disposal of untreated effluent either to the drainage systems or soakaways, or via burial in the ground.

Materials may have been released as a result of demolition works in the past, for example asbestos used for pipe and plant insulation, or asbestos sheeting used for roofing or cladding. Polychlorinated biphenyls (PCBs) may have been used in dielectric fluids in transformers and capacitors. Radioactive contamination may have arisen from the disposal of dials from broken instruments.

Numerous organic and inorganic compounds are present within the formulations used for sealants, adhesives, linings and various synthetic resin systems. It has been estimated that more than 5000 chemicals and mixtures of chemical compounds are commonly used in the aircraft industry. In general, these compounds have been introduced during the more recent history of aircraft manufacturing, when waste disposal operations have been more closely regulated.

A variety of other process activities may have been carried out, particularly if research and development facilities were operated. The wastes and associated potential contamination from these activities will vary from site to site.

3.2 Migration and persistence of contaminants

3.2.1 Organic solvents

Surface waters may be polluted by seepage of solvents or solvent-contaminated groundwater into drains or sewers which ultimately discharge into watercourses. Groundwater may be affected by the infiltration and flow of solvents. The magnitude of the risk to groundwater depends on the depth of the water table, and the soil structure and properties. Generally, the higher the natural organic matter and clay content of the soil, the greater the adsorption of contaminants and the lower their mobility. Conversely, the greatest migration of contaminants will occur in coarse-grained sands and gravels.

Solvents are typically highly mobile, volatile liquids. Certain solvents such as alcohols, ketones and glycols are water-soluble. Relatively small quantities of solvents can have a severe impact on water resources, particularly potable water supplies, even if the solvents are of low aqueous solubility (for example benzene).

Non-chlorinated solvents, which are of limited water solubility and which are less dense than water, form separate floating layers in surface and sub-surface water bodies. Free solvent residue within the soil matrix and floating solvent layers are long-term sources of pollution. Non-chlorinated solvents are potentially biodegradable but may persist in soil due to conditions unfavourable for microbial activity.

Chlorinated solvents have limited water solubility. They are generally more dense than water, forming sunken layers and penetrating to considerable depths in underlying aquifers. Chlorinated solvents are persistent, their biodegradability decreasing with increasing degrees of chlorination. They biodegrade slowly and only under specific conditions.

3.2.2 Oils and fuels

Oils, hydraulic fluids and cutting fluids are mobile liquids and flow under the influence of gravity and the surface tension forces exerted by unsaturated soils.

Certain cutting fluids, such as those containing glycols, are water-soluble, although typically oils have a limited solubility. Thus, surface water may be contaminated by run-off from oil-saturated ground and groundwater may be contaminated by the downward flow of oils and cutting fluids or by rainwater infiltration through oil-saturated ground. Contamination by oils may extend from the ground surface to the underlying water-table.

Generally, as is the case with solvents, oil migration will be greatest in soils with little natural organic matter.

Liquid hydrocarbon fuels are highly mobile and flow under the influence of gravity and surface tension forces in unsaturated soils. They have limited water solubility but even small dissolved quantities can contaminate water. The volatile components of petrol and aviation fuels can migrate as vapours. Groundwater may be affected by the downward flow of fuels under gravity. Surface waters may be polluted by seepage of fuels into drains or sewers which ultimately discharge into watercourses, or the discharge of fuel contaminated groundwater into surface watercourses. The fuels form separate floating layers on surface and underground water bodies.

The light fuel oils used for aircraft are generally biodegradable. However, biodegradation processes in soils can be influenced by a number of factors, namely moisture content, oxygen concentration and pH, acting separately or in combination. For example, low moisture content reduces microbiological activity, while high moisture content can reduce oxygen penetration and possibly lead to anaerobic soil conditions. Such conditions enhance the biodegradation of some materials, for example chlorinated compounds, while aerobic conditions are needed to biodegrade many oils. Also, low pHs tend to reduce the bacterial population and encourage fungal activity; at pHs lower than 5 microbiological activity is much reduced. The presence of heavy metals also inhibits micro-organisms. As a result of these factors, at high concentrations in soil, even relatively non-persistent compounds may not biodegrade readily.

3.2.3 Other organic materials

The non-solvent organic materials used in paints and resins are generally not water-soluble and tend to be of high molecular weight. They biodegrade slowly and are therefore expected to be fairly persistent. Some organic compounds that are insoluble in water may dissolve in organic solvents and therefore become more mobile.

3.2.4 Metals and metal compounds

Metals and some metal compounds contained in paint sludges and treatment process sludges are not readily water-soluble. However, in the presence of acids, metals and their salts may form soluble compounds and therefore greatly increase their mobility. In other cases the relationship is more complex. For example, trivalent chromium is more soluble under acidic conditions, whereas the solubility of hexavalent chromium is increased under both acidic and alkaline conditions. Metals may pose a hazard through uptake by plants and concentration in their tissues. Metals are not biodegradable.

3.2.5 Inorganic compounds

Simple cyanides are slowly hydrolised in water to form the carbonate and ammonia. Under acidic conditions, hydrogen cyanide gas may be evolved.

Asbestos is neither water-soluble nor biodegradable and persists in the soil. Wind dispersal of contaminated soil may be a further transport mechanism where there is gross surface contamination by some of the less mobile contaminants, particularly metals and asbestos.

4. Sources of further information

4.1 Organisations

For further information concerning the aircraft industry in the United Kingdom, the following organisations should be consulted:

Civil Aviation Authority
CAA House
45-59 Kingsway
London
WC2B 6TE

Defence Research Agency
Farnborough
Hampshire
GU14 6TD

Royal Aeronautical Society
4 Hamilton Place
London
W1V 0BQ

Society of British Aerospace Companies Limited
29 King Street
St James's
London
SW1Y 6RD

4.2 Sources of information concerning the activities described in this profile

Hayward K. *The British aircraft industry.* Manchester University Press, 1989.

Horne D F. *Aircraft production technology.* Cambridge University Press, 1986.

Nachtman E S and Kalpakjian S. *Lubricants and lubrication in metalworking operations.* Marcel Dekker, 1985.

Information on researching the history of sites may be found in:

Department of the Environment. *Documentary research on industrial sites.* DOE, 1994.

4.3 Related DOE Industry Profiles

Airports
Asbestos manufacturing works
Chemical works: coatings (paints and printing inks) manufacturing works
Chemical works: explosives, propellants and pyrotechnics manufacturing works
Chemical works: rubber processing works (including works manufacturing tyres or other rubber products)
Engineering works: mechanical engineering and ordnance works
Metal manufacturing, refining and finishing works: electroplating and other metal finishing works
Metal manufacturing, refining and finishing works: non-ferrous metal works (excluding lead works)
Profile of miscellaneous industries incorporating:
- Charcoal
- Dry-cleaners
- Fibreglass and fibreglass resins manufacturing works
- Glass manufacturing works
- Photographic processing industry
- Printing and bookbinding works

4.4 Health, safety and environmental risks

The Notes issued by the Chief Inspector of Her Majesty's Inspectorate of Pollution (HMIP) provide guidance for the processes prescribed for integrated pollution control in Regulations made under the Environmental Protection Act 1990.

The Control of Substances Hazardous to Health (COSHH) Regulations 1994 and the Management of Health and Safety at Work Regulations 1992 are available from HMSO. Information on relevant health and safety legislation and approved codes of practice published by HSE publications are available from Health and Safety Executive Books, PO Box 1999, Sudbury, Suffolk, CO10 6FS (telephone 01787 881165), as well as HMSO and other retailers.

Information on the health, safety and environmental hazards associated with individual contaminants mentioned in this profile may be obtained from the following sources:

Howard P H. *Handbook of environmental fate and exposure data for organic chemicals.* Vols I and II. USA, Lewis Publishers, 1990.

Sax N and Lewis R. *Hazardous chemicals desk reference.* New York, Van Nostrand Reinhold Company, 1987.

Verschueren K. *Handbook of environmental data on organic chemicals.* 2nd Edition. New York, Van Nostrand Reinhold Company, 1983.

4.5 Waste disposal and remediation options

Useful information may be obtained from the Department of the Environment series of Waste Management Papers, which contain details of the nature of industrial waste arisings, their treatment and disposal. A current list of titles in this series is available from HMSO Publications Centre, PO Box 276, London, SW8 5DT.

Publications containing information on the treatment options available for the remediation of contaminated land sites, prepared with the support of the Department of the Environment's Research Programme, can be obtained from National Environmental Technology Centre Library, F6, Culham, Abingdon, Oxfordshire, OX14 3DB.

A full list of current titles of Government publications on all aspects of contaminated land can be obtained from CLL Division, Room A323, Department of the Environment, Romney House, 43 Marsham Street, London, SW1P 3PY.

Advice on the assessment and remediation of contaminated land is contained in guidance published by the Construction Industry Research and Information Association (CIRIA), 6 Storey's Gate, Westminster, London, SW1P 3AU.

Annex Potential contaminants

The chemical compounds and other materials listed below generally reflect those associated with the industry and which have the potential to contaminate the ground. The list is not exhaustive; neither does it imply that all these chemicals might be present nor that they have caused contamination.

Solvents (chlorinated)	trichloroethene 1,1,1-trichloroethane tetrachloroethylene (perchloroethylene)
Solvents (non-chlorinated)	alcohols benzene esters glycol ethers ketones eg acetone methylethyl ketone toluene xylenes
Metals, metalloids and their compounds	aluminium antimony cadmium chromium copper lead nickel silver tin titanium zinc
Oils	aviation fuel fuel oil hydraulic fluids lubricating oil
Organic materials	polychlorinated biphenyls (PCBs) polyurethanes precursors (isocyanates) nitrocellulose
Inorganic ions	chlorides (ammonium, nickel) cyanide (sodium, potassium, cadmium) phosphates
Acids	boric chromic hydrochloric hydrofluoric nitric oxalic sulphuric
Alkalis	sodium hydroxide sodium metasilicate
Asbestos	

Table 3 Main groups of contaminants and their probable locations

Engineering works: aircraft manufacturing works

Main groups of contaminants	Location						
	Materials delivery areas	Cutting and forming areas	Surface and protective treatment areas	Assembly line	Waste treatment storage and disposal areas	Heating systems/ fuel or oil storage areas	Electrical substations/ transformers
Metals and metalloid compounds	[shaded]	[shaded]	[shaded]	[shaded]	[shaded]		
Acids and alkalis	[shaded]		[shaded]		[shaded]		
Organic compounds	[shaded]	[shaded]	[shaded]	[shaded]	[shaded]		
Solvents	[shaded]	[shaded]	[shaded]	[shaded]	[shaded]		
Oils and lubricants	[shaded]	[shaded]		[shaded]	[shaded]	[shaded]	
Polychlorinated biphenyls (PCBs)							[shaded]
Asbestos	[shaded]	[shaded]			[shaded]	[shaded]	

Shaded boxes indicate areas where contamination is most likely to occur

Recycled paper

DOE Industry Profiles

Airports
Animal and animal products processing works
Asbestos manufacturing works
Ceramics, cement and asphalt manufacturing works
Chemical works: coatings (paints and printing inks) manufacturing works
Chemical works: cosmetics and toiletries manufacturing works
Chemical works: disinfectants manufacturing works
Chemical works: explosives, propellants and pyrotechnics manufacturing works
Chemical works: fertiliser manufacturing works
Chemical works: fine chemicals manufacturing works
Chemical works: inorganic chemicals manufacturing works
Chemical works: linoleum, vinyl and bitumen-based floor covering manufacturing works
Chemical works: mastics, sealants, adhesives and roofing felt manufacturing works
Chemical works: organic chemicals manufacturing works
Chemical works: pesticides manufacturing works
Chemical works: pharmaceuticals manufacturing works
Chemical works: rubber processing works (including works manufacturing tyres or other rubber products)
Chemical works: soap and detergent manufacturing works
Dockyards and dockland
Engineering works: aircraft manufacturing works
Engineering works: electrical and electronic equipment manufacturing works (including works manufacturing equipment containing PCBs)
Engineering works: mechanical engineering and ordnance works
Engineering works: railway engineering works
Engineering works: shipbuilding, repair and shipbreaking (including naval shipyards)
Engineering works: vehicle manufacturing works
Gas works, coke works and other coal carbonisation plants
Metal manufacturing, refining and finishing works: electroplating and other metal finishing works
Metal manufacturing, refining and finishing works: iron and steelworks
Metal manufacturing, refining and finishing works: lead works
Metal manufacturing, refining and finishing works: non-ferrous metal works (excluding lead works)
Metal manufacturing, refining and finishing works: precious metal recovery works
Oil refineries and bulk storage of crude oil and petroleum products
Power stations (excluding nuclear power stations)
Pulp and paper manufacturing works
Railway land
Road vehicle fuelling, service and repair: garages and filling stations
Road vehicle fuelling, service and repair: transport and haulage centres
Sewage works and sewage farms
Textile works and dye works
Timber products manufacturing works
Timber treatment works
Waste recycling, treatment and disposal sites: drum and tank cleaning and recycling plants
Waste recycling, treatment and disposal sites: hazardous waste treatment plants
Waste recycling, treatment and disposal sites: landfills and other waste treatment or waste disposal sites
Waste recycling, treatment and disposal sites: metal recycling sites
Waste recycling, treatment and disposal sites: solvent recovery works
Profile of miscellaneous industries incorporating:
- Charcoal works
- Dry-cleaners
- Fibreglass and fibreglass resins manufacturing works
- Glass manufacturing works
- Photographic processing industry
- Printing and bookbinding works

Copies may be purchased from:
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Block 3, Spur 7,
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Lime Grove,
Ruislip, HA4 8SF

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