A BRIEF HISTORY OF FLYING CLOTHING

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Summary

From the earliest days of flight, the aviator has needed some form of personal protection against the elements. The earliest form was a good tweed jacket, a hat and a pair of goggles; as the technology of aviation developed - flying faster, higher and longer - better and differing levels of protection were required.

Conflict invariably brings rapid technological development and during the two World Wars, and the lingering Cold War, development of aircraft required complementary development of protective flying clothing. The later advent of electronics, computing and lightweight optics provided a new and additional role for flying clothing, particularly flying helmets, to supplement the weapons systems, primarily in the form of helmet mounted sights and displays.

This paper looks briefly at the role and development of flying clothing, over the last century or so, in the protection of aircrew

Introduction

Over the last 100 years or so, aircrew or pilots have been the been airborne to direct aircraft operations, controlling the flight and performance, managing the aircraft systems, maintaining communications and providing, in war, much of the tactical intelligence. This approach has been highly successful and development of aircraft has been rapid, particularly during the two World Wars and the Cold War, when greater levels of finance for research, experimentation and development were available than in times of peace.

There is, however, a downside to using a human in the loop. Aircrew are relatively frail and need to be protected against the cold, air-blast, noise, heat, noxious substances, chemical and biological weapons, nuclear flash, laser weapons, fire, the many effects of altitude, bright light, instantaneous and continuous acceleration and impact, and enabled to escape from the aircraft and subsequent survive immersion in cold water. When suitably protected, aircrew have to be able to fly, communicate, calculate, maintain mental agility and see clearly at all times. Under this plethora of needs, personal protection by the use of man-mounted equipment has been found to be the best technical and economic solution.

This results in the pilot tending to be an expensive liability (not only in cost but also in weight and complexity of cockpit systems) and it is not from sentimentality that, for the last hundred years or so, aircrew have been central to, and the focus of, the aircraft system. It is because they can do the required job better than any other option. To date, technology had been unable to match the flexibility and operational effectiveness that a well-trained pilot can bring to the job. However, in some areas, there now appear to be some changes on the horizon. From the earliest of days, when protection was mainly against cold, weather, slipstream and, in some aircraft, oil from the engine, improving technology increased the capability of the aircraft and their combat effectiveness. The pilot then had to be protected from the new threats to his performance and operational effectiveness. War significantly increased the speed of development of both aircraft and flying clothing and it is no coincidence that development was at its peak during the two World Wars and the lingering Cold War.

Thus, in general terms, the requirement by the Service operators for the development of flying clothing has tended to be re-active, rather than pro-active. However, proactive research and development into such clothing has taken place at the Royal Aircraft Establishment and the RAF Institute of Aviation Medicine at Farnborough, both working with British industry. The results of this research were not always taken up by the Services, even though each step to improve aircraft performance or to gain an advantage in times of war had necessitated improvements in the protection of the pilot.

This paper looks at the development of flying clothing from the early days, when motorists regularly travelled faster and higher than pilots, to present times when pilots fly in the stratosphere and at speeds exceeding Mach 2. Passengers in Concorde flew similar flight profiles, but in rather more comfort, and this paper considers primarily the military environment where aircraft manoeuvring needs to be more violent and generally more precise in a wide range of battlefield conditions, both at altitude and low-level and many other threats are present.

Over the last century, there have been many countries that have developed and produced flying clothing for their own military services – USA, Canada, Germany, France, Russia, Japan etc., but for relative brevity this paper concentrates mainly on British equipment.

Part 1 The early days: 1904 to 1918

1.1 Introduction

The first manned, controlled and powered flights of the Wright brothers in the USA, Cody in Great Britain, Santos-Dumont, Farman and Bleriot in France were inevitably of limited altitude, speed and duration. The humble motorist travelled at faster speeds – when Wilbur Wright flew in 1904 (at around 30 mph) the motorist was capable of travelling at up to 70 mph and four years later at the time of Cody's flight (at 35-40 mph), the car was capable of travelling at 120 mph – and as they travelled in the same environment, it was natural and economic to use the protection afforded to motorists by the larger department stores like Gamages in Holborn and Benetfinks of Cheapside.





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Figure 1 A Tweed jacket, cap and scarf was adequate protection in the pioneering days of flying Claude Graham-White 1910 (left) and F. Warren-Merriam, Bristol Aviation School, Brooklands c 1912

Thus these early pilots flew often in just a tweed jacket and trousers, suitable hat and a pair of goggles. With the frailty of the early aeroplanes and the problems of control and stability, flights were normally made only when wind-speeds were negligible, gusting was absent and the effect of the environment to which they were exposed was minimal. With airspeeds up to 60mph and altitudes generally below a few thousand feet, the major enemies were the cold and protection against the elements in these early flying machines. As aircraft became more capable, pilots needed better protective clothing both for their longer duration flights and against being caught in inclement weather such as rain. The readily available motoring apparel was the norm and could be obtained at reasonable cost



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Figure 2 Wrapping up warmer. Henri Farman (left) and Samuel Franklin Cody (and his lady passenger) highlight the exposed conditions and lack of protection against the elements in these early flying machines. Both are wearing better protective clothing for their later and longer duration flights



Figure 3 Commercial companies, supplying protection to the motorist, soon saw the opportunities in adapting their existing clothing to the new 'sport' of the aeronaut

1.2 Specialised protective clothing up to 1914

As flying developed and engines became lighter, more powerful and more reliable, the increasing band of aviators, flying longer distances, often had their good tweed suits damaged by oil, dirt and weather and looked for something more suited to flight.

When Bleriot accomplished his 37 minute flight across the English Channel in July 1909 he was wearing his tweed suit, a khaki jacket lined with wool, a blue cotton boiler-suit and a skull cap with ear-flaps. Leading European stores, such as Burberrys, Gamages and Roold soon noted the potential for sales in this exciting new 'sport' and rose to the occasion, producing aviators' combination suits, fleece-lined boots, more specialised goggles, rainproof gauntlets and leather coats. These were probably the first items that could be classified as 'bona-fide' flying clothing, although not yet military.

As many of flights of the period ended in a 'controlled crash' or a heavy landing, with many pilots sustaining varying levels of head injuries from coming into contact with the aircraft structure or the earth, aviators took a further leaf from motorsport and started to use hard helmets from motor-cycle racing. These were modified for the purpose of flying and establishments such as Dunhills in England and Roold in Paris began to manufacture such specialist helmets. Individuals such as Mr Warren from Hendon also produced their own design of helmet, which, with its excellent shock-absorbing qualities, was widely used by pilots. Samuel Cody also used a helmet to his own design and sold by Gamages of Holborn as the "Farnborough".

By this time flying was coming of age and was no longer regarded solely as an exciting sport. Shadows of war were beginning to spread across Europe and the expansion of the Royal Engineers School of Ballooning to form the Air Battalion of the Royal Engineers in 1911 at Farnborough was a step towards the formation of an air arm as a separate corps or service. The final step was taken in April/May 1912 when the Royal Flying Corps was formed. But flying clothing still generally comprised adapted motoring apparel.

1.3 The Great War 1914 – 1918

By the start of the War in 1914, developments by the Royal Aircraft Factory and British industry had provided more refined aircraft in which the pilot was contained more within the fuselage, rather than perched on a wicker seat and fully exposed to the elements. At this stage there was no formal issue of clothing specifically for flying but the military, with their wide experience of Army motor transport, had a range of readily available motoring garments which they offered to the newly formed Royal Flying Corps and Royal Naval Air Service pilots. Thus, at the start of the war pilots were provided with a more formalised issue of motoring gear – weatherproof coats, goggles, gauntlets, leather boots etc. – all of which were worn over the uniform. Although pilots were able to use the military issue they were also at liberty to purchase their own clothing and commercial companies continued to develop their motoring clothing into more specialised flying clothing (Figure 4).





FAST Library Aeroplane 1917

Figure 4 Although both the RFC and the RNAS supplied clothing to their pilots and observers, there was the freedom to purchase from commercial suppliers which allowed the crews to incorporate individual needs from their London tailors



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FAST Archives

Figure 5 A French Roold helmet worn by Wingfield-Smith, one of the test pilots at the Royal Aircraft Factory

1.3.1 The Sidcot suit

In the winter of 1916 the first significant stride was made to providing effective protection for the pilot and this arrived from the brain of Sidney Cotton, an RNAS pilot with No.8 Squadron. Cotton had been working on his own aircraft when a 'scramble' was called and he flew in his dirty overalls for an hour or so and upon landing found that, unlike his fellow pilots who were shivering from the cold, he was quite unaffected. Having thought through this effect, he realised that it was the oil and grease soaked into the overalls that had retained the body heat. Picking up on the idea, he took leave and travelled to London, to Robinson & Cleaver, where he had a flying suit made for him to his design. The suit had three layers, a thin lining of fur, a layer of airproof silk, and an outside layer of light Burberry material, all made into a one-piece suit, just like his overalls. Robinson & Cleaver were asked to register the design on behalf of Cotton and the flying suit took its name from the inventor and was called the Sidcot suit (SIDney COTton).

By late 1917, tests had shown that the Sidcot Flying Suit No 5 was regarded by pilots as the most suitable for operational use. Consequently the manufacturers of the suit, Robinson & Cleaver, were asked to produce 250 suits per week, just fourteen days after the order. Deliveries were later expected to reach 1,000 per week just four weeks after the initial order. By December 1917 the orders for leather flying coats, some 3,000, were cancelled in favour of the Sidcot suit. This suit met virtually every requirement for protection against the primary threat, the cold, and was in service in a number of modified and development forms right through into WW2 and only ceased being used as closed cockpits, combined sometimes with cabin heating, became the norm in aircraft design.

'Fug boots', a further layer of protection for the legs, were generally discarded with the introduction of the Sidcot suit, but they continued to be used in the 1920s in combination with

the Sidcot in the Middle and Far East when the RAF were policing the protectorates, and longendurance high-altitude flights were needed to clear the many mountain ranges.



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Aeroplane 1917

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Figure 6 Sidney Cotton's inspiration for an effective protective garment was sold by Robinson & Cleaver as the SIDCOT flying suit at a very reasonable eight guineas. Whilst providing good levels of protection, the legs could still get cold on longer flights and crews often wore 'fug' boots shown on the right by Capt. Halley and his observer whilst serving on the Northwest Frontier in India in 1918 and flying the Handley Page V1500 bomber

An excellent summary of the necessary levels of protection from the cold earlier in the War is given in Winter (1982) "..... clothing had therefore to be put on just before flying, otherwise the body would give out moisture which would freeze again at altitude. Dressing would then be in strict sequence. Silk underwear, close-woven woollen underwear duplicating the silk and worn loose, cellular two-inch squared vest, silk inner shirt, Army khaki shirt, two pullovers, tight woven gabardine Sidcot Suit lined with lamb's wool and muskrat-lined gauntlets with silk inners.

Thus dressed the pilot could tolerate temperatures of minus fifty degrees Centigrade – though high wind, poor fit, sweat before dressing or the poor circulation of an unfit man could chill him to the point of tears at ten degrees Fahrenheit. One final military touch before leaving the dressing hut – the presentation for signature of an Army form FS20. 'Date, time, pilot's name, thigh boots, fur-lined boots, gauntlets, fur-lined goggles with Triplex glasses, Sidcot suit & oversleeves. These are the property of the public. Losses due to exigencies of campaign must be certified by the Officer Commanding.

The final adjustment would be to the head area. A silk scarf would be wound carefully around the throat to prevent air entering the vulnerable neck area and getting inside the flying suit as well as preventing skin chafing from that constant turning round in flight to check for enemy behind the tail-plane. The face would then be smeared with whale-oil, surrounded by a balaclava helmet and covered with a non-absorbent face mask, ideally of Nuchwang dog-skin from China. If dog-skin was unavailable, the mask would be wolverine fur, favoured anyway by the Canadian flyers since breath would not freeze on it. The triplex goggles, which covered the single gap in the mask (32s 6d over a London shop counter) were of fur lined moulded sponge-rubber with sage-green-tinted-glasses to absorb ultra-violet rays. Various preparations would finally be rubbed on to the glass to counter fogging below ten degrees Fahrenheit and frosting at minus ten, with perhaps a touch of ointment on the lips, though pilots philosophically accepted the facts that all lips cracked at altitude whatever specifics were used.

Fully dressed, the flight would walk together to the CO's hut stumping as noisily and heavily as lunar astronauts."

1.3.2 Flight at high altitude

By this time the altitude ceiling of the new varieties of aircraft had increased. The Sopwith Pup had a ceiling of just over 17,000 ft and the Spad IV managed 18,000ft. Patrols were flying regularly at 10 to 15,000ft and above with outside air temperatures, in the cold winters, often at -35° C or lower. To combat the cold soak induced during long patrols at these type of altitudes, - the Pup had a 3 hour duration - the first efforts at electrically heated clothing were introduced, and this generally marked the introduction of technology into the development of flying clothing.

Although introduced for only half of the piloting complement, each set of issued clothing comprised an electrically heated waistcoat, gloves and a pair of soles for the boots (Figure 7). These items were not intended as a replacement for the normal flying clothing but were meant to be worn under the existing kit. Power for the clothing was provided from a small windmill generator mounted on the wing struts or fuselage and was normally satisfactory, but, when in a dive and often with no voltage regulator incorporated, the higher voltages generated often caused burns, particularly to the hands and fingers.

A number of constructional problems ensued in operational use, however, particularly in the gloves – where continuous flexing caused the wires to break and also in the boots where the mica heated sole inserts were prone to cracking. But in spite of these problems, and when they were working, the heated systems provided some respite from the cold. In July 1918, some 2,171 electrically wired suits had been shipped to the front (Greer & Harold, 1979).



Imperial War Museum

Figure 7 The crew of an FE2b night bomber wearing an electrically heated waistcoat and gloves which was worn under the RFC uniform and a leather coat. The officer on the right wears a new Sidcot Suit and both wear Mk1 mask goggles of the type similar to that shown in the Dunhills advertisement (Figure 4)

1.3.3 Oxygen supply and breathing systems

Higher altitudes also meant diminished oxygen levels and increased the threat of hypoxia, as an altitude of around 10,000ft marks the onset of deterioration in human performance, a condition often exacerbated by the low air temperatures and duration of exposure. As in many aviation areas, the Germans had led the field in the use, by military aviators, of oxygen systems. The Zeppelin raids on England earlier in the war were carried out from 17,000ft and above and their early oxygen systems used compressed gas, turning to the use of liquid oxygen in later years.

The early British systems were produced by the Siebe-Gorman Company, already well versed in underwater breathing systems and comprised a simple regulator valve, feeding from two 500 litre oxygen bottles, with three manually selected altitude settings providing increased gas flow at each setting – the highest being effective up to 29,750ft. A rubber mask, fitting over the nose & mouth, fed the oxygen continuously to the pilot. A rapid improvement was devised by Major Georges Dreyer, RAMC, and used an aneroid controlled regulator, allowing variable control of the oxygen feed with height, which helped conserve the contents of the oxygen cylinders. The mask was light and comfortable and contributed to protecting the face against the cold air blasts.



RAE negative FAST Archive

Figure 8 The provision of oxygen in WW1 was either by a Liquid Oxygen supply or from pressurised bottles – which were heavy. The system shown here is the low-pressure (25psi) liquid oxygen system feeding from the spherical liquid container (a Dewar flask), through the vapouriser to the regulation valve and oxygen altitude gauge to the oxygen mask (Type B shown). The oxygen mask could be replaced by the 'pipe-stem' system.

Oxygen-masks were, however, not universally used. Many pilots disliked the apparent restrictions that resulted from such a covering of the face and there were problems with the moist expired air freezing and restricting, or preventing, the flow of oxygen. This was a problem that continued into WW2; an obvious problem that, perhaps, should have been solved a long time before it became a serious operational issue. A preferred option was often the use of a 'pipe-stem' system where the stem was gripped between the teeth and inhaling was exclusively through the mouth. This, of course, restricted inhaling through the nose, which would dilute the concentrations of oxygen intake. It was not comfortable but adequate, although still not a demand system, which could provide the aircrew with the exact quantities of oxygen needed, but rather a continuous flow system where close to 50% of the oxygen was wasted on exhaling.

The oxygen systems were, however, more suited to bomber crews who generally flew longer sorties constantly at high altitudes, particularly the DH4s flying sorties over Germany at heights up to 18,000ft. The only fighter unit issued with such systems was 88 Sqn, flying the Bristol Fighter, which was carrying out patrols for two-and-a-half hours of up to 19,000ft.



Figure 9 The pipe stem, held between the teeth and used for the inhalation of the oxygen supply, was used, prior to the use of the oxygen mask, by the British and German pilots and with both bottled and liquid oxygen systems. The German gunner on the right uses such a system in his Staaken bomber and, incidentally, shows the hard helmet and cold weather clothing of the German flyers. The liquid oxygen vapouriser sits to the right of the gunner with a white-faced pressure gauge.

By August 1918 the Air Board had issued specifications for the Mk1 flying helmet, fitted with wireless earpieces and a detachable oxygen mask. So, by the end of the war in 1918, the Air Ministry had defined the flying clothing issue to pilots and observers and this is shown below along with the rates chargeable for lost kit.

This essentially defines the official flying clothing issue at December 1918 and these formed the first of the RAF stores reference numbers (prefaced with 22C/) approximately from 22C/1 to 22C/10 (e.g.22C/5 Caps Fur-lined). Oxygen equipment has a 6D prefix and electrical equipment for clothing a 10A prefix.

In the absence of documentary evidence (eg FS Form 20 or certificate) each						
pilot or observer will be deemed to have received a complete outfit, and will be						
charged with the value of any article not forthcoming.						
A complete outfit consists of the following articles:						
Boots, thigh or knee						pairs 1
Cap, fur-lined						I
Gauntlets						pairs 1
Gloves, silk						,, I
Goggles, mask (without glasses)						,, I
Glasses, triplex, tinted						,, I
Glasses, triplex, non-tinted						,, I
Suits, aviation; or jackets, leather						Ι
Overshoes, gaitered						pairs 1
This order will be repeated in the orders of all formations of the RAF, both at						
home and overseas.						

The rates chargeable against individuals deficient of flying kit are as set out below: £, S d Boots, thigh ... 3 18 . . o pair knee . . ,, . . ' . . 2 18 4 ,, Caps, fur-lined (summer) 12 o each (winter) 8 ,, I 3 ,, Gauntlets, observer's, old pattern ... pair . . 17 . . 0 . . pilot's, old pattern . . ,, . . 2 0 I ,, pilots' and observers' (new pattern) ,, 17 0 ,, linings, worsted Ι •• . . 9 ,, Gloves, silk 6 9 . . ,, Goggles, mask, Mk I (without glasses) 12 0 ,, Mk II (without glasses) • • 12 0 ,, Glasses, triplex, tinted 5 7 . . ,, non-tinted 4 7 Suits, aviation (Sidcot) . . 7 16 • • 6 each . . Jackets, leather . . 6 7 6 each Overshoes, gaitered ... • • 9 10 pair • • Adjustment of stoppages will be made as laid down in Weekly Order No 903 of 1918, as amended by Weekly Order No 1071 of 1918.

Weekly Orders 5 December 1918

Air Ministry

Part 2 1918 to 1945

2.1 Between the Wars 1918 to 1939

At the cessation of hostilities, demobilisation of the RAF was both dramatic and quick. The RAF strength was reduced from 280 Squadrons to just 28 and Lloyd George's '10 year rule'^{*} ensured that the small amounts of finance available was used by the RAF, perhaps necessarily, to purchase and maintain aircraft rather than ancillary equipment. Similarly for research and development the Royal Aircraft Establishment portion of the Air Estimates was only between 2.5 and 3% (Caunter, 1949); not much in that for aircrew clothing development when considering the basic need for research on aerodynamics, structures, materials, communications and engine development.

Notwithstanding these financial restrictions, these inter-war years were filled with the yearning to be able to fly faster, higher, longer and break aviation based records. Private flying rose in popularity and flying clubs were formed to cater for the need. The aircraft, however, did not change significantly and military models were essentially no different from the WW1 concepts and this was particularly apparent in the area of flying clothing. The major threats still remained the cold and the blast of the slipstream. War surplus clothing was widely available on the market and a Sidcot suit, a leather coat or just overalls were the normal wear for civilians.

In the military, the Sidcot suit became the preferred flying suit and by 1922 the leather coat and trousers were fully withdrawn from the RAF inventory. Improvements in the basic Sidcot suit included fireproofing and the RAF 1930-pattern suit was an all-in-one rubberised linen suit of

^{*} No war was likely within the next 10 years

grey/green colour and this was later superseded by the 1940-pattern suit. The suits were fitted with a detachable fur collar and a large pocket on each knee and fastened with the newly developed technology in the form of the zip fastener. A woollen or a quilted kapok lining was available but not always popular due to its lack of adequate ventilation.



Hulton Picture Library Radio Times

Figure 10 Alan Cobham and Sir Sefton Brancker refuelling their DH50 on their routeproving flights from London to Rangoon. Cobham, piloting from an open cockpit, wears a Sidcot suit and Sir Sefton (travelling in an enclosed compartment) needs less protection except for the feet

2.1.1 Electrically heated clothing

As the extremities of the human frame, the hands, fingers, feet and toes, generally suffer more from cold exposure, it was these areas that needed to be adequately protected. The WW1 issue of knee or thigh boots, often worn with socks with multiple loose layers of silk and wool were superseded by the 1930-pattern boot; a knee length, light brown suede-boot lined with sheepskin with a rubberised section covering the foot. This rubberised covering prevented the lower areas of the boot absorbing water when traipsing across the apron to the aircraft and the water subsequently freezing in flight.

In spite of the many technical, operational and installation problems, it was recognised that electrical heating remained a prime solution to the problem of cold and, post-WW1, research and development effort continued in electrical heating of flying clothing. The distinction needs to be made between electrically heated clothing and clothing that is wired (electrically wired) to conduct the electricity to the heating clothing at the extremities i.e. generally heated gloves and boots. In the late 1920s Farnborough produced an electrically wired suit which was tested into the 1930s but was only issued to a few bomber and high-altitude meteorological observation crews. Such development continued well into WW2 and was further developed in the Cold War period but only used for specialist purposes as, by then, cabin heating generally provided an adequate alternative.



Airlife Publishing (1979)

Figure 11 The 1930 pattern boot with the protective rubberised covering on the lower foot and the Triplex goggles used by the Military and sold commercially by Dunhills and other companies. The surplus at the end of WW1 and the continued commercial sales made these well liked goggles popular through the inter-war years and into early WW2.

The need for good sight and clear vision has always been paramount for pilots and protection of the eyes from air-blast through the use of goggles was generally well catered for. In WW1 the Mk I and Mk II goggles were the approved RFC issue available with clear (Mk I) or tinted (Mk II) Triplex lens and the war surplus ensured that these were utilised well into the 1930s. Identical goggles were sold commercially and simply bore the Triplex trademark. By 1933 these were superseded by the Mk III, which, unlike the flat lenses of the previous marks, had a curved plastic lens and some distortions meant that they were not universally liked or used – resulting in the continued use of the Mk II types up to, and often through, WW2.

2.1.2 Breathing systems

The increasing ability of RAF aircraft to fly at higher altitudes in this period resulted in a range of more sophisticated oxygen masks & delivery systems and aircrew had finally accepted the oxygen mask as an efficient way of delivering the life-saving oxygen. Initially the Mk II mask was virtually identical to the WW1 Mk I type but was made of black leather lined with fur to

Aeroplane 1916

reduce leakage and had a small opening at the front to enable either direct-voice communication or via a hand-held microphone.

By 1930 the Mk II and the later 1921 pattern masks had been superseded by the introduction of the Type A mask. It was constructed of waterproof cloth instead of leather with a carbon microphone housing clipped into the opening in the front of the mask. This mask was short lived with the Type B (stores ref 6D/100) being introduced in 1933 and this variant was used up to 1939. Constructed of brown water-proof twill lined with linen it had a 2 1/2 inch ring sewn into the front which could be fitted with a microphone or just a chamois leather plug. Whether there was a Type C is shrouded in mystery; it never received an official stores reference number. The next in production was the Type D mask, made from green melton wool with a chamois lining, which was introduced in the late 1930s and was the mask with which the RAF started WW2 and used throughout the Battle of Britain.



RAE negative FAST Archive



2.1.3 Flying helmets

The evolution of the flying helmet through these inter-war years was, like other areas in flying clothing, quite limited. The RAF was serving both in the temperate climes of Europe and on the North West Frontier of India and Iraq – a somewhat hotter and sunnier climate. Flying in

the open cockpit bi-planes of the time the sun shone relentlessly on the pilot and pilots often wound light cloth around their necks to prevent serious and injurious sunburn. To combat this, the RAF supplied the specialist Type A helmet for use 'East of Malta'. It comprised the body of the traditional pith helmet complete with brim, ear flaps and secured under the chin. Constructed of lightweight cork and covered with a light khaki drill-fabric, it provided adequate protection but was limited in its use as higher aircraft speeds in open cockpits became more prevalent after the 1920s. It was finally superseded by the generally issued Type D helmet in 1941.

The prevalent helmet of this inter-war period, however, was either the WW1 helmet or the 1930 pattern helmet. This latter helmet was made of chestnut brown chrome leather lined with chamois leather and was elasticated at the back better to suit the wide range of head sizes. Either radio-telephones or acoustic Gosport Tubes were accommodated by ear-pads. By 1936 the Type B helmet was being introduced, similar to the 1930 pattern and designed to make the best use of the Type D oxygen mask.



Airlife Publishing (1979)

Figure 13 The Type A helmet (left) was used solely 'East of Malta' and provided some respite, in open cockpits, from the blazing sun at altitude. The Type B helmet (right) was introduced around 1936 to accommodate the latest developments in radio-communications.

The major differences were confined essentially to large-domed and zippered ear-pads and the back of the helmet was split with a Bennet quick release buckle, pulled together to fit (and apart for a quick release) The electrical wiring for the earphones was external on this helmet. The D Type oxygen mask was attached by two press studs. This was the helmet and mask with which RAF crews went to war in September 1939 – at least in the European theatre.

In the early 1930s the expanding use of the supercharger had enabled aircraft engines to produce power at higher altitudes and allowed world altitude records to be attempted, both as prestige for the RAF and for Great Britain and to develop oxygen, and other, equipments for sustained high altitude flight. The RAF and RAE Farnborough had been carrying out high

altitude flying for both meteorological flight and for experimental purposes (Taylor, 1933) and a 1921 pattern helmet/mask combination was the system used. Similar to the Mk I helmet but with lace-up earphone pockets and a system of buckles and straps to attach the oxygen mask securely, the mask was of fur-lined leather with a microphone or blank fitted into a dome-shaped aluminium housing at the front end. The continuing problem in the oxygen mask was the risk of exhaled condensation freezing in the low outside-air-temperatures and blocking the inspiratory or expiratory valves or the oxygen delivery systems; further problems occurred with freezing of the goggles and the resulting lack of vision. These were partially resolved by the use of electrical heating,



Greer and Harold (1979)

RAE Negative 33357 December 1940 FAST Archives

Figure 14 Early in WW2 this fighter pilot wears the Type B helmet, the Type D fabric oxygen mask and Mk II goggles. The goggles on the right are the experimental Mk VIB type with the Polaroid pull-down shade

In 1932 Cyril Uwins, the Chief Test Pilot of the Bristol Aeroplane Company, reached 43,976ft in an open-cockpit Vickers Vesper, becoming the first Englishman to hold the world altitude record. This again needed a level of experimental specialised equipment. The standard RAF oxygen apparatus was used but modified to allow pure oxygen to be breathed and the supply needed to be manually set on the regulator for different altitudes. In 1933, on another high-altitude expedition, a Westland PV3 flew over, and circled, Mount Everest – an indication that these altitudes, of around 30,000ft, could be reached conventionally without too specialised equipment.

However, to fly at altitudes above 45,000ft, specialised flying clothing was required which allowed oxygen to be breathed under pressure to maintain the diffusion gradient between the lung tissue and the blood at a level high enough to maintain sufficient oxygenation of the blood. One solution was to envelop the pilot in his own pressurised environment – the full pressure suit. The Air Ministry showed some interest in this high altitude work, and issued Specification 2/34, in June 1934, for a research machine capable of reaching at least 50,000ft with a wing loading not exceeding 9 lb/square foot and a span loading of not more than 1.4 lb/square foot (Sturtivant, 1990). This led to the Bristol 138 series of aircraft.

As part of this programme, Haldane and the British specialist firm of Siebe, Gorman & Co Ltd arranged, in conjunction with the Ministry technical staff, to make and submit for trials a highaltitude suit that would be appropriate for high altitude aircraft flight. It was made of rubberised fabric, made in two parts and joined around the waist by a flexible steel band. The helmet was also of rubberised fabric which incorporated a large, double layer, curved visor. A closed circuit breathing system was incorporated using a chemical absorber to remove the expired carbon dioxide and the suit was inflated with oxygen to a pressure of up to 21/2 psi. Tested at Farnborough in the pressure chambers up to 80,000ft, it was first used in 1936 by Sdn Ldr F D R Swain, reaching 49,967ft and later by Flt Lt M J Adam who reached 53,937ft (Figure 15). Both of these flights secured the World Altitude Record for Britain. However, the main disadvantages of the full pressure suits remained, in that it was unwieldy and restricted limb movement which, although just acceptable in these single experimental flights, would not be



FAST Archive Flt Lt Adam 30 June 1937

FAST Archive Sqn Ldr Swain 27 Sept 1936

Figure 15 After some preliminary trials of the Siebe-Gorman manufactured full pressure suit,
Sqn Ldr F R D Swain DFC, flying in the new supercharged Bristol 138A monoplane, took off from Farnborough on 27th September 1936 and 70 minutes later reached an altitude of 49,967ft - a new world altitude record (Swain, 1936). In early 1937 it was broken by the Italian, Pezzi, reaching a height of 51,361, but regained by Flt Lt M J Adam on 30 June 1937. On this occasion the 138A, used for the 1936 record attempt and originally designed for 54,000ft, had been modified by reducing weight and propeller modifications. This time a height of 53,937 ft. was reached and the record regained

considered suitable for operational flying. This problem of lack of flexibility would dog its development until the early 1960s.

2.1.4 Overalls

In many photographs of the inter-war period, particularly at air-displays, RAF flying teams are seen dashingly dressed in a white overall. These were issued to RAF pilots for air-displays and were used as a 'mark of status' up to late 1940 for all of those who had flown in those formative days. Also, many of the newly formed RAF Auxiliary prior to 1939 often provided much of their own flying clothing and opted for the unlined white cotton overalls purchased from the many commercial suppliers. The overalls were also available in a dark blue or black cotton, so pilots had a choice of colour but although used by a few during the Battle of Britain, clothing after this period of the war became more specialised and their use fell by the wayside.



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Figure 16 A selection of flying clothing worn by pilots of the London Air Defence at Kenley 1928. Sidcot Suits and Fug boots (still) and the 'prestige' flying overalls

2.2 World War II: 1939-45

Up to the start of, and into the beginning of, World War II little had changed in these inter-war years. Late in this period aircraft, both Bombers and Fighters, were changing to closed cockpits and higher speeds, the closed cockpits providing greater protection from air-blast and the cold. However, cockpit heating remained glaringly absent and aircrew continued to suffer from exposure to the low temperatures at altitude and oxygen masks and systems still failed from the same freezing problems that had happened in WWI – particularly in the longer range aircraft.

The standard-issue kit comprised the 1930-pattern flying suit, a development of the WW1 Sidcot suit of a grey-green rubberised material, with a detachable fur collar and an optional quilted lining, all of which were worn over the standard service uniform (often complete with tie). The flying helmet was the Type B, designed to take the Type D oxygen mask. Mk III/A goggles were still being issued, but the Mk IV and IVA goggles were coming into use. The standard flying boot in use at this time was the 1936-pattern black leather sheepskin-lined boot and over the top of this ensemble was worn the 1932-pattern life-saving waistcoat*. Also the

* A flotation device

Irving thermally insulated sheep-skin jacket and trousers were beginning to be issued, but with the bulk of the suit and the restricted sizes of the fighter cockpits were not universally used and

"moreover, when it was worn occasionally to stave off the misery of winter cold, the jackets with the hood attached were a positive menace as, turning quickly to search for the German fighter on his tail, the pilot's face was apt to disappear into the woolly lining of the hood, that part of the garment not turning with his head" (Neil, 1982)

However, they were of considerably more use in bombers where there was more space and they provided more protection against the cold over the longer sortie times. Probably the greatest risk in interceptor fighters of the Spitfire and Hurricane type was the fuel fire hazard. With a fuel tank virtually situated over his knees and with, obviously, little room to escape from the fire, other than abandoning the aircraft, fires developed very quickly and temperatures of several thousand degrees were generated within seconds and the hands and face were particularly vulnerable. For the hands there was suitable protection from the multiple layers of glove. First, the soft cape leather next to the skin, then silk inners and finally the leather elbow length gauntlets which, although adequate protection against fire, still provided limited protection from the cold at altitude. As far as the face was concerned the leather helmet and oxygen mask provided reasonable fire protection when combined with suitable goggles. Early in the war many aircrew preferred the old Mk II goggles to the more used Mk IIIs, but the Mk IV and IVA were coming into service. Introduced in August 1940, the Mk IV series were of complicated construction with a large metal loop which held around the 'doughnut' ear-pads on the Type B helmet and kept in place by press studs. They were the first goggles with split-lenses and some had a polarised screen which could be swung down to protect the eyes against the sun.

During the Battle of Britain the English summer was one of those rare hot periods and, during the sometimes long stand-by periods, RAF fighter pilots found the standard-issue flying suits hot and uncomfortable and the average pilot flew in his blue service dress uniform, the life-saving waistcoat – locally painted with yellow aircraft dope - the Type B helmet, Mk III or IV goggles and the Type D, green canvas, oxygen mask and a variety of boots, usually the 1936 pattern (Figure 17).



Imperial War Museum

Figure 17 A variety of flying clothing, worn by the pilots of 242 Sqn in 1940 at Duxford, includes the Sidcot Suit and two colours of 'prestige' overalls

During periods of war there had always been an operational need for specific and rapid development of flying clothing and equipment for specialised needs. This is amply illustrated by a particular development in late 1940. By October 1940 the day-battles of the Battle of Britain had ceased but night bombing by the Luftwaffe continued. This required interception by night-fighters, but this specialised development had been ignored and a collection of generally unsuitable, but available, aircraft types were used - Blenheim, Hurricane and Defiant. Specific problems had arisen in the Defiant from the small escape exits in the gun-turret. This required a special parachute-suit and GQ designed and produced a 'parasuit' (also known as the 'rhino' suit) which integrated the harness and parachute in a single torso-covering garment, small and compact enough to allow adequate escape (Figure 18). With the rapid development of AI (Airborne Interception) Radar and its fit to the more appropriate Beaufighter and Mosquito, this specialised need later disappeared.



Imperial War Museum CH874 Figure 18 The GQ 'Parasuit'

2.2.1 Breathing systems

Unlike the Germans who, in 1936, had developed the Auer A-824 demand regulator, British oxygen systems still used the constant-flow approach which was, of course, wasteful with oxygen being supplied during the necessary inhalation phase and, unnecessarily, during exhalation. In essence, aircraft were carrying over twice the amount of oxygen storage (in heavy cylinders) than was needed with the resulting increases in aircraft weight, particularly bombers with their longer duration sorties. All aircraft, at that time, with their limited engine power needed every possible reduction in the weight of ancillary equipment to carry higher bomb loads or, for fighters, for better performance.

In 1939 the RAF Physiological Laboratory, formed in August 1939 and then working as an RAE Department (originally named 60 Department, subsequently renamed 17 Department), and the RAE Instrument & Physics Department seized the moment to produce a system that had been long in gestation, but considered unnecessary by the RAF in the bi-plane era, that would eliminate this particular problem. The RAE design and build of the prototype Economiser – nicknamed the 'Puffing Billy' – was completed by mid-March 1940 and lab and flight tests had confirmed that the PB Economiser was satisfactory from a physiological view-point (Figure 19) (RAE, 1940). The weight saving on an aircraft of the Wellington type by the reduction in number of oxygen bottles was some 500lbs. By September 1940 it was decided that 1000 Economisers should be retro-fitted, mainly to Spitfires, with all new builds fitted in production. Bombers were fitted with the developed Mk II and were used throughout the war (RAE, 1941). It remained in service in the Avro Shackleton and Jet Provost Mk III well in to the 1970s.

2.2.2 Protection against acceleration

As the war progressed there was a natural evolution of the basic flying clothing – sometimes to improve performance and at other times to reduce costs. In addition, in areas where the developing performance of the aircraft affected the efficiency of the pilot and crew, specialist solutions were promulgated. One of these latter areas was in the effects on the pilot of the turning performance and rate of turning in fighter aircraft.

The concerns had arisen from reports by pilots flying the Schneider Trophy flights on the tendency to 'black-out' during the necessary high-speed turns around the course. It had been decided during practice flights with the S.6B that a turn producing $4 - 4\frac{1}{2}g$ was the optimum rate to save the most time and which would produce a 'grey-out' with only partial loss of vision. During the practice for the 1929 contest in the S.5, the RAF pilot Richard Atcherley described his experiences:

"I went "out" halfway round a turn at Calshot Castle, and flew completely unconscious at about 500 ft halfway back to Cowes before regaining my senses. Even then there was a very frightening lapse of seconds when one realised one was flying and had been "out", but still could not see or move one's hands' In my lapse of consciousness, I dreamt I was sitting in the housemaster's garden at Oundle in a deck chair ... I could see the flowers – and hear the bees – the noise of which got angrier and angrier, until I started to wonder where I had heard that noise before. Then I realised that it was the Napier engine in the S.5 and gradually came the frightening realisation that I was going like a bomb and might expect to hit the water at any second I was a very frightened officer!" (Mondey, 1975).



3.1 Struan Marshall's proposal for an oxygen regulator as sketched by Mr Eric Taylor of the R.A.E. 1 Oxygen cylinder, 2 reducing valve and pressure gauge, 3 flow indicator, 4 oxygen inlet valve, 5 injector, 6 adjustable air inlet, 7 lever operating oxygen inlet valve, 8 breathing bag, 9 inspiration valve, 10 flex tube, 11 mask, 12 expiratory valve.



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Figure 19 A sketch by RAE's Eric Taylor in January 1933 based on a proposal by Gp Capt Gerard Struan Marshall OBE of the layout of the Prototype Oxygen Economiser (Puffing Billy) for the Physiological Laboratory and a photograph in 1940 of the finished experimental prototype

Wh+ilst a serious problem for the Schneider Trophy pilots, it was clear that the scale would be exacerbated during plane-to-plane combat. The Schneider Trophy pilots had tried body belts - to no avail* - and by 1940 considerable empirical research by the RAF Physiological Laboratory in a number of flight trials at Farnborough had shown that the adverse effects of increased g were caused by blood pooling in vessels in-line with the g force (i.e. in the 'z' axis of the body).

^{*} Body belts had been previously suggested by Struan Marshall and investigated in 1934-6 by a Flt Lt Wallace (in a University of Glasgow MD thesis).

Experiments on three types of body belt produced no significant increases in g threshold and the approach was then changed to wider lower-body coverage by the use of hydro-static leggings, where an increase in threshold of 0.5 g was attained.

This technique was never to enter RAF service as, by that time, the work of Franks in Canada was evolving. The idea of using water to provide g protection had been promulgated by him in 1938 and Canadian Government funding had been sought to carry out the work, to no avail. But a private benefactor philanthropically provided the funding and Franks was able to make, tailored to himself, a garment made of non-stretch fabric containing water-filled bladders which fitted over his abdomen and lower extremities (Figure 20). After similar reluctance to provide a suitable aeroplane for flight research, a vintage bi-plane was offered and trials carried out before structural engineers put an end to the high-g manoeuvring on safety grounds. But in that short time, Franks had managed to show significant increases in the raised-g threshold.

In mid-1940 the RAF agreed to supply a Spitfire to Canada for further flight trials and in early 1941 Franks came to Britain to demonstrate and develop his suit. Considerable development took place and once experimental flight reports had been completed, two operational squadrons carried out preliminary service trials. These demonstrated the raising of black-out thresholds by up to 3g and reduction of the fatigue from high-g manoeuvres.

After some further refinements, the Franks Mk III suit was produced, issued for trial to the Fleet Air Arm, and was successfully used in 1942 by Seafire pilots of 807 Sqn at Oran in French North Africa. Later in the war, on D-day+1, Seafire pilots were still using the g-suits and Mike Crosley, flying the Seafire in combat against FW190s and Me109s notes:

"Thanks to my g-suit I remained conscious in the steep pull-out and regained altitude astern of their ar**-end Charlie after all" (Delve, 2007).

The suit was little used by the RAF, partly because of worry that with such g-protection pilots might exceed the structural limitations of the aircraft, and the security limitation that aircrew were forbidden to use this secret system over enemy territory, largely because there was no evidence of g suits in shot-down German aircraft.

As an alternative to water-pressure to inflate the suit, the use of air-pressure was promulgated in Australia by Frank Cotton, whose 'pneumo-dynamic suit' was a two-piece gradient pressuregarment made, like the Franks suit, from rubber and an outer layer of inextensible fabric (Gibson and Harrison, 1984).

After development in Australia, by the end of 1941 it was ready for trials with the RAAF and a suit was sent to Farnborough, to the RAF Physiological Laboratory, for evaluation. For various reasons the PL was unenthusiastic, partially because that the ancillary equipment to operate the suit was bulky and heavy – the Franks suit needed no connection to the aircraft - and partly because the Franks suit was in development at the same time, with a production contract let, and time and money precluded the development of both simultaneously. However, the good performance of the suit *per se* was recognised and it was recommended that it should be pursued further – not by the RAAF but by the RAAF. The suit was developed and used by the RAAF in late 1943 by Spitfire pilots flying from Darwin against the Japanese.

It was one of those anomalies of aviation history that the air-operated suit – where the future lay – was shunted into a side-line. The Americans, however, took a different view and embraced the operational potential with vigour.



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2.2.3 Helmets and clothing

By the end of 1941 the Type B helmet was superseded by the Type C which was intended to be used with the later Type E and F oxygen masks. A Type E helmet variant was the same pattern as the Type C but in an aertex material and was produced for the other RAF Commands such as Coastal Command flying long sorties in their Sunderlands and Liberators.

Outside the European theatre of war, the RAF were fighting on a number of fronts – North Africa, Malta, Crete and Greece – with their hotter climates. Although it was hot on the ground, at altitude it still remained bitterly cold. Aircrew were issued with the standard ground-clothing of khaki shorts, tunics and trousers but the only desert related issue of flying clothing was the D type helmet made of fabric and with a rear flap to protect the neck against the sun. Consequently a variety of flying clothing was worn, ranging from the 1930 or 1940 pattern flying suit to flying just in tunic, shorts and desert boots.

In 1941 a new style of flying dress was introduced, initially to aircrew only, in the form of Suits, Blue/Grey, Aircrew (blouse and trousers). Known later as 'battledress', it became the standard wear for all RAF personnel. Similar in design to the Army battledress it was waist length, made of blue/grey serge wool, belted at the waist and with two breast pockets with flaps. The trousers could be buttoned tightly around the ankles allowing fitting more easily into flying boots and had a single pocket either with a flap or button closure. It changed very little during its lifespan, the only conspicuous change being for pilots of the Tactical Air Force after D-day who were issued with an Army khaki battledress as the blue/grey colour of the Battledress could be

Figure 20 The prototype Franks anti-g suit in December 1941and the same suit worn under the uniform and being filled with water

mistaken for the German *feldgrau*, if aircrew were returning to Allied lines after being shot down, and khaki was also a better camouflage against German troops.



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Figure 21 A selection of the flying clothing worn by Gladiator pilots in the Middle East in the early war years. A miscellany of White and Khaki flying overalls, Type B helmets with Type D oxygen masks, 1936 pattern boots and desert boots, tinted Mk II goggles and 1932 pattern life jackets

The needs of bomber crews were often different than aircrew in smaller aircraft. The major difference was, of course, that bombers spent more time in the air – often having to sustain flight for more than five to six hours in the early stages of the war. The major problem was the cold and draughts and even if there was some rudimentary heating it did not extend to all aircrew stations and the rear gunner drew the shortest straw in nearly all bombers throughout the war. Although electrically heated clothing would have provided some respite, it invariably failed and bomber crews took the more pragmatic and reliable route of using the Irvin type heavy fleece or fur-lined suits with multiple layers of underclothing; bulky, but there was generally room in the bomber's aircrew positions, although not always in all aircrew stations. The standard RAF issue helmets – the B or C type – were used, similarly the multiple layers of gloves, the standard flying boots and oxygen masks.

In spite of their shortcomings, electrically heated suits were used, and essentially two quite different systems were in use. RAE, in the pre-war years, had developed a system for use with high-altitude meteorological crews, and this was developed around the Irvin Thermally-insulated Flying Suit. With this system the jacket and trousers were not directly heated but wiring sewn into the jacket and down the sleeves where plugs fed the electrically-heated gloves and boots. For extended flights at high altitude an electrically heated waistcoat was available. This was a quilted brown waist length jacket – often referred to as a 'kimono' by aircrew from its wrap-round fastenings – and was also often used by Spitfire pilots as it fitted under their normal flying kit; the Irvin suit was generally too bulky to easily fit into the cramped cockpit.



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Figure 22 Battledress (left) worn by Wg Cdr Beamont of No 150 Tempest Wing mid-1944. The two Blenheim crew on the left use the Irvin jacket and the associated trousers whilst the operator on the right wears a Sidcot Suit and leather gauntlets

The other solution was an electrically wired version of the ubiquitous Sidcot suit – now the 1940 pattern suit - with power being fed to press-stud connectors on each cuff and leg to fit the D-type electrically heated boots and gloves. The dc power systems of different aircraft, 12V and 24V, did not allow standardisation, which was only accomplished in 1944. Adaptors for plug or press-stud connections were produced in 1942 allowing use of either suit in an aircraft. Late in the war the Type H system was introduced where gauze wire strips acted as the heating elements and these were sown into the clothing. Alternative snap connectors placed different distances apart allowed the suit to be used with either 12V or 24V supplies. This H type was standardised in 1944.

2.2.4 High-altitude breathing equipment

With the introduction to Bomber Command of the B-17 in 1941, two major problems arose from the ability of the aircraft to fly at over 35,000ft and operate at, with a full bomb load, at 26-30,000ft with normal sortie durations of up to six hours. One was that in the region of 30,000ft, quite apart from the intense cold and hypoxia, the 'bends' was a medical risk. This is a result of gases dissolved in the blood and body tissues at altitude emerging as bubbles during descent to lower altitudes. The risk is always present when flying above 30,000 ft and can range from severe pain to fatal. This was ameliorated by careful choice of aircrew for Fortresses who were rejected if they were unable to pass muster during tests in the decompression chambers at 32 to 35,000 ft for four hours. The other was the ability to provide the correct oxygen supply to the crews and development of a new mask was started at Farnborough which, after much collecting of information and testing in the laboratories and in-flight, resulted in the Type E* mask. This mask was designed to avoid the icing of the inlet and exit valves and was slightly smaller with improved vision. It was operational from early 1941 but the development for the next generation of masks went on when crews were critical of the low-altitude breathing resistance and excessive condensation in the mask, which collected on the oxygen inlet valve and froze. The result was the Type G mask which virtually eliminated valve freezing problems by introducing the oxygen at the upper part of the mask and was lined with suede to improve comfort and enabled that part of the mask in contact with the face to remain dry. Priority of introduction into service was for Bomber Command which started in 1942 at the beginning of significant offensive operations. A final war-time element was the Type H mask, which was similar in design and build to the Type G but with a few improvements and which incorporated a smaller and lighter microphone. This was introduced in 1944.



FAST Archive RAE Negative 37365

FAST Archive RAE Negative 40724 PL 28.5.1942

Figure 23 The experimental oxygen mask with the modified oxygen inlet tract manufactured for the RAFs Fortresses which formed the basis of the E Type and the 1942 Altitude Chambers of the RAF Physiological Laboratory which tested the altitude susceptibilities of Fortress crews

A further important operational area requiring high altitude flight and where it became necessary to develop greater levels of specialist flying clothing was in the increasingly important photo-reconnaissance role. Right from the start of hostilities it was recognised that up-to-date information on the current state, the intentions and movements of the enemy would be essential for tactical & strategic planning and action – and aerial photography would provide the solution.

Early attempts using the Blenheim IV were unsuccessful, partly because they were too slow and vulnerable to the Luftwaffe Me109s and 110s and partly because they could not reach operationally effective altitudes to provide inherent levels of protection against interception. The development of suitable aircraft has been well reported (Conyers Nesbit, 1996; Brookes, 1975) and it was Sidney Cotton that again provided the stimulus and pragmatic proof that his methods actually worked. The end result was that towards the end of the 'phoney war', the RAF had two Spitfires, fitted with the help of RAE Photographic Department, with suitable cameras. The first operational flight of the Spitfire took off on 18th November 1939, flying over the German border as far as Aachen and bringing back high quality photographs from an altitude of 33,000ft. At this height, outside-air temperatures were often -55^o C and without cockpit heating there were high risks of frostbite and significant risk of deterioration of mental and physical capability.



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Figure 24 The Type E* mask (left), a combination of the better parts of the Type E and F experimental masks, was eventually replaced by the G Mask (right) which virtually eliminated the problem of breathing moisture freezing on the oxygen inlet valve Both wear Type C helmets and Mk VII goggles are used

For these relatively short flights from the French mainland, a well-fitted 1940 pattern flying suit or the earlier Sidcot suit, enhanced with plentiful layers of underclothing (as in WW1) sufficed, but it was obviously not going to be adequate for the later operational necessities of higher and longer operational sorties

Also, in 1941, a further problem with a similar solution arose. The Ju86 reconnaissance aircraft were crossing Britain at heights of 43 to 46,000ft, a height which made them invulnerable to interception by the RAF. Unlike the German Junkers, the British did not have pressurised cockpits in their operational interceptors and had to rely on make-piece interception with stripped down Spitfires (Operation Windgap), and whilst the Spitfires could just reach these altitudes safely, the pilot could not due to lack of oxygen. The common solution to both of these areas was in developing suitable protection for the pilot to survive and operate normally at these extremes of altitude. For the immediate photo reconnaissance needs, breathing 100% oxygen was adequate but with the risk of mental and physiological deterioration of the pilot – who still needed all his wits about him to resist interception by German fighter aircraft. It was recognised that such operational sorties were inevitably going to increase in duration, height and radius of action, with proportionally increasing problems.

Up to 30 to 33,000ft survival can be attained by breathing 100% oxygen, but above this height pressure breathing is needed where oxygen under pressure is fed into the lungs. Under such pressures the lungs could be damaged and respiratory fatigue increased. The solution would be to apply a counter-pressure to both the respiratory tract and the outside of the chest and abdomen.

The system finally used had been designed and built by a Canadian, Professor H.C.Bazett, where counter-pressure of ¹/₄ psi, and later ¹/₂ psi, was applied to the chest by inflating bladders in a waistcoat and oxygen supplied under pressure from a bag worn around the trunk (RAE, 1931).



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Figure 25 Spitfire PR1A pilots in November 1939.
The PR pilots were flying from Seclin and Coulommieres in Northern France. To combat the cold at the 33,000ft working altitude, three of the pilots wear the Sidcot suit/ 1940 pattern flying suit and scarves which provided almost adequate protection for the short sortie times that the Spitfires could fly on its 84 gallons of fuel .

Bazett came to Farnborough and worked at the Physiological Laboratory developing and improving his system and carrying out experiments in the decompression chambers and flight tests. Final versions were found to add 3 to 4,000ft to the altitude tolerance and it was flown to 46,000ft by the RAE Experimental test pilot Wg Cdr Roland Falk who noted "Although the system of breathing in no way replaces a pressure cabin, it may prove of great value for test work and also possibly for use in fighters in the case of urgent operational necessity' (RAE, 1943).

With pressurised oxygen being fed into the lungs, the current D type mask was too loose a fitting and the subsequent leakage made them totally unsuitable for use with the Bazett system. The use of a new oxygen mask – the F type – sealed all leaks around the face and, along with the PB

Economiser, virtually doubled the range of the early reconnaissance aircraft. This suit was of major use to the PR Squadrons, entering service in early 1944 and allowing PR crews to safely fly long and high sorties and formed the basis of the later partial pressure suits used in jet bombers (Figure 26).



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Figure 26 The Bazett suit used by the high flying Photo Reconnaissance Spitfires which, with its pressure breathing and chest counter pressure jacket, allowed a further 4000ft of altitude to be safely tolerated. The pilot wears a J type mask

By the end of the war, in mid-1945, aircrew generally were flying with the Type C helmet and Type G mask, battledress or Irvin Suits for fighters and bombers respectively, the 1941 pattern or 1943 pattern 'escape' boots and the 1941 pattern gauntlets. Depending upon type of sortie, geographical location and altitude, fighter or bomber crews were supplied with essentially the same flying clothing with specialist changes supporting the particular aircraft. It was the advent of the jet engine that would provide major changes in the way that flying clothing needed to be designed to protect aircrew against the potential future threats of the new era of military aviation.

Part 3 Post WW2 to the present

3.1 1946 to 1990

3.1.1 Protection against high altitude

The trend of aircraft design early in this period was finally towards pressurised cockpits and cabin conditioning which was essential for future jet aircraft designed to fly at speed and at high-altitudes and, to a large extent, this virtually eliminated the effects of the cold, hypoxia and decompression sickness (the 'bends').

Aircraft such as the English Electric Canberra, designed in 1945 against MoS Specification B.3/45 as a high-altitude unarmed bomber, in the Mosquito tradition, called for a cruising speed of 518 mph at 40,000ft and a service ceiling of 50,000ft. Air Staff Operational Requirement OR.229 (B35/46) called for a replacement for the Avro Lincoln with a four- jet bomber capable of delivering a 10,000 lb nuclear weapon at 500kn/575 mph from a height of 45,000ft, with a still air range of 3500 miles (but a later development increased to 5,000 miles and operational ceiling to 50,000ft).

The new range of RAF interceptors (Meteor, Vampire, etc.) were, of course, expected to be able to intercept and attack at these altitudes and since these altitudes and speeds were regarded as being the future norm for any enemy, interception times to altitude needed to be short enough to prevent enemy bombers, with their free-fall atomic bombs, intruding into British airspace and within bombing range of the major British towns and military installations.

Whilst aircraft cabins were pressurised, allowing aircrew to fly at up to 50,000ft with a cabin altitude of around 8,000ft and minimal use of oxygen, there remained the problem of structural failure of the pressure cabin or sudden de-pressurisation caused by combat damage. Protection would be needed to prevent the aircrew being either totally or partially incapacitated. This would require either a full pressure suit, giving the pilot his individual pressure 'cabin', or partial pressure protection allowing the aircraft to descend below 40.000ft where the normal oxygen systems could cope.

The early requirement for the V Bombers was for the crew to maintain the operating height and this needed a full pressure suit 'suitable for sustained flight at a cabin altitude of 60,000ft for 5 hours'.

For this full-pressure suit, RAE Mechanical Engineering Department (ME) formulated the concept and specification. Industry, in the form of Frankenstein in Manchester, Siebe Gorman and Baxter, Woodhouse & Taylor developed the suits which were then sent to ME Department for evaluation and onto RAF IAM for testing. Many suits and variations were tested – all of the same principles – but which varied mainly in the materials of construction, differing external connections, and in the traditionally difficult areas of flexible joints to allow free movement of the arms, hands, legs and feet. As this was a research programme, leading to development of an operationally acceptable suit, some of the research suits were just that and were cumbersome



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Figure 27 An experimental 1957 full pressure suit from Normalair used as a research tool in the MOD/RAE programme and the final two suits – the Type 51 and the Type B respectively – which, although a practical solution, could not fully meet the Ministry and RAF requirements.

but were constructed to concentrate on one or two aspects of research, such as flexible jointing. Research connections and programmes with the USA allowed US full-pressure space-suits to be obtained and tested, but were found to be not fully acceptable for this particular type of RAF operations. Two suits were designed jointly by RAE and Industry, one with Frankenstein called the Type 51 suit and the other by Siebe Gorman named the Type B suit (Figure 27). In spite of extensive testing, modifications and re-testing, neither type of suit fully met the Ministry requirements. One of the major disadvantages was that the suits needed to be individually sized and a large number of different sizes would need to be produced to fit the anthropometric range of RAF aircrew. This would be expensive both in initial production and maintenance during its service life.

An alternative was to use partial-pressure protection which would be unable to allow aircrew to carry out the sortie at high altitude but would give them adequate time to descend to a safe altitude if cabin decompression occurred. Providing pressure breathing was employed and counter-pressure applied to the body there was around one minute to descend from 60,000ft to 40,000ft to prevent incapacitation. This allowed a considerably simpler solution but, of course, did not meet the full Ministry specification. However, by this time it was realised by the RAF that such altitudes no longer provided protection from ground-to-air missiles and that this approach would be a suitable technical and financial compromise.

The first approach was to use an American 'Capstan' partial pressure (PP) suit with a British PP helmet and although this principle continued to be used by the USAF, and Russia and its satellites, it was only used in the UK during the trials at high-altitude of the Canberra (Figure 28). Again, the 'Capstan' suit was considered too complex and with a number of operational disadvantages that outweighed its' advantages. The solution for British aircrew was to use the principles of the WW2 Bazett jerkin and to extend the pressure bladder coverage to the lower neck, shoulders, groin and crutch area and which, with a pressure helmet and g suit, provided safety at 70,000ft for one minute and for longer at lower altitudes.

There was a potential operational need to fly even higher with the Saunders Roe SR.177, designed to reach 80,000ft but with a limit at 100,000ft, and this extra protection was resolved by the use of further pressure bladders to envelop the arms. John Ernsting of the IAM took this suit, with the addition of pressure gloves to prevent the tissue fluids 'boiling' at 63,000ft, to 140,000ft in the RCAF altitude chambers, staying at this altitude for one minute before descent to 38,000ft in 25 seconds (Gibson and Harrison, 1984).

In April 1957, Government politics had intervened and the defence White Paper of Duncan Sandys opted for missile defences and, apart from the EE Lightning, which was to belatedly enter service in 1960, all other fighters were ruled out. Thus the operational requirement for the SR.177 was cancelled and the need for protection at these extreme altitudes withdrawn.





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Figure 28 The American 'Capstan' partial pressure suit with the British helmet (left) and (right) a later development of a combined PP and Immersion Suit with the RAE/Taylor pressure helmet

3.1.1.1 Oxygen masks

At that time the RAF operated a number of interceptors whose operational ceilings were lower than these extreme altitudes but might occasionally need to reach above 40,000ft where pressure breathing was necessary and such pressures could not be accommodated in the H type mask. This mask had been designed for low resistance to breathing and pressurising the mask merely opened the expiratory valve. The obvious solution was to increase the stiffness of the springs controlling the expiratory pressures. To meet the contradictory requirements of low breathing resistance and increased resistance to higher mask pressures, a rotating knob was incorporated in the valve housing which would adjust the spring tension when required. This became the 'Oxygen Mask Type J'. However, there were still problems with sealing the J mask around the face against the oxygen over-pressure and a better pressure breathing mask, the Type M developed by Sqn Ldr Tony Greening, was introduced to be used with the pressure breathing waistcoat and continuous flow oxygen systems.

A further development, the Type N, was designed to replace the American A13A mask and be used with a demand system. In the late 1950s, the P series of masks were developed by Dr John Gabb with a new toggle to allow tensioning on the face. This provided a more efficient face/mask seal and enabled higher pressures to be held within the face-piece, allowed better vision and was more comfortable.



RAE Negative 104447 July 1942 FAST Archive



Figure 29 The Type M Oxygen mask, replacing the J type, was used to allow increased oxygen inlet pressures in the mask and thus pressure breathing with the expiratory spring pressures controlled by the rotating knob on the front of the mask. It has a re-designed face-piece and improved suspension harness.

This basic design finally became the universally used mask across aircraft types and the three services. The Q series were the same as the P series but smaller, to fit smaller face features, and the later S, T and V series were derivations of the basic P design for use in different aircraft types. A series of suffixes were added to the basic type designation (e.g.P1, P1A, P4, P6, Q2A, etc.) depending upon the accessories supplied with the mask. This design is still in use in 2014.

Thus partial protection was considered as an adequate solution and the use of the Taylor/RAE partial pressure helmet along with the pressure jerkin and g trousers were used in the Lightning. In the meantime research was looking into a simpler approach using just the current P/Q type oxygen mask with the pressure jerkin & g suit and this was found to be adequate to 56,000ft. This then replaced the partial pressure helmet which had provided a pressurised environment for the whole head and neck as well as the floor of the mouth and cheeks as, by now, research had shown that the pressure differentials imposed by pressure breathing of oxygen could be tolerated across the neck, eardrums and the soft tissues around the mouth.

3.1.1.2 Oxygen supply systems

The other critical part of the oxygen system was the mechanism for supplying the oxygen to the mask. The RAF, virtually right up to the end of the war, had still used the Economiser continuous flow oxygen system, which did not provide pressure breathing. The Germans, however, in 1936 had a demand system and after the war the Americans had taken advantage of the technology and produced the D-1 regulator, a modified version of the German Draeger regulator. This was the version that was fitted to the F-86 Sabre which the RAF purchased in the period of the conflict in Korea and was used with the US A13A oxygen mask. Although acceptable for use, the A13A mask/D-1 combination suffered from high resistance to breathing but was accepted as a compromise until a better mask/regulator system could be evolved.

The first half of the equation, the regulator, was a UK development of the D-1 regulator and undertaken by Normalair Ltd. Combined with research from IAM and RAE on the definition of acceptable characteristics for breathing systems, taking fully into account the dynamics of inspiratory and expiratory flows, a new series of UK regulators was developed and produced. The early series of these regulators were panel mounted in the cockpit, followed by the manmounted regulator and finally to the most recent which are seat mounted, combining the advantages of the other two types.

3.1.2 Protection against acceleration 'g'

The effectiveness of the partial pressure suits was dependent, to a considerable extent, upon the technologies incorporated in the development of the g suit. The RAF had, towards the end of the war, shown a distinct lack of enthusiasm regarding the use of g suits, but the Americans were more enthusiastic. Farnborough, however, was still interested from a research point-ofview, and the Physiological Laboratory was involved in testing and evaluating the various American suits. After US research into bladder sizes and pressures and the fabrics from which the suits were constructed, the first commercially made suits were tested both sides of the Atlantic and were very well received. A further factor, which was to remain crucial to the success of the operation of the suit, was the g valve which controlled the rate of inflation and the bladder pressures of the suit. Modifications were made to improve comfort by moving from a fully covering suit to a skeleton type of suit which was also lighter and cooler. This formed the basis of the RAF Mk 1 anti-g suit, which was again modified to use softer rubber tubing connecting the bladders and this became the Mk 2 suit. By now, the war was over and the RAF remained uninterested in the suit as 'so far as the RAF were concerned, blacking out did not provide any limitation to any form of operational activity ...' (Gibson and Harrison, 1984).

Perhaps this view was a consequence of the limited performance of the RAF's front line fighters just post-war, the Meteor and Vampire, and it was the Korean conflict that forced the RAF to review its policy on g protection. From the early days of this war it became clear that the days of dog-fighting were not over and the combat environment would be more severe with faster, highly manoeuvrable jets capable of high g. The RAF hurriedly purchased the F-86 Sabre from Canada.

There were two British suits available to the RAF at that time, the Mk 1 and Mk 2, and these were joined by the Type 3, a copy of the American skeletal type, designed to fit over the flying coverall. With the RAF now interested, some development took place, resulting in the production of the Mk 4, essentially a cut-away version of the Type 3, and the Mk 5, the same construction but with the air-inlet hose for suit inflation on opposing sides to cater for differing aircraft types. In operations in the Middle and Far East these suits were found to be hot and uncomfortable and in 1962 an IAM programme changed the fabric of the garment and rubber bladders and these eventually became the Mk 6 and 7 anti-g suits.

The g-suit (Figure 30), when pneumatically inflated, has five bladders which press on five areas of the body, the abdomen, the thighs and calves; inflation tightens the material around the sides and back of the leg, which prevents pooling of the blood in the feet and legs and also maintains blood pressure at the heart and brain. The cut-outs at the knee and groin allow mobility. The shoelace type lacings adjust the size to fit and once fitted to the individual pilot form a comfortable but snug garment. The shoelace fittings tighten over the thighs, leg and the

back of the abdominal bladder and are often covered by a velcro-closed flap to prevent snagging in the cockpit.

The onset of pressure in the suit is controlled by a g-valve, and pressure increases linearly with acceleration at around 8.6 kPa (1.25 psi) per g in UK aircraft [(10.3 kPa or 1.5 psi per g in the USA). In general the garment inflation does not start until +2g is exceeded, which prevents unnecessary inflation during turbulence, buffet and gentler turns. G suits can be worn inside or outside the flying coveralls

3.1.3 Protection against heat

With RAF commitments and operations in the Middle and Far East, daytime temperatures could reach 50 $^{\circ}$ C on the aircraft aprons and pilots on standby, dressed with thermally insulated clothing for high altitude flight, were suffering from heat overload – which was exacerbated by the kinetic

thermal heating of the airframe at high speed at low altitudes, together with the thermal output of the instruments, the radiant heat through the canopy and the heat produced by the physical work of flying the aircraft. Whatever was worn was not fully compatible with the different phases of flight. Cockpit air-conditioning was the obvious answer but was not available on the Vampires and Venoms of the period, due mainly to the aircraft performance penalties of the weight of such equipment and the reduction in performance because of drawing pressurised air from the engine to supply the cooling system.

An economical compromise was to supply cooling air to the pilot's flight clothing and this led to the development of the Air-Ventilated Suit (AVS). This comprised a nylon garment with a ventilation harness of narrow bore PVC tubing through which cooled air was blown. After flight trials in Khartoum in May 1950, development of this Mk 1 design, ventilating just the trunk and thighs, went into service in 1954 in Canberra and Venom aircraft. Between 1954 and 1957, IAM and RAE developed a whole body suit, the Mk 2, with better distribution of cooling and this design of suit stayed in RAF service until the early 1970s.

The fundamental disadvantage of this type of cooling is that it was primarily evaporative cooling, requiring pilots to sweat before cooling became effective. Heat transfer by conductive cooling would be a more effective and in 1959 Des Burton at the RAE Human Engineering Department promulgated the liquid cooled suit as an alternative. Water has a far greater thermal capacity than air and when circulated through a flight suit allows a more efficient absorption of body heat. Where some AVSs use some 700 litres/min of air to cool, the equivalent water flow needs to be only one litre/min (Gibson and Harrison, 1984). Prototype suits were produced by RAE in 1962, working in cooperation with Flt Lt John Billingham from the RAF Institute of Aviation Medicine, and reported in 1964 (Burton and Collier, 1954). The results were effective enough for NASA to request a demonstration of the RAE suit, which was demonstrated at Houston late in 1963. The effectiveness of the suit was suitably demonstrated and the Americans undertook a development programme of their own culminating, in the late 1960s, in the Apollo suit (Engel and Loft, 1979).

In early 1964 the RAF expressed an interest in the concept of liquid cooling. Over the next two years a number of developments were completed and these are well described in detail



FAST Archive Figure 30 The Mk5 g-suit

(Harrison 1978). However in March 1966 an IAM Staff Note, arguing mainly from the physiological viewpoint, came out strongly against the LCS. Concentrating on four physiological disadvantages, the conclusions of this Staff Note considerably hindered the research programme. This is discussed by Harrison (1978), who concludes on this episode *"The feeling remains, however, that the physiological assessments were coloured by preconceived notions regarding the operational suitability of liquid personal conditioning for aircrew"*

However physics prevailed, development flight trials continued and in 1972 a trial was undertaken in a Vulcan which achieved its objective of establishing the acceptability of liquid conditioning for aircrew. By the time that the LCS could have entered service the RAF had withdrawn from Middle and Far East operations and, apart from Cyprus, aircrew rarely experienced tropical or deserts environmental conditions and the need diminished.

The fruits of the years of research have not, however, been abandoned and developments of the original LCS, now called Liquid Conditioned Coverall LCC, is still available for current RAF operations in Typhoon providing cooling, or heating, to the upper body.



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Figure 31 The Mk 1 Air Ventilated Suit (AVS) of 1953 with short legs (left) and the Liquid Conditioned Suit (LCS) showing the myriad of water carrying tubes (right) often called the Water Cooled Suit



RAE negative FAST Archive

Figure 32 Testing of experimental high altitude flying clothing in the RAE Human Engineering Dept. pressure chambers and the testing, on the Farnborough Ergonomic Bicycle, of the suitability and comfort of the flying clothing when workload was high and body temperatures rising. The pilot wears the combined AVS / Pressure /Anti-g suits and the Taylor partial-pressure helmet, later used on the Lightning

For the more conventional aircraft sorties, such as those operating in northern Europe on the normal low/medium-level sorties, in the period from the Hunter and Swift right through to the Phantom, Jaguar and Harrier, the standard flying clothing was a simpler mix. Crews wore the standard aircrew coverall, with an immersion suit where over-water flying was involved, the standard helmet, gloves, boots and life preserver and the appropriate g suit. In the Harrier and Phantom the personal clothing was similar but the crew wore the individual skeletal torso harness to hold them in the ejection seat and other aircraft used the standard RAF combined harness which was part of the ejection seat ensemble (Figure 33). The oxygen regulators were aircraft mounted apart from in the Harrier, Jaguar and Phantom, which used the man/chest-mounted Type 317 regulator. In the winter more substantial clothing was worn in the form of a cold weather jacket and trousers. If the threat of chemical warfare was present the Aircrew Respirator No 5 (AR5) and NBC inner coverall was worn.

By the time of the introduction of the Lightning to service in the high altitude interceptor role, aircrew were required to wear increasing layers of individual protective clothing and the move was made to combine three of them into a single garment. This resulted in 1967 in the Combined Partial Pressure/Anti-g/Air Ventilated Suit that, with the Taylor Partial Pressure helmet which, with its opening visor that shut automatically upon de-pressurisation of the cockpit, provided the necessary high-altitude protection in an explosive decompression. The Lightning had both a high and a low altitude role and the clothing varied with the role as depicted in the Mk 3 Lightning Aircrew Equipment Assemblies (AEA) poster (Figure 34).



Courtesy of Martin Baker Aircraft Co Ltd

- Protective Helmet Mk2A, 3C series or 4B
- V type oxygen mask
- Type 317A chest mounted oxygen regulator
- Lightweight Boots
- Aircrew Coverall Mk 14A
- Life Preserver
- Anti-g trousers Mk7 or external Mk1
- Gloves and Boots
- Leg restraint Garters
- Immersion Suit (where appropriate)

Figure 33 A Harrier Pilot in the Mk 9 type seat wearing typical Summer Aircrew Equipment Assemblies fit



ML Aviation Co Ltd

Figure 34 The Aircrew Equipment Assemblies (AEA) for the Lightning Mk3 which had both a high and low altitude role, each role having different specialist equipment needs (zoom page to read details of poster).

3.1.3 Ejection seats and head protection

The coming of jet propulsion meant not only higher altitudes but also considerably higher speeds. In terms of speed, for instance, the de Havilland Vampire was 130mph faster than the Spitfire XIV at sea level and some 70 to 95 mph faster between 20,000 to 40,000ft. Tested at the Central Fighter Establishment in early 1946 and flying against the Tempest V, the Meteor III was faster at all heights, particularly at 1,000ft where the Meteor attained 465 mph and the Tempest at 381 mph. At these higher speeds, escape from a stricken aircraft became more problematical. The Luftwaffe, in the closing period of the war, had provided their high speed aircraft (Do 335, He 162 and He 219) with ejection seats and this was followed post-war in Britain and Sweden with seats manufactured by Martin Baker and SAAB respectively.



He 162 RAE Negative 66466 FAST Archive



He 219 RAE Negative 66469 FAST Archive



Do335 Sept 1945

RAE Negative 64980 FAST Archive

Figure 35 The ejection seats of three of the high speed WW2 Luftwaffe aircraft being evaluated at Farnborough during and at the end of the war. The Heinkel 219 had two seats fitted back-to-back. The German seats were ejected either by pneumatic means or by the more successful powder charge.

Ejection at high speeds can be accompanied with considerable buffeting of the pilot, particularly in the unrestrained areas of the head and neck. There had been some attempt to provide some head protection by either a C type helmet with three heavily padded segments sewn around the crown (in a similar way to the tank helmet) or the evolution of the lightweight crash helmet. The latter was a helmet shell, moulded from pressed fibre board and covered in brown-painted linen. Although tested operationally it was never used to any extent by RAF crews, but was issued to RAF and Army glider pilots where robust landings were often the norm.

In 1948 the Air Staffs had noted that there was no requirement for a protective helmet for the RAF and it was left to the Admiralty to raise a requirement in 1951 for a protective helmet for Naval aircrew (FPRC, 1953). At this time the WW2 Type C series helmet had been replaced in some areas by the Type E - a lightweight version of the Type C - made of lightweight unlined cotton 'Aertex', and this was followed by the Type F. Made of open weave fabric it could be used as a general purpose helmet or as head cover under a protective helmet.

This helmet, the Protective Helmet Mk 1, was shaped to fit over the Type F inner and constructed from moulded and bonded laminations of nylon fabric. It was intended to 'protect the head from injuries that may be caused by buffeting or a crash landing, and increases the chance of a safe ejection if the canopy release mechanism fails' (Air Ministry, 1951-68).



RAE Negative 92056 FAST Archive



RAE Negative 95154 FAST Archive

Figure 36 An early attempt to replace the long used goggles by a visor & track and fitted to an E type leather helmet prototype (left). One of the prototypes of the early Mk 1 protective helmet which fitted over the F and later G cloth helmets (right). It would later be fitted with a the visor and track very similar to the E helmet on the left

The helmet could be worn with goggles or with a new visor system, the Mk 1 visor (RAF Pattern) or Mk1A (RN Pattern), the RN version having a deeper transparency. Held onto the helmet by a simple elastic strip and slip buckle, it had a tendency to fly off on sudden exposure to air-blast and was replaced by the Mk 1A helmet which used an RAE/IAM designed visor which slid on a track attached from the centre to the front of the helmet and could be locked in a number of positions making it more robust to air-blast. The Type F inner-helmet later replaced the Type G, being more robust in construction. The neck adjustment was permanently

attached to the head harness and non-elastic; this was the final 'soft' helmet used by RAF aircrew.

The use of the combination of an inner and outer helmet led to some problems of stability of the helmet on the head and this system was replaced in the early 1960s by the first of the one piece protective helmets, the Mk2. It provided the same facilities as the separate items in a single headpiece and had retractable anti-glare visors, in light or dark tint, designed for blast protection. The visor mechanism had a manual raised-or-lowered capability as well as an automatic lowering mechanism actuated at around 10 to 12g acceleration experienced in the ejection sequence by a weight and arm connected to the visor arms.

A minor modification to the Mk 2 resulted in the Mk 2A which had a friction clutch adjustment on the visor mechanism (rather than a ratchet) and an operating bar of modified shape. For nonejection seat fixed wing aircraft and for helicopters, a Mk 3 was produced which was basically the same as the Mk 2 but with a manual visor as used on the Mk1A helmet, now called the Mk 2C visor.

The Mk 3C superseded both the Mk 1A/G combination and the Mk 2A & 3A/B type helmets and covered, in one basic design, a helmet for aircrews operating at low & high altitude (rotary & fixed wing) with or without ejection seats. Finally, in this series, the Mk 3D was produced with the double visor system – clear and tinted visors - used on the later Mk 4 series helmets.





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Figure 37 The Mk2/2A helmet with the g-operated visor and was the first of the one piece integrated helmets (left) and a Phantom pilot wearing the later Mk 3 series helmet with the hand operated visor (right) Zoom page to read text on left hand illustration

Whilst operationally effective, the helmets were considered heavy and bulky and this was addressed in the next generation of helmets, the Mk 4 series. This was designed as a team

effort between IAM, RAE and Helmets Ltd as a lighter and more stable helmet. It had cutaway sides which significantly increased the visual field, an important factor in air combat.

The Mk 4 superseded the Mk.3C helmet in the 1980's and is the current Royal Air Force / Royal Navy / Army Air Corps issue. The shell is made of glass fibre impregnated with polyester resin and lined with shock absorbing expanded polystyrene, the interior being fitted with an adjustable webbing harness system with adjustable and independently suspended earcups, whose design provided good noise attenuation and with the individual telephone transducers providing high quality communications. The Mk 4A has locating holes allowing the fitting of RAF or similar Boom Microphones. The ear-shells can be fitted with the RAE/ Industry developed Active Noise Reduction systems to reduce further the cockpit noise and is in use with the Royal Navy Sea-Kings

A development of this Mk 4 helmet, arising initially from discussions between the producers, Helmets Ltd, and RAE resulted in the design of a lighter weight variant, designated the Type 10 helmet, to help combat the higher neck loads imposed on pilots by higher g manoeuvres and high g onset rates of the newer generations of fighters. Variants of this helmet, for differing aircraft, continue to be developed.

In the mid-1950s, the increasing complexity of operational systems and the need for low-level attacks led directly to the development of the Head-Up Display (HUD). This allowed the pilot to assimilate the multitude of information during flight without the distraction of looking down at the cockpit (head-down) displays. First implemented in the UK in 1958 for the Buccaneer, it was used to display navigation and weapon-release information for use in the low-level attack mode.

3.2 1990 to the present3.2.1 Helmet mounted displays

The expanding use of electronics, miniaturisation and computing in military aircraft led to the ability to provide simple information in front of the pilot's eye, projected onto the helmet visor via a dichroic patch (Figure 38). Initially used as a weapon sight, it allowed a pilot to aim, by the turn of his head, the missile tracking heads leading to the potent capability of off-boresight weapon release. Then followed simple matrix displays allowing cueing the pilot towards air or ground targets seen by the aircraft radars and sensors. The development of accurate head-tracking, using either magnetic or optical technology, and the improving technologies of miniaturised high-brightness displays, often miniature cathode ray tubes, wide field-of-view optics, all formed the capability of the binocular helmet mounted display. Here virtually all the information available on the HUD, such as flight and weapon symbology and mission information, could be presented in front of the pilot's eye on the helmet visor, with the added capability of presenting images obtained outside the normal human visual range, such as infra-

red or image intensified pictures, transmitted from aircraft sensors.

The ability of the technologies to allow safe flight in the dark, and the consequent enormous increase in operational capability, was exemplified by the development and use of night vision goggles. Used initially in the helicopter force, the goggles were mounted on the helmet with a mounting that allowed quick manual attachment and detachment. The manoeuvring of the helicopter during nap-of-the–earth sorties was not enough to put an unacceptable strain on the aircrew's necks, but when they were promulgated for fixed wing use, the neck loads during ejection were considered unacceptable. This led to research which allowed the goggles to be

detached immediately prior to the ejection seat starting its sequence by means of a small explosive charge.



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Figure 38 The helmet on the left contains the helmet mounted sight. A small 'projector' fitted to the upper brow rim of the helmet projects a sight onto the dichroic patch on the visor in front of right eye of the pilot. The helmet has a head-tracker fitted which slews the missile seeker head to follow the pilot head movement. The helmet mounted display (HMD) on the right has wide field-of-view binocular optics through which FLIR images can be viewed as well as weapon and flight information.



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RAE Negative B6941 FAST Archives

Figure 39 Left: Early experimental work at RAE of the use of night vision goggles in fixed wing aircraft, in this case an RAE Experimental Flying Department Hunter

Right: An operational fit in a Harrier with the face-blast visor in place behind the goggles to protect the pilot's face should an ejection become necessary

There is, as always, a down-side to such operational advances and the problem of helmet weight, even with the standard helmet, has always been present. Of particular importance during high-g manoeuvres and ejection and with the added complications of neck loads, the added weight of more complex helmet mounted display (HMD) systems led to a series of compromises. Impact protection can be traded for mass, and size is often restricted by the internal dimensions of the aircraft canopy, and these problems led to difficult development.

Today the helmet is a device for holding the oxygen mask and its systems, the communications components, noise suppression, perhaps with active noise reduction, the ability to see at night, a head tracker, and high resolution and complex display system. It must also provide impact protection and visors for protection against glare, lasers and bird-strike, while being comfortable and fitting varying size heads with stability. All this must be achieved at a weight and weight distribution which will not injure the crew during ejection and is stable on the head up to 9g.

Development continues with the Typhoon HMD; the US F-35 will be the first of the so called 4^{th} generation combat aircraft to dispense with a HUD and rely solely on the HMD and the cockpit head down displays.

3.2.2 Protection against NBC hazards

Technical development in the means to wage war inevitably means some countermeasure and complications where aircrew are involved. In the mid-60s it was apparent that, if there were to be another war, chemical weapons could be used along with the potential for biological attack. Below the neck it was possible to use conventional over-garments impregnated with activated charcoal to absorb and neutralised chemical agents, but this was difficult for aircrew who would need access to specialised equipment under the garments and the various hoses that pass through the garments create a contamination hazard.

The challenge was taken up by a team from the Human Engineering Department at RAE Farnborough, the RAF Institute of Aviation Medicine and the Chemical Defence Establishment at Porton Down, all of whom played a significant part in this very successful project. The first problem was solved by the RAE's suggestion of wearing the impregnated clothing underneath the flight clothing; garments such as the life preserver, the g suit and flying coverall would remain contaminated and be re-used in that condition. This solution was relatively simple compared to the protection of the highly susceptible eyes, lungs and skin.

A respirator was required that could be used that would allow the aircrew to fly with their existing helmet, oxygen mask and communication system whilst providing the necessary protection. The early solutions were an over-hood with filtering to give a chemical-free environment while using the existing helmet and systems. Unfortunately the bulk of the hood system in this approach and the subsequent head mobility was unacceptable and the large domed visor necessary interfered with the many optical systems that a pilot is expected to use (Figure 40).

In 1976 RAE's Bob Simpson suggested that a respirator worn under the helmet would suffice in the same way as the lower body clothing. A rubber hood would completely enclose the head with the seal at the neck. Blown, filtered air fed into the cowl thus maintained a positive pressure, which prevented the entry of chemical agents in the event of leaks. Called the 'Aircrew Respirator (AR) No.5', it was to be worn under the existing Mk 4 helmet (Figure 41). Considerable testing by IAM and RAE in the laboratory, in experimental flight and under operational conditions resulted in the highest levels of protection, a high degree of acceptability and all of this in a period of only three years from concept to production.



FAST Archives



Figure 40 Early potential solutions to NBC protection was(left) the AR3 (Aircrew Respirator No3) hood which fitted over the flying helmet assembly, which was not considered operationally acceptable. It was superseded by the very effective AR5 (right) which used a protective hood which fitted on the head under the helmet proper and went into full production. The AR5 was used in conflicts from the Gulf War onwards where chemical attack was a probability

The aircrew equipment developed for the latest generations of high-performance fighters and, in particular, the RAF interceptor the Eurofighter Typhoon, needed considerable improvements, primarily in g protection and high altitude protection as well as a far more sophisticated, and therefore heavier and complex, helmet mounted display (HMD). The aircraft specification called for sustained turns at 9g and an altitude capability of 60,000 ft.

Protection for the pilot against these requirements was resolved by the use of a combined anti-g and oxygen supply system. After some considerable research and development by IAM and RAE in the centrifuge and in-flight, the pilot was fitted with an anti-g suit which covered considerably more of the torso, legs and feet, called Full Cover Anti-g Trousers (FCAGT), which cover over 90% of the lower limbs, and a Chest Counter Pressure Garment (CCPG) which operated synchronously with the oxygen pressure breathing system to counter the positive pressures in the lungs. Similar in principle to the WW2 Bazett jacket and the later partial pressure jacket, it allowed, during high-g manoeuvres and high-g onset rates, oxygen to be breathed at higher pressures. This allowed sustained g without too high a level of discomfort, with the FCAGT providing the means of minimising the blood flow away from the upper body, eyes and brain. Similarly, protection by this system at high altitudes was acceptable during any explosive decompression of the cockpit.



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Figure 41 A fully kitted-out pilot in the AR5 with the Ventilator, used to provide the necessary air and cooling (commonly known as the 'whistling handbag') on the ground, which is disconnected upon entry into the cockpit and connections made to the aircraft system. The image on the right shows the system in use on a Harrier

Development of the HMD/HEA was considerably more difficult, with all the conflicting requirements and multitude of flight, weapon, sensor input information and human engineering/medical requirements and will be part of the normal Eurofighter upgrade



Figure 42 6 Squadron Eurofighter Typhoon pilots RAF Leuchars

programme. The AEA also included a liquid conditioning (cold or hot) vest and the same generation NBC protection in the form of the AR5. More complex under the outer clothing, the basic AEA does not appear significantly different from previous generation flying clothing although considerably more capable, but, when finished, the HMD/HEA may be a somewhat different affair.

Part 4 The tentative Crystal Ball

Whilst it is always difficult to see into the future for Aircrew Equipment Assemblies (AEA), such products have usually been driven by aircraft technologies and operational requirements. Future manned aircraft that need further development of specialised AEA will be far and few in between and the current protection afforded by the below neck assemblies (g suits, coveralls, boots, gloves, life preservers, etc.) are liable to be largely adequate in their present form, apart from probably a few minor speciality changes. Also NBC/CB protection using an AR5 type system should provide the necessary protection levels, although biological attack remains a possibility and, even then, personal protection of the AR5 provides a physical barrier but protection will depend on detection, avoidance, immunisation and treatment. Protection against nuclear flash may be a further area of concern. Tom Whiteside from IAM developed an automatically deployed, helmet mounted, screen to protect against nuclear flash and this was actually tested at Christmas Island but never entered service. An alternative American technology, developed in 1975 at the Sandia National Labs, used goggles made of a sandwich composite of polarised glass with an inner layer of a transparent electro-optical ceramic called PLZT (lead lanthanum zirconium titanate) which turned from clear to opaque in less than 150 microsecs - providing the necessary flash protection. They were, however, bulky and perhaps some development of this technology is a possibility?

Future developments for fixed and rotary wing aircraft would appear to generally lie in the avionics systems area – computing technologies, sensor improvements and integration and visual/audio communication techniques and systems. If this is correct, it makes some sense to see any major improvements and developments largely through the helmet mounted display as the pilot, where used, remains the primary receptor and user of this information.

HMDs need to be reduced in mass and physical size, which future technologies should be able to accomplish, and in the balance of the HMD in terms of its centre of gravity and neck loadings. Perhaps the increasing reliability of military aircraft and their operational effectiveness may reduce the risk of ejection to a level where helmet mass and volume could be reduced without increasing the overall risk of injury to the pilot. After all, level of risk is one of the primary deciding factors, but adequate protection for the pilots head either needs to be provided or dispensed with – it is exceptionally difficult to steer a mid-course.

The potential of alternative control technologies were discussed by NATO RTO in 1998 (NATO, 1998), as means of linking the pilot with control of the aircraft systems. Speech recognition systems, allowing the pilot to talk to the aircraft directly, and vice-versa, are current and successful and are, of course, transmitted through the head-mounted oxygen mask microphone and the helmet ear-shells. In the longer-term, perhaps a sense of smell may be utilised as a warning device and the very powerful response of a pilot to the smell of burning in a cockpit indicates one of its strong properties. Again the nose is head-mounted.

Other areas, perhaps communicating with the pilot through tactile sensors and with the aircraft through gesture, may have a future but information flow will remain predominantly through the primary human sensors, the eye and the ear (visual, audio and audio/visual).

Manned systems in space are perhaps the area which, if required, will need the most effort to provide and these problems are not far removed from exposures at 60-100,000ft needing full pressure suits. Also they are not any easier to solve, for manned aircraft, than 45 years ago if the operational needs are similar, but it is difficult to see the need for manned combat in space (as distinct from man-controlled combat).

So, from an aircrew clothing perspective in direct combat aircraft, it is probable that the major and significant advances will need to be made in the development of helmet technologies and integration.

There will remain a need for protective clothing, perhaps smart materials, and some specialist development in transport, helicopters, surveillance and similar aircraft where aircrew will still be the norm and perhaps the long term dream of truly flying in a shirt-sleeve environment, as pilots essentially did in the early 1900s, will only be realised by those operators involved in the remote control of unmanned aircraft.

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Further Reading

There are a number of excellent general publications on Flying Clothing, a few of which are set out below. In addition the original reports of many of the Flying Clothing and technology developments are available through the many aviation libraries and museum archives *Into Thin Air: A History of Aviation Medicine in the RAF* T M Gibson and M H Harrison Robert Hale London 1984 ISBN 0 7090 1290X

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