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SELECTED ABBREVIATIONS

A&AEE	Aeroplane and Armament Experimental Establishment (from 1992 Aircraft and Armament Evaluation Establishment)
AAM	Air-to-Air Missile
AFB	(United States) Air Force Base
ALBM	Air Launched Ballistic Missile
AQM	Air Quartermaster
ASI	Airspeed Indicator
ATC	Air Traffic Control
BLEU	Blind Landing Experimental Unit
BMW	*Bayerische Motoren Werke*
CAA	Civil Aviation Authority
CFE	Central Fighter Establishment
CG	Centre of Gravity
ETPS	Empire Test Pilots School
FAA	(US) Federal Aviation Authority
FL	Flight Level
IAM	Institute of Aviation Medicine
IMN	Indicated Mach Number
ISTAR	Intelligence, Surveillance, Target Acquisition and Reconnaissance
LABS	Low Altitude Bombing System
MAP	Ministry of Aircraft Production
OASC	Officer and Aircrew Selection Centre
OP	Observation Post
RAE	Royal Aircraft Establishment
SAR	Search and Rescue
SBAC	Society of British Aircraft Constructors
TMN	True Mach Number
VSI	Vertical Speed Indicator

THE RAF IN THE EARLY YEARS OF THE JET ERA

RAF MUSEUM, HENDON, 19 OCTOBER 2011

WELCOME ADDRESS BY THE SOCIETY'S CHAIRMAN

Air Vice-Marshal Nigel Baldwin CB CBE

Ladies and gentlemen – it is good to welcome you back to our well loved venue for a day that should be full of interest. Before I introduce our Chairman, let me give my usual thanks to the Director General of the RAF Museum, Air Vice-Marshal Peter Dye, and to his always most helpful staff for allowing us to use their magnificent facilities.

Today's Chairman, Air Chief Marshal Sir Richard Johns, and I are both ex-Cranwell flight cadets. Sir Richard preceded me at Cranwell and was trained on the Provost and then the Meteor; I was a member of the first 'all through jet' Cranwell entry on the Jet Provost, (we were given our wings by Sir John Slessor – but that's another story) but we then went to RAF Valley to fly the Vampire – and thus, at the very least, both Sir Richard and I have a feel, and a great respect, for what the pioneers achieved with those early jets. You will hear more of this at first hand today.

After a first tour on Javelins, followed by Hunters in Aden, Sir Richard became a QFI during which time he taught the Prince of Wales to fly. He was then much involved with the Harrier, eventually commanding RAF Gutersloh and the Harrier Force in the early 1980s. He was SASO at HQ Strike Command when the first Gulf War broke out in 1991, and went on to be Deputy and then Commander-in-Chief of Strike Command and then CinC Allied Forces North West Europe. He was Chief of the Air Staff from 1997 to 2000 and then, on retirement from the RAF, became Constable and Governor of Windsor Castle until early 2008.

With that background, he will be well placed to keep today's show on the road.

Sir Richard – you have control

THE WORLD'S FIRST JET ENGINES: THE SERIOUS PURSUIT OF INNOVATION IN MILITARY AVIATION, 1936-1945

Dr Hermione Giffard

Hermione Giffard read physics at Stanford CA, graduating in 2005. In 2006 she was awarded a Masters degree with distinction by Imperial College, London and in 2011 she completed her doctorate, sponsored in part by the RAF Historical Society, again with Imperial College, specifically, its Centre for the History of Science, Technology and Medicine, her thesis being 'The Production and Development of Turbojet Aero-engines in Britain, Germany and the United States, 1939-1945'. She has recently finished a post-doctoral Guggenheim Fellowship at the National Air and Space Museum in Washington DC.

I would like to begin by thanking the organisers for the invitation to contribute to this seminar as well as the RAF Historical Society for supporting my work. With the help of a whole group of organisations that gave me funding through various awards – the Royal Air Force Award for Research into the History of Aviation (funded by the Royal Air Force Historical Society and Royal Aeronautical Society Historical Group, among others); a Hans Rausing Scholarship, Imperial College's Centre for the History of Science, Technology and Medicine; an Imperial College, UK Overseas Student Award; a German Academic Exchange Grant; a Guggenheim Fellowship, Smithsonian Institution, the National Air and Space Museum, Washington DC – an undertaking that began as a one-year research project became a four-year thesis on the early history of the production and development of jet engines in Britain, Germany and the United States, which took the question of how to study invention as its central problem.[1]

In my thesis, I was particularly interested in the road from prototype to service article. This suggested studying a time period from about 1936 to 1945 and looking closely at the work of the aero-engine industry. I argued that the skills of British industry were indispensible in creating a viable British service jet engine as well as fundamental in shaping the very details of early jet engine technology. Here was another view of what makes nations strong, their industrial expertise.

Going back to the archival record with fresh ideas about how novel machines are made allowed me to uncover new aspects the history of the jet engine. My work has already been criticised because what I have written is different from what has been written in many books on the jet engine before. Because I chose a new perspective, my story departs from the familiar story in many ways. My thesis demonstrated, for example, that the national British jet effort was ultimately very successful, setting up Britain as a leading manufacturer and exporter of jet engines in the immediate post-war period. I also showed that the argument that Germany was much more successful than Britain because it produced more jet engines is a confused comparison of two very different histories.

We all know the story of Sir Frank Whittle's extraordinary achievement as a student at Cranwell, in originating the idea of a practical gas turbine to power an aircraft at high speeds and altitudes through jet propulsion. The Royal Air Force recognised Whittle's genius, training him from a young recruit into an officer and giving him the opportunity to study engineering further at Cambridge University. This, along with his experience as a pilot, was crucial to Whittle's later inventive work. It is to the RAF's credit that it recognised and nurtured – took advantage of, even – Whittle's extraordinary talents as both an engineer and a pilot.

In my research, I chose not to look at the question of who came up with the idea of the jet engine because I judged that this question has been well studied already. I thought that I could contribute more by looking at topics that have been largely ignored up to now. In this way, my research has put the work of Whittle and Power Jets into a new context – the complex networks of innovation and production of which they were a part. My decision to focus on subjects that we don't know much about is not meant to be a rejection of the stories that we know. It neither detracts from the established understanding of Whittle's work, nor lessens his contribution to the jet engine.

Given the topic of the Society's seminar, instead of discussing theories of invention or the new stories of the German and American jet engine programmes that featured in my thesis, I would like to discuss my conclusions about how and why the British Air Ministry and RAF decided to pursue jet engines so early; and thus how Britain ended up with the sort of leading jet engine programme that we see in 1945. I will outline a new story of the whole British jet programme, emphasising how the jet engine demonstrates the Air Ministry's and the RAF's pursuit of innovation in military aviation. These organisations envisioned and made possible a leading place for Britain and its aero-engine industry in military and civil jet aviation, thus the jet engine demonstrates both the benefits, and the limits, of the enthusiasm for innovation that characterised the Air Ministry and RAF before 1945.

Rather than telling the stories of individuals, I want to draw your attention to innovative organisations that were established and promoted in Britain in order to bring novel ideas in aviation into use. The story of the emergence of the British jet engine as a military aero-propulsion system is an important story of an innovative community cultivated by the Air Ministry that included, of course, Frank Whittle and Power Jets; but also Whittle's many colleagues and fellow RAF officers, NCOs and others; British industry; and scientists and administrators like Sir Henry Tizard, Harold Roxbee-Cox, Hayne Constant and George Bulman. It included the Air Ministry's research establishment at Farnborough, the Royal Aircraft Establishment, which played a central role in the emergence of the British jet engine, as a chief advisor to both government and industry.

Production Figures

Usually, the British jet position at the end of the Second World War has been characterised as a weak one. Because of its early start, so the argument goes, Britain should have had the biggest jet fleet in the world by the end of the war. The fact that it didn't is taken as proof of failure.[2] Table 1 gives figures for the production of jet engines in Britain, Germany and the United States during the war. Production figures for the Allies include production until the end of 1945.

It is true that the Nazis produced many more jet engines during the war than Britain – although Britain produced considerably more than the United States. Yet the reason that Germany produced so many jet

	Engines	Total
Britain	Welland, Derwent, Goblin	745
Germany	Jumo 004, BMW 003	6,569
USA	GE I-16, Allis-Chalmers H1	296

Table 1. The total figures reflect production in the years up to and including 1944, plus January to March 1945 for Germany and the whole of 1945 for Britain and the USA. Particularly in the case of German jet engine production, these figures should be viewed as approximate.

engines was not so much due to technical brilliance or generous government support but to the fact that Nazi Germany was willing to sacrifice reliability, safety and performance in order to optimise its jet engines for quick and easy production, in the context of Germany's shortages of labour, material and fuel in the last years of the war. Indeed, the optimisation of their engines for production was so successful that, in March 1945, the German leadership actually decided to switch production completely to jets – and away from piston engines, which were then more costly to produce. Before the end of the war, Germany built lots of poor quality jet engines. The compromise necessary to enable the scale of German output is demonstrated by the inferiority of their product compared to contemporary British engines, which were not only more reliable and safer but also quickly surpassed them in top performance in the immediate post-war years.

Accounts that focus on numbers of jets produced have put production at the centre of the jet story. But the production record alone tells us nothing of the quality of the machines produced. Production is in this sense a bad measure of invention.

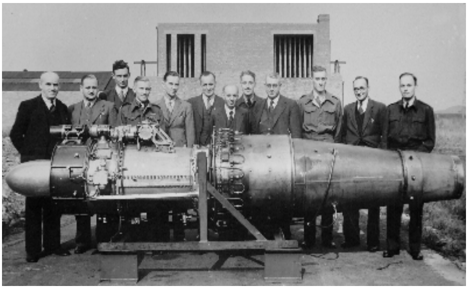
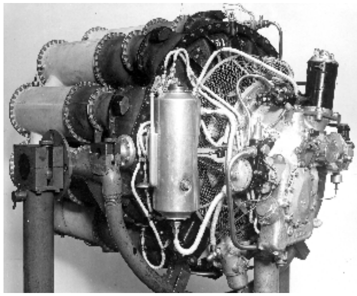
Although they started out neck and neck in 1939, both having the idea of gas turbine jet propulsion at their disposal, by the end of the war, the British and German jet engine programmes had markedly diverged. The German programme adopted production numbers as its sole criterion, whereas in Britain, production ultimately took second place to development. My thesis provides a new account of the German jet story that explains the reasons that Nazi Germany made these decisions and how they impacted the design and performance of

Empire News*, 9 January 1944; Nazi Germany's scientists are satirised as failures, while a smug RAF officer looks over the fence at Germany's motley collection of rockets and secret weapons. A jet flies overhead, the practical result of British effort.*

German jet engines during the war. It is difficult to argue that the German record with jet engines during the war was superior to that in Britain.

Jet Publicity

Britain's programme of jet engine development remained secret until 6 January 1944, when the first official press release about the project was made public. Due to a previous agreement over jet publicity, the same release was made simultaneously in Britain and the United States. The story that the release presented was a simple, largely biographical, one that promoted the jet as a British invention by advertising Frank Whittle's role in its conception. Whittle was promoted as a representative of British inventive genius in order to prove British success against both its enemy – Nazi Germany – and its future economic rival – the United States.[3]

The contrast between the many projects that were being pursued by the British aero-engine industry is epitomised by the differences between the elongated Metrovick F.2, on the left, and Rolls-Royce's more compact Welland.

The Air Ministry and Ministry of Aircraft Production (MAP) wanted to reassure the British public, while not revealing too much information about their jet capability to the enemy. Promoting Whittle enabled Britain to claim credit for the invention of the jet (a key focus of the Air Ministry's and the Ministry of Aircraft Production's jet publicity policies), while still protecting potentially sensitive information about the extent of the British jet programme.

In fact, when the first press release appeared advertising Britain's first jet engine, there were more than ten different British jet engine projects underway, including: Power Jets' W.2/500 and W.2/700; Rolls-Royce's centrifugal Derwent and Nene; Rolls-Royce's axial project, the RCA.1; Armstrong-Siddeley's axial ASX; Metropolitan Vickers' axial F.2 and F.3; de Havilland's H.1 and Bristol's turboprop – the Theseus. British Thomson-Houston (BTH) – Power Jets' first subcontractor and second largest private investor – was also still developing gas turbine units of its own. The only British aero-engine firm that did not yet have any work underway on a gas turbine aero-engine was Napier, but it too would undertake work on one before the year was out.

By the following year, 1945, Britain had the largest number and variety of gas turbine aero-engine types in development in the world, as well as the greatest number of different engines flying – although only two had actually been deployed by the RAF. The story of the jet engine in Britain is much broader than that of Whittle and Power Jets;

the most well known story of the British jet engine represents only one part of a broad secret development programme.

Enthusiasm

The Air Ministry supported research and development on gas turbines and jet engines in Britain from early on. In 1937, it was already supporting two British jet engine research projects: one at Power Jets and the other at the Royal Aircraft Establishment (RAE). The first British laboratory prototype of a gas turbine jet engine ran at BTH on 12 April 1937.[4] Soon the progress of Power Jets, the designing firm, had inspired such great enthusiasm in the Air Ministry that plans for production were being vigorously pushed ahead.

As part of its constant and serious pursuit of improvements in military aviation,[5] the Ministry moved quickly from viewing the jet engine as a focus of research and development to promoting its production as a potential service engine and a future aero-propulsion system. By the end of the war, the Ministry's investments in its wartime jet engine programme included three jet engine production factories (at Barnoldswick, Clitheroe and Newcastle-under-Lyme; the first two dating from 1940-41, the last from 1944), one development factory (Whetstone; mid-1941), and one set of dedicated research facilities (RAE Pyestock, also mid-1941).

The Air Ministry brought attention and money to the work of Power Jets, which it commissioned with the design of the country's first production jet engine, the W.2B. The Air Ministry also brought its tried *modus operandi* to the new project: the expertise and work of its research establishment; its insistence on the production of reliable engines for service use; its advocacy of industrial competition to promote innovation; its success with shadow aero-engine production during rearmament; and its responsibility to the state and its people.

In early 1940, the Ministry took its first steps towards establishing the series production of jet engines for service in Britain – well over two years before the German Air Ministry made a similar decision.[6] It brought in a car manufacturer, the Rover Company, to build and supervise the nation's first jet engine factory. In fact, this was much the same way that Rover had been brought into conventional piston aero-engine production during rearmament. Rover chose Bankfield Shed in Barnoldswick, Lancashire, which had already been allotted to

Aerial photograph of Bankfield Shed, Barnoldswick taken after the war when the factory was managed by Rolls-Royce. It is still a Rolls-Royce factory today. (Rolls-Royce Heritage Trust)

it for aero-engine production, as the location to establish the factory. It set up a development factory at Waterloo Mill in Clitheroe, for the development work that it would undertake to prepare the new engine for production – a departure from the shadow production model that reflected the jet engine's status as an undeveloped type.[7] The two factories that Rover built cost some £1.5 million[8] – a significant investment that the Air Ministry committed to at virtually the start of the war, at a time when it did not actually have a service jet engine design to produce.

Interest in the jet engine ran high among the country's technically attuned leadership. Already in April 1941, the Air Staff had noted that they 'regarded the Whittle engine as an essential requirement.'[9] Churchill hoped that jets could be used to intercept high altitude German bombers over England – although this threat never materialised.[10]

In 1941, the British government chose to share the design of the W.2B with the United States. This suggests that MAP was serious about the jet as a potential weapon, and although perhaps overconfident about the engine's development status, the Ministry wanted the engine to be produced not only in Britain but also in the United States.

The RAF shared the enthusiasm for the potential of using jet

Above, one of the Hucknall-based Wellingtons used by Rolls-Royce to test jet engines, Below ,installation of a Whittle engine in the tail of a Wellington test-bed. (Rolls-Royce Heritage Trust)

engines in combat and had placed its first fitters at Power Jets for training before the end of 1940.[11] It also provided several heavy bombers for flight-testing the new engines – although MAP eventually objected to the 'continual mopping up of first class heavy bombers for test bed purposes.'[12] Here again, valuable resources were being spent on jet engine development and production during the very years when Britain is supposed to have been at its weakest.

Crisis

Despite all the enthusiasm demonstrated by the country's aviation organisations, the W.2B did not seem, in 1942, to be all it was hoped to be. In May 1942, the engine had still to demonstrate the required degree of reliability or its design power output. It was then producing only 1,050 pounds of thrust,[13] which meant that it was still not powerful enough to propel the Gloster F.9/40, the country's first twin-engined jet fighter airframe that had been commissioned by an optimistic Air Ministry as early as February 1941 – yet another indication of the Ministry's serious commitment to the jet engine.

The W.2B's developmental problems precipitated a crisis in the British jet engine production programme. It became clear by November 1942 that, in Sir Henry Tizard's words, 'the gamble in preparing for the production of the W2B engine on a large scale *has not quite come off*'.[14] Attempting to produce an undeveloped type had resulted in failure rather than producing a service article sooner.

The country's first jet engine, which the Ministry had seriously supported for some five years, looked to be a flop. MAP decided to end the programme at Barnoldswick. It cancelled its 1941 contract for 550 production engines and declared that Rover should finish all of the material that was already under fabrication at Barnoldswick as development and training – rather than service – engines.[15]

In 1942, MAP began seriously considering the production of alternatives to the W.2B that were under development at other British firms. The Metropolitan Vickers F.2 was appealingly powerful but as yet too heavy to be mounted in an aircraft (closer to a stationary power turbine than an aircraft power plant in construction). Rolls-Royce's centrifugal WR.1, which the firm was developing in collaboration with Power Jets, was running but unimpressive. It was the de Havilland H.1, designed by Frank Halford, that seemed most likely at this point to become the country's first service engine.

MAP began to seriously consider production of the H.1.[16] Because of the disappointment with the W.2B, the bar was set higher for investment in additional production plant. Even so, in late 1942, de Havilland was given a contract for the pilot production of 100 engines and was promised more resources – including production plant from Barnoldswick.[17]

Work on adapting the F.9/40 airframe (which the W.2B was too weak to power) to carry H.1 engines was also undertaken – this prototype would have led to the Meteor Mk II. An F.9/40 first flew, powered by two H.1 engines rated at 2,000 pounds thrust each, on 5 March 1943. (The first to fly with Power Jets/Rolls-Royce W.2B/23 engines, rated at 1,450 pounds thrust each, took off for the first time on 12 June 1943.)

Although the main focus of the Air Ministry's programme had been ambitiously oriented towards the large-scale production of a service engine 'off the drawing board' – a not infrequent method to accelerate new weapons production – the Ministry had also been busy pursuing a second goal. With an eye on a post-war jet future, MAP had begun building up a new British jet engine industry.

In addition to the infrastructure that the Air Ministry and MAP had invested in, during 1942, the Ministry convinced Armstrong-Siddeley to give up piston engine design entirely and take up development of a simple axial engine. With the help of the RAE's compressor design (a development of the compressor used in the Metropolitan Vickers F.2), the company quickly developed its first axial jet engine, the ASX. An axial engine was chosen for the firm because there were already several centrifugal engines then in the design stage – including the W.2B, the H.1, and the WR.1.

Another Beginning

MAP had all but given up on the W.2B, when Rolls-Royce offered to take over Rover's ailing jet factories. Rolls-Royce already had a good record of cooperation with Power Jets as well as with MAP and had some experience with the design and development of gas turbine jet engines. Unoptimistic about the engine's future, MAP let the aero-engine firm decide what to do with the remains of the abandoned Barnoldswick programme.

With the change in management, the W.2B's fortunes changed dramatically. Rolls-Royce decided to finish Rover's development contract. Under Rolls-Royce's experienced leadership, proven testing methods and ample resources, the resuscitated W.2B engine moved quickly towards production readiness in 1943. The first Welland engine – as the W.2B was named – was completed in October 1943. Safe and reliable, the engine was certified at 1,600 pounds thrust with a time between overhauls of 150 hours. One hundred Welland engines were produced before the end of 1944. Saved by Rolls-Royce, Britain's first production jet engine went into service in the Meteor I in July 1944. More than an addition to the air war, it was a vehicle proving Britain's technological achievement to the world.

Rolls-Royce quickly set about designing its own jet engine, developing the centrifugal type to higher performance. The firm's

Rolls-Royce Derwents in production at the purpose-built factory at Newcastle-under-Lyme. (Rolls-Royce Heritage Trust)

second jet engine, the Derwent, was designed at Barnoldswick, and MAP paid for a new purpose-built factory for its production at Newcastle-under-Lyme, where the first production Derwent was completed in November 1944. A total of 550 of these engines were produced before the end of 1945, and the first Derwent-powered Meteor IIIs had been deployed in Europe before the end of the war by an enthusiastic RAF.[18]

Rolls-Royce may be the best known firm for its wartime jet work, but the other manufacturers that made up Britain's pre-war aero-engine industry were also encouraged to take up the design of gas turbine aero-engines. The MAP urged these companies to apply their particular expertise to devise engines unlike those being developed by their competitors. In this way, the British programme would explore many different developmental routes.

The Ministry's emphasis on different groups pooling their insights into the new engines in order to promote national advance was already well established by the Gas Turbine Collaboration Committee (GTCC), which the MAP had established in late 1941. The GTCC was a successful forum within which to promote the exchange of information about jet engine research and development problems. It helped to quickly build up experience with a novel concept.

Thus the engines developed by other companies looked different from the first wartime engines. Many were aimed at the civil or transport markets and took low fuel consumption as their goal – high fuel consumption was a particular problem of early pure jet engines optimised for speed. Armstrong Siddeley developed the ASX into a turboprop, the ASP (later the Python). Bristol's turboprop scheme included a heat exchanger, although it was soon proven to be less useful than expected. Napier began designing a diesel piston engine/axial gas turbine combination, with incredibly low fuel consumption figures, later seen also in the Nomad. Rolls-Royce too, although successfully pursuing the pure jet line, developed successful turboprops like the Dart.

The Air Ministry and MAP were convinced that Britain could and should play an important role in the post-war jet market. At the end of the war, the country had a multitude of different engines under design. The outlines of what would become a national centre for research into gas turbines had already been established, building on the government's earlier investments in jet engine research and development and ensuring that British industry – and thus the British military – would remain in the forefront of international jet technology.

Conclusion

Britain had envisaged a technological contest from early on[19] and its Air Ministry had anticipated the production of jet fighters from the outset of WW II. By the end of the war, the country had decided against an intensive production programme. Instead, the Air Ministry's support of research and development into a variety of jet engines had led to the establishment of a new, broad-based national industry which would play a vital part in Britain's post-war economic recovery, as jet engines would become an important British export.

In order to appreciate the full scale of the Air Ministry's jet ambitions, we must look beyond the biographical mode that has dominated the telling of the British jet engine story. Through that lens, it appears indeed to be failure in certain respects. For this reason, the story of Frank Whittle has been, and continues to be, used to elaborate tales of British decline and Government failure to nurture

British leadership in jet engines was a key part of the country's post-war technological identity – see The Times*, 3 February 1947. These are Derwents being assembled beside Eagle piston engines at Derby after the war.* (Rolls-Royce Heritage Trust)

innovation.[20]

Yet overall, the Air Ministry's early jet engine programme must be judged a huge success, for after the war, Britain had the best jet engines in the world and its aero-engine industry was poised to continue its dominance in the field. Such an interpretation fits with recent re-evaluations of the technical success of Britain's war effort, giving a new understanding of its strengths. We seem to have lost sight of these, but it was no accident that Britain led the world in jet engine technology in 1945.

Notes:

1 Giffard, Hermione; 'The Production and Development of Turbojet Aero-engines in Britain, Germany and the United States,' 1936-1945. PhD Thesis, University of London, 2011.

2 See for example, Gunston, Bill; *Plane Speaking: A Personal View of Aviation History*. (Sparkford, 1991).

3 TNA AIR2/7070, Enc 1A; Letter Freeman to Evill, 22 November 1943; The rivalry in aviation technology remained intense in the early post-war period. See also Engel, Jeffrey; *Cold War at 30,000 Feet: The Anglo-American Fight for Aviation Supremacy* (Cambridge, MA, 2007)

4 Whittle, Frank; *Jet: The Story of a Pioneer* (London, 1953) p57.

5 TNA CAB66/15/22: Memo by Beaverbrook, Minister of Aircraft Production, 3 March 1941.

[6] TNA AVIA15/2305, Enc 5A; Minutes of Meeting, Whittle Jet Propulsion Engine, 26 February 1940.

[7] Rover received a slightly higher than usual management fee for the turbojet factories of £16,000 per annum. (TNA AVIA15/1802, Enc 5a; Interdepartmental note of 15 December 1942); Brooks, David S; *Vikings at Waterloo: The Wartime Work on the Whittle Jet Engine by the Rover Company*. Rolls-Royce Heritage Trust Historical Series (Derby, 1996).

[8] TNA AVIA15/1806, Enc 1A; Interdepartmental letter to Freeman dated 11 December 1942. TNA AIR62/608;Meeting at Power Jets, Brownsover Hall on 5 January 1943.

[9] TNA AVIA46/234; Air Supply Board Meeting Summary dated 18 April 1941.

[10] TNA PREM3/21/4, Enc 183; Memo from Winston Churchill to John Moore-Brabazon, Minister of Aircraft Production, late July 1941.

[11] TNA AVIA15/1611, Enc 11; Memo dated 5 March 1942.

[12] TNA AVIA15/1614, Enc 23; 10.6.42, Memo CRD to DCRD, dated 10 June 1942, responding to 8.6.42, Enc 22A; Recommendations of the Jet Propulsion Panel, 6th Meeting dated 8 June 1942.

[13] TNA AIR62/990; Gas Turbine Collaboration Committee Progress Reports dated 31 May 1942.

[14] Emphasis added. TNA AVIA15/1708, Enc 18; Memo from Henry Tizard, dated 13 November 1942, responding to Air Marshal Francis J. Linnell.

[15] TNA AVIA15/1708, Enc 15A; Meeting about abandoning W.2B design dated 7 November 1942 and Enc 17; Minute Air Marshal Francis J. Linnell to Henry Tizard dated 9 November 1942.

[16] TNA AVIA15/1614, Enc 11; Intradepartmental minute dated 9 March 1942.

[17] TNA AVIA15/1599, Enc 21; Minute Linnell to Bulman dated 1 September 1942.

[18] TNA AIR20/5169; Freeman to Portal dated 5 December 1944.

[19] Edgerton, David; Warfare State: Britain, 1920-1970 (Cambridge, 2006) and Peden, G C; Arms, Economics and British Strategy: From Dreadnoughts to Hydrogen Bombs (Cambridge, 2007).

[20] See, for example, Jones, Glyn; *The Jet Pioneers: The Birth of Jet-Powered Flight*. (London, 1989) and Dyson, James; ‘Britain can lead in technology, but it must change,’ Telegraph.co.uk published 5:27pm BST 27 May 2010 accessed on 21 July 2010.

Q&A SESSION

Ian Whittle opened the discussion by reading a prepared statement, which largely revisited the position he had established at the 2006 AGM (*see Journal 39*) before commenting on the way in which Dr Giffard had dealt, or not dealt, with these issues in her thesis. However, since very few members of the Society will be familiar with Dr Giffard's thesis, these observations lack context so your Executive Committee has decided not to publish Mr Whittle's statement, but copies will be provided on application to the Editor.

Copies of Dr Giffard's thesis have been deposited in the libraries of Imperial College, London, the RAF Museum, the Royal Aeronautical Society and the Farnborough Air Sciences Trust, but it is not currently accessible on-line, nor are hard copies likely to be distributed any more widely, at least, not until the potential for commercial publication has been fully explored.

Al Pollock. I was fortunate enough to know Arthur Fishlock, an ex-'Fighting Cock' of 43 Squadron who recently died, aged 104. At one stage in his career he worked with Frank Whittle at Power Jets where he nearly lost his life when an engine exploded. Arising from that experience, Arthur gave me the impression that metallurgy was a major problem in the development of jet engines, because of the stresses involved in high speed rotation at high temperatures. Could you comment on that?

Hermione Giffard. Metallurgy was an aspect that did interest me but, unfortunately, there were so many other factors to consider that I was unable to give it a great deal of attention. Nevertheless, it was recognised, from the outset, that it would be an issue, because the forces that would be exerted within a jet engine were going to be far greater than those which anyone had worked with previously. Many commercial companies, along with institutions like the RAE, would have been involved in the refinement of existing materials and in the creation of the new alloys that would be necessary to sustain the emerging programmes. One factor that did become apparent to me was that there were differences in the ways in which this issue was explored. Conditioned by previous experience and the availability of, for instance, different types of stress-testing devices, sometimes led different countries to draw different conclusions. Even more significant perhaps, was the availability of specific minerals in industrial quantities, which may have imposed constraints on land-locked Germany in the last year of the war. Metallurgy is obviously a very important aspect of the jet story and one on which I hope to elaborate on in the future.

Sir Freddie Sowrey. Could I ask if you had any difficulty in the verification of information from German sources? One wonders whether it might have been exaggerated – for propaganda purposes – to create the impression that Nazi technology was superior to that of the Allies.

HG. That's a very good point. One problem that I did encounter while doing research in Germany was that a lot of records had been destroyed. As a result, I would sometimes be able to trace only one reference to a particular development. The critical decision to switch over completely to jets was a case in point – I found just one memo relating to this key issue.

But, in the context of propaganda, it worked both ways – as you may have gathered from the cartoon that I showed. When Air Marshal Wilfrid Freeman came back to the Ministry of Aircraft Production as Chief Executive he was very concerned to dispel the growing myth of Nazi technical superiority. He wanted to make sure that people understood that the new jet aeroplanes that they were seeing flying over the Midlands were British and not German.

I did find it necessary to treat some of the statistics with a pinch of salt, because the German system would sometimes have made it politically advisable to doctor one's results in order to create the illusion of success. Nevertheless, I believe that sufficient accurate data has survived to permit us to see what was really going on. Speer was well aware of the truth, of course. In his memoirs he writes of the conflict between the information being fed to the public about the forthcoming wonder weapons that would turn the tide and the reality – which was that he was faced with a confused jumble of research projects from which he had to pick those in which to invest.

Sir Mike Knight. For two-and-a-half years I had the pleasure of working for Johannes Steinhoff, one of the first *Luftwaffe* pilots to fly the Me 262; he was very nearly killed in a crash on take off. I don't have a specific question, but I was surprised at the production figures that you cited – something like 700 engines built in the UK and a couple of hundred in America compared to more then 6,500 in Germany! That seems almost incredible.

HG. The contrast is startling, I know, but I did pay particular attention to this aspect. I am confident of the figures for Britain and America, and, while the total for Germany may not be absolutely precise, it will not be far out. There were two reasons why the Germans were so successful – or *apparently* successful. One is that at least one third of the output came from a government-controlled production facility, which produced something like 815 engines in March 1945 alone. The other is that they optimised their engines for production – and your reference to an Me 262 crashing on take off hints at the consequences of what was involved in that. That crash, and others, was an indication that the Germans were prepared to sacrifice the lives of their pilots. Safety margins were reduced to a minimum and degraded engine performance was accepted in the interests of maintaining output. Something like a third of the engines produced never entered service; many exploded while being tested. This sort of thing was an inevitable result of late-wartime policy in Germany – large scale mass production, at any cost, implied some difficult decisions which an increasingly hard-pressed administration was prepared to make. Large scale production was never the aim of the British government, so it never had to consider those decisions, preferring instead to put quality ahead of quantity. Hence the very different industrial outcomes.

Sebastian Cox. Hermione, from what you have just been saying, in terms of the spectacular headline figures and the associated underlying problems within the German programme, can you say a little more about, what we would now call, the 'mean time between failures' of the German engines, and whether, when they initially set up their mass production programmes, they were aware of the scale of the problems that they would encounter? This had obvious operational consequences, of course, so, had they allowed for a high rate of failure, or did this come as a surprise?

HG. I don't think that they had foreseen the extent of the problems that they eventually had to cope with. That said, they were knowingly taking risks. After all, the aeroplanes, and the engines, that they were building weren't meant to last fifty years, or even one year. Since they had such very short service lives, cutting corners on production standards was seen as a reasonable trade-off if it meant that more of them could be made available. Mechanical defects aside, there was another reason why these late-war aeroplanes had such short lives – the inadequacy of their pilots. The *Luftwaffe's* training system had failed to keep pace with losses and by 1945 they were scraping the bottom of the barrel to the extent that recruits from the Hitler Youth were going straight from gliders to jets. They surely cannot have anticipated *that* when they embarked on their jet programme. Another problem that they had to deal with, and which grew worse as the war progressed was the shortage of strategic materials. This led them to make increasing use of wood. The He 162, for instance, had wooden wings and when a prototype was flown, its wings came apart, rather spectacularly, killing the pilot. They cannot have expected that either. The fact is that the Germans had a lot of problems by 1945 and, because many of them arose from changing circumstances, most could not really have been anticipated. Nevertheless, the Nazi government was willing to take certain decisions and damn the consequences, especially as the war progressed.

Patrick Hassell. I have a question about the Halford engine – the H.1 – which powered the first Meteor to fly. Did you find an explanation for why the aircraft it was actually designed for – the Vampire – was not ordered earlier?

HG. An aircraft to take the de Havilland engine was ordered quite early on, to Specification E.6/41. This became the Vampire, which first flew in 1943 but did not enter service for another three years. One reason for the delay would have been that the parent company lacked the capacity to build them, so production was contracted out – to English Electric. But they were currently building bombers and the Ministry was not prepared to sacrifice production until the H.1 was performing satisfactorily, and, as with practically all engines, the H.1 had its teething troubles. When the Vampire eventually began to demonstrate a rather better performance than the early Meteors, there was something of a rethink, but too late for the aeroplane to see wartime service.

Problems with the Whittle engine meant that it was not available to power the Meteor so it actually flew for the first time with a pair of H.1s. These were not yet producing their design thrust either, but, since they were intended to be significantly more powerful, a pair of derated H.1s was quite sufficient to get the flight test programme started. Before committing to the H.1, however, MAP wanted it to realise its full potential. This took time, hence the delay in producing the Vampire, and priority being allocated to the Welland and Derwent.

Air Cdre Bill Tyack. Is it possible to say where the balance lay, in terms of policy, between the immediate need to get the jet engine into service with the Royal Air Force as quickly as possible, and the long-term prospect of post-war civil applications?

HG. That's a difficult one, but there was a detectable shift in thinking as the war progressed. In the early days it was all about the military potential of the jet engine. You will recall that I referred to Churchill's concern at the threat represented by high altitude bombers as early as 1941. This never materialised, but the jet engine had been seen to be the answer. While I would not say that enthusiasm for jet fighters ever waned, there was a steady increase in the attention being paid to the post-war market, although responses differed from firm to firm. Rolls-Royce, for instance, certainly saw the jet as a better commercial prospect than the Merlin, whereas Bristols were more inclined to stick with their well-established piston-engines, which did continue to sell in the early peacetime years. So, industry was certainly paying increased attention to the civil market towards the end of the war, but I do not believe that this was at the expense of the military. Government was certainly aware of the commercial potential and as early as 1942 it outlined the requirement that would eventually become the Comet.

Mike Meech. You referred to the number of jet engines being developed in Britain during the war. Do you think the balance was right between the number of projects and the available expertise? Was the number of skilled personnel a limiting factor? Did not having enough people to solve all of the problems, perhaps cause delays?

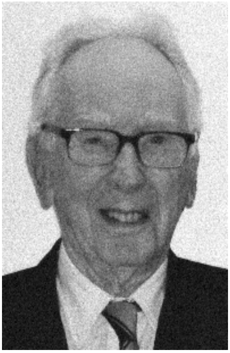
HG. No I don't think it was a major problem. Each company had its own design team and, in the early stages, at least, these involved relatively few people. It's in the development phase that you really begin to need manpower, and this inevitably meant a degree of learning on the job while adapting familiar skills for use in an unfamiliar environment. But even then the numbers required to build and test one or two trials engines are not excessive. It's when you start production that manpower becomes a real issue. This varied from firm to firm, of course. In the UK, for instance, since Armstrong Siddeley's Deerhound and Wolfhound were unsuccessful, the company abandoned its entire piston engine programme, so its whole design team could work on jets and its production facilities were made available to build other companies' engines. Other firms struck a balance. Rolls-Royce pursued both jets and piston engines while Bristols stayed with pistons – perhaps because Frank Owner had problems recruiting design staff. That does suggest, of course, that there may have been a shortage of skilled people, but I did not get the impression that it was a real problem.

Sir Richard Johns. Did your research consider the operational successes of British jet fighters in the last year of the war? I do hope that I'm not treading on Captain Brown's preserve in asking that question.

HG. Well, I was just going to say, I hope that we are going to hear about that from the next speaker! As you will have gathered, my focus was much more to do with supply and with industrial planning. There was some read across to aspects that had operational implications, of course – the training of fitters and the procedure for creating the nucleus of service squadrons, for instance, but I didn't look specifically at the operational record.

BRITAIN'S EARLY JET AIRCRAFT

Captain Eric Brown



After an operational tour flying from Britain's first escort carrier, Eric Brown became a test pilot in 1942 and spent much of the next twelve years flying from Boscombe Down and Farnborough and with the US Navy at Patuxent River. More conventionally, before retirement in 1970 he was OC 802 NAS (Sea Furies), OC 804 NAS (Sea Hawks), Commander (Air) at Brawdy, Naval Attaché in Bonn, Deputy Director of Naval Air Warfare at the Admiralty and commanded RNAS Lossiemouth. He is the FAA's most decorated pilot and has flown no fewer than 487 basic types of aircraft and made 2,407 aircraft carrier landings in fixed-wing aircraft – both world records that are unlikely to be beaten.

Quite fortuitously on 15 May 1941 I witnessed the maiden flight of Britain's first jet propelled aircraft, the Gloster E.28/39, at RAF Cranwell. This historic event took place with the minimum of fuss and publicity, and I had no idea what kind of aircraft was involved.

Almost exactly three years later, as a test pilot at Farnborough I was to join the Top Secret Jet Flight, located at a highly guarded remote part of the airfield, and at that time operating only one aircraft, the original prototype E.28/39. A second prototype had been built but was lost on 30 July 1943 when the CO of the Jet Flight baled out at 33,000ft when the ailerons jammed due to icing of the control cables, thus causing loss of control.

The tiny first prototype, W4041, had in the interim since its maiden flight, been fitted with the upgraded W.2/500 Whittle engine of double the thrust of the original W.1, had received a new high speed E-type wing and end-plate fins fitted to the tailplane to cure directional snaking.

It was a beautiful looking little craft and delightfully simple. It had no trimmers, a small tricycle undercarriage retracted by hydraulic pressure supplied by an accumulator which was manually charged on the ground before each flight. The hydraulically operated split trailing-

The first prototype E.28/39.

edge flaps were powered by a hand-pump in the cockpit. The total fuel capacity was only 81 gallons. Loaded weight at this stage was 3,748lb. The cockpit had a very simple layout with as many engine gauges as flying instruments, for this was primarily an engine test bed.

My first impressions on flying the E.28/39 were of the superb view it afforded, of the lack of engine vibration and engine noise in the cockpit. Taxying was delightfully simple with the steerable nose wheel, but for take-off the engine had to be opened up slowly (about 10 seconds) to prevent excessive jet pipe temperatures.

In normal flight the controls were all quite light and effective, but the ailerons heavied up with speed. The aircraft was longitudinally unstable, and marginally stable both laterally and directionally. From a handling standpoint therefore the E.28/39 would have made a good fighter, but it would have been badly underpowered and short of range. Performancewise it achieved its maximum level speed of 466 mph at 10,000ft. The highest height and Mach number I personally reached were 35,000ft. and M0.82 achieved in a 40° dive to 20,000ft. Landing was a dolly at 80 mph.

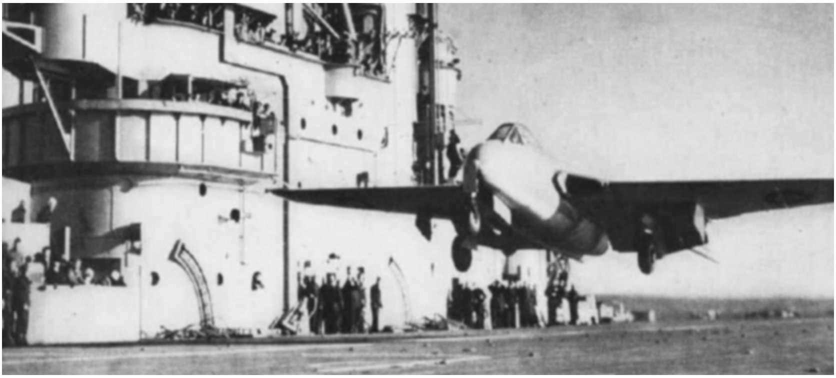
The jet engine was a new form of propulsion in aviation, so a wide range of flight tests had to be carried out not only on its mechanical aspects, but on its effects on flight handling. These latter tests encompassed aerobatics, formation flying, simulated combat, flight in rain and icing conditions, surface water ingestion and engine relighting. A major deficiency thus came to light – lack of adjustable drag. This was necessary for accurate formation flying, in combat and for landing. In piston-engined aircraft the interaction of throttle and airscrew provided this requirement, but in jets it was obvious that air brakes were a necessity at the design stage. Interestingly enough, the Germans made the same mistake in the design of their initial jet aircraft.

Although I had anticipated the likelihood of mechanical failures being fairly common in the early days of jet flying, this was not so with the E.28/39. The fuel used was kerosene, much less volatile than aviation gasoline, but it gave a lot of problems in getting the fuel metering right over a wide altitude range and this was the main cause of flame-outs in the early trials.

The aircraft was easy to glide to one of the many airfields around Farnborough and make a deadstick landing, but in those days the only one in the south-east of England with a supply of jet fuel was Farnborough itself. For such an emergency a Lancaster equipped with a belly tank of jet fuel was based at the RAE and rushed with maintenance crew and security guards to the forced landing site. The arrival of a propellerless aircraft with a naval pilot asking for paraffin to refuel, caused some considerable confusion at RAF airfields, to my quiet amusement.

Shortly after I joined the Jet Flight a Gloster Meteor prototype arrived, and I actually flew it before the E.28/39, thus becoming the first naval pilot ever to fly a jet aircraft. The Meteor was powered by two Whittle-designed Welland engines, each of 1,700lb static thrust, and I found it a rather mediocre aeroplane from the handling and performance standpoints, and this was reflected in its shocking accident rate as the RAF converted from the piston to the jet age. Records show that during its 10 years of operational service 890 aircraft were written off with the loss of 434 pilots plus 10 navigators.

The flight tests carried out on the Meteor expanded on those made on the E.28/39 and included gun firing, reheat, the effect of bird strikes and eventually arresting on an aircraft carrier. However, the most time-consuming tests were on trying to eliminate directional snaking which plagued jet aircraft because of the destabilising effect of losing the slipstream from a propeller. Eventually one of our captured German scientists at RAE solved the problem with a rudder



Eric 'Winkle' Brown taking off from HMS Ocean on 3 December 1945 after making the first landing of a jet aeroplane on an aircraft carrier.

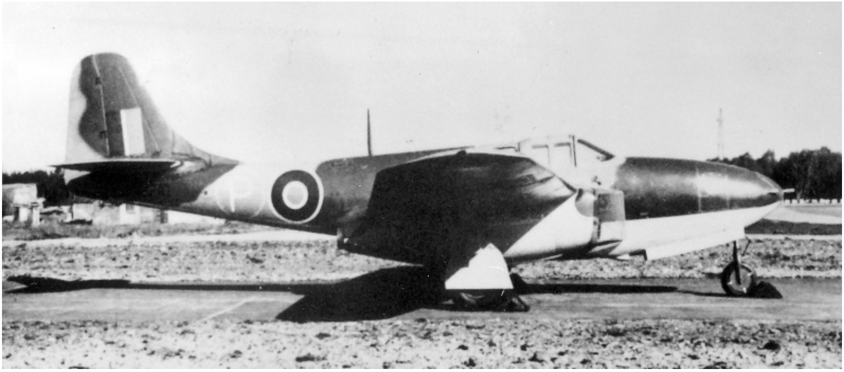
auto-pilot. Transonic flight testing now began to take precedence.

By the summer of 1944 the early Meteors were in operational service with the RAF, just in time to oppose the rash of German V-1 flying-bomb attacks on Britain. It was a useful blooding for the Meteor, but it had limited success and showed its limitations at that early stage in its development.

By mid-1944 we received another new prototype aircraft in the Jet Flight, namely the De Havilland Spider-Crab, later to be renamed the Vampire. At this point in time the Royal Navy had decided to carry out deck-landing trials on an aircraft carrier, and as the designated trials pilot I chose the Vampire for the task, although it was really Hobson's choice.

The Vampire was designed as a single-seat interceptor fighter, and was powered by a 2,700lb static thrust Goblin 1 turbojet also manufactured by the De Havilland company. It was a nippy little aircraft with light and effective controls, although laterally and longitudinally unstable – often the hallmark of a good day fighter. Top speed was 540 mph at 30,000ft. With this performance we began to expand our work on transonic testing, and it was in a Vampire that I made the first in-flight photograph of transonic shock waves.

The Vampire made the world's first jet landing on an aircraft carrier on 3 December 1945, but was rejected for naval operational service because of its short range and the slow acceleration of its centrifugal flow engine. However, it was the ideal aircraft on which to



The sole Bell P-59 Airacomet to fly in British colours.

introduce pilots to jet flying, and was used by many foreign air forces with great success.

The poor acceleration and deceleration of early jet engines, both of centrifugal and axial flow type, was a temporary shortcoming but one that imposed significant restrictions on the jet aircraft of World War II and the immediate post-war period.

The Americans were left on the starting line of jet development, but General Hap Arnold of the USAAF realised the huge significance of Frank Whittle's pioneer work and in 1941 had a Whittle engine shipped to the USA and handed over to General Electric to imitate and develop.

On 5 November 1943 the first American-built jet aircraft, the Bell Airacomet, arrived in the RAE's Jet Flight, having been exchanged for a Meteor 1.

The Airacomet was a ponderous looking aircraft and flew like it looked. It was a mid-wing twin-engined fighter with a laminar flow wing section. The General Electric engines were each of 1,300lb static thrust, and the aircraft was badly underpowered, with an unacceptably long take-off run, and of course had the expected slow acceleration characteristics of early jet engines.

In the air it had satisfactory longitudinal and lateral stability, but snaked very badly directionally. The controls were heavy although reasonably effective, but in transonic testing it displayed a critical Mach number of only 0·74. It also was without air brakes, and suffered the consequent shortcomings.

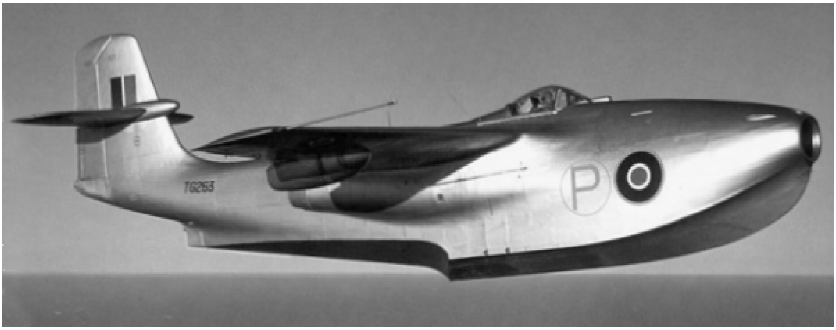
The Metrovick F.2-powered F.9/40 that was lost, along with its pilot, Sqn Ldr Davie, on 4 January 1944. Note that the axial F.2s were installed in Me 262-style underslung nacelles.

While Frank Whittle's early development work on jet engines was based on the centrifugal principle of jet propulsion, contemporary experiments were being pursued on axial flow engines, mainly at RAE and Metropolitan Vickers. Indeed a few days before I joined RAE Farnborough on 17 January 1944, the CO of the Jet Flight was killed in a Meteor when one of the two Metrovick F.2 engines disintegrated. However, this setback was overcome and the F.2 proved of great power, the thrust being increased by 90% over a two year period of development.

The Germans favoured axial flow engines, but had limited success with their Junkers Jumo 004 and BMW 003 models because they lacked the strategic metals to withstand the inherent heat stresses, and were highly sensitive to throttle movement.

The early problem of slow acceleration and deceleration of the jet engines of the 1940s virtually disappeared with the introduction of the Rolls-Royce Nene which I first flew in 1947 in the Supermarine Attacker, and also with the Metrovick F.2/4 Beryl in the Saunders-Roe SR/A1 flying boat fighter which I flew in 1949. From the 1950s the axial flow jet totally supplanted the centrifugal flow type, but the latter had been the simpler and more reliable engine to see aviation through the teething troubles of its jet beginnings.

Although the advent of the Jet Age can justifiably be said to have



The axial Beryl-powered Saunders Roe SR/A1.

got off to a shaky start, things rapidly improved in the design and reliability of both the engines and airframes of jet aircraft. This is perhaps best illustrated in the case of the Meteor, of which the Mk IV was fitted with the 3,000lb thrust Derwent V engines in long chord nacelles. Its wings were clipped, and the resultant big increase in performance necessitated a strengthened airframe for the Mk IV. It was also given a high-speed paint finish and established an Absolute World Speed Record of 606 mph on 7 November 1945. Progress indeed!

The 606 mph speed record was set by the camouflaged Mk IV, EE454; this is the other competitor, the bright yellow EE455, still with long-span Mk III wings, that managed 603 mph.

DISCUSSION

Capt Eric Brown. Picking up on Seb Cox's earlier question – about the life expectancy of the German engines and whether the *Luftwaffe* was fully aware of these limitations (*see p24*). Yes, they knew, because industry knew that it lacked the necessary strategic metals and the air force was told that the engines had a 'scrap life' of 25 hours. But that was only a notional figure because Adolf Galland told me that when he was flying the Me 262 in the last months of the war they were lasting for only half of that – just 12½ hours.

Richard Bateson. When the enemy aircraft exhibition was held at Farnborough in the autumn of 1945 they were able to show examples of the Me 262, Ar 234 and He 162. Was any thought given to doing comparative trials between these aircraft and the Meteor, as the Americans did in 1946-47 with Chuck Yeager flying a P-80 against a pair of Me 262s at Wright Field?

Brown. We were doing speed trials, of course, all the time, in all types of aircraft so we had the data at our fingertips. To give you some idea, at the time you are talking about, the fastest fighter in this country – indeed, in the whole Allied Forces – was the Spit 14 with a top speed of 446 mph. When I flew the Me 262 at Farnborough – and I flew it many times there – the top speed was 568 mph. That's almost 125 mph faster than the fastest Allied piston-fighter. When you get a quantum jump in performance like that, it certainly makes you sit up and take notice. So, yes, we did a lot of testing on the three German jets and we had all the relevant comparative performance figures.

Sir Mike Knight. You have written rather well of the Me 262 – not so much from the engine point of view but with respect to its handling. I believe that you have said it would have been a very good fighter, had that been allowed. Could you expand on that a little?

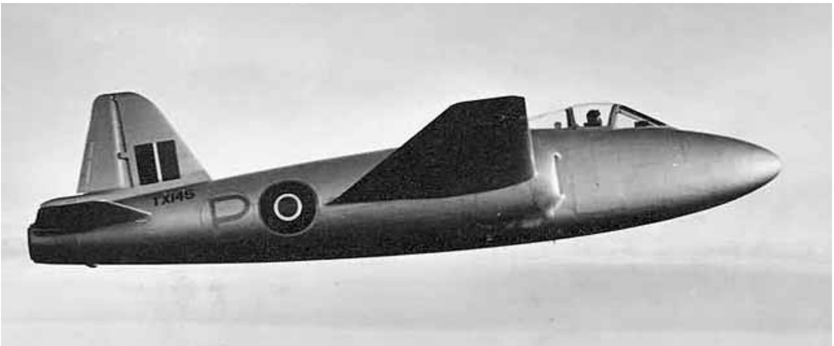
Brown. Handling was good. But with a fighter that went as fast as this one, you would avoid dogfighting. You would simply use your huge speed differential to make a slashing run – at a time of your choosing. You have the initiative both in choosing when to make your attack and when to break away. The main task for the Me 262, as a fighter, of course, would have been to deal with the B-17, so dogfighting was simply unnecessary. But the B-17 still represented a

Me 262A-1a fighters of Erprobungskommando 262, the trials unit set up at Lechfeld in January 1944 to devise appropriate tactics for jet combat. Note that, unusually, the nearest aircraft is short of, at least, one cannon.

problem – because of your speed. The Me 262's four 30mm cannon had an accurate range of about 650 yards so you would be looking to open fire at about 600 yards and at more than 550 mph – and with no air brakes – you had no more than two seconds of firing time. That is not enough time to permit you to aim properly so, in effect, it was just shooting at random. If the aeroplane had had air brakes, you could have doubled your firing time and that would have made all the difference. So speed was a problem, as well as an advantage. But, generally speaking, the handling was good.

Jefford. This is not really a jet question – more to do with being a test pilot. Naval aeroplanes, I think, always had their airspeed indicators calibrated in knots while, until early 1945, most of the RAF worked in mph and the instruments in German aeroplanes were presumably calibrated in kms per hr. Was that a problem for you – trying to remember which numbers to fly with which aeroplane?

Brown. I was German-speaking, so it didn't cause me too much difficulty. But we did we sometimes take out the German ASI and put in a British one. Perhaps more to the point, we were now entering the



The straight-winged, Nene-engined Gloster G.42 fighter to Specification E.1/44. Initial handling problems were alleviated by the fitting of a Meteor F8-style fin and tailplane but the aircraft offered little advance on, and was deemed to have less development potential than, the Meteor and the programme was cancelled.

era of Mach Numbers, and while we speak naturally of these today, at the time there was not a single operational aircraft – anywhere – fitted with a Mach meter. So, along with a mph ASI we also fitted the German jets with Mach meters.

Gp Capt Jock Heron. While you praised Glosters for the design of the E.28/39, and were rather less enthusiastic about the Meteor, did they not produce another aeroplane immediately after the Meteor which was considered for the RAF? Can you tell us anything about that one?

Brown. I never flew it, so I can only tell you what I have heard. I believe that it was rejected mainly because it did not represent enough of an advance over the Meteor. It was not much better than the Meteor IV. By this time, speed was all about critical Mach Numbers and we were moving away from the piston engine fighters at about 0·7M and creeping into the transonic range. The Spitfire could fly at well above 0·8M and the Meteor IV got up to 0·84, with the Me 262 at 0·86. We were going up the scale and the next aeroplane that Gloster built did not get beyond that base line, so it failed.

THE JET INTO RAF SQUADRON SERVICE

Air Cdre Graham Pitchfork

Following an initial Canberra tour in Germany, in 1965, Graham Pitchfork, a Cranwell-trained navigator, was seconded to the FAA to fly Buccaneers. Thereafter his career was inextricably linked with that aeroplane, culminating in command of No 208 Sqn. He later commanded RAF Finningley and was Commandant OASC before a final tour as Director of Operational Intelligence. While at Finningley in the 1980s he became associated with the No 616 Sqn Association and he has been its Honorary Air Commodore ever since.

As early as the end of 1940, the Air Ministry issued a specification, F.9/40, for a jet fighter and the Gloster Aircraft Company submitted a twin-engined design. In February 1941, approval was given to build twelve experimental aircraft to this specification. The first flight of the aircraft was on 5 March 1943. The aircraft looked almost identical to the Meteor that soon followed with the prototype Meteor F1 making its first flight on 12 January 1944.

The distinction of being the first jet squadron in the history of the Royal Air Force fell to 616 Squadron one of the last of the twenty-one Auxiliary Air Force squadrons to form. There has been much speculation as to why one of the RAF's youngest squadrons should have this unique honour and the reasons have never been fully explained. It has been claimed that Wing Commander Ken Holden, a founder member and former Flight Commander of the squadron, was serving in the Plans Division of Fighter Command when he cheekily nominated '616' and, to his great surprise, it was never challenged.

No 616 Sqn had been in existence for a mere six years when the Squadron Commander, Squadron Leader Leslie Watts DFC, was informed in April 1944 that his squadron was to re-equip with a 'secret' aircraft. Together with Flying Officer Mike Cooper, one of the squadron's most experienced pilots, he left for Farnborough on 26 May. There they discovered that their new 'secret' fighter was the Meteor powered by the Rolls Royce W2B/23 Welland jet engine

An early Welland-powered Meteor F.1, EE214.

generating 1,700lbs of static thrust.

The following morning the two pilots arrived at the dispersal to find the two prototype Meteor F1s being prepared for flight. Mike Cooper explains what happened next:

> 'The CO and I were introduced to Wing Commander Willie Wilson, the CO of the experimental flight, at his caravan; he was most pleasant and easy going. He handed each of us a sheet of paper on which was typed 'pilot's notes' which explained how to start up and fly the aircraft. We were each led to one of the two aircraft and climbed into the cockpit and studied the notes. After completing the study we reported back to the Wing Commander who asked us 'Any problems?' We said no to which he replied 'Then fly the bloody things.' We each had two flights that day and a further two on the following day. We believed we were the first two squadron pilots, as opposed to test pilots, to fly the Meteor.'

Indeed they were. After three flights each, they were sufficiently confident to fly around in formation; possibly the first jet formation flying in the RAF. Watts and Cooper remained at Farnborough for a week flying the Meteors each day and returned to the squadron's new base at Culmhead on 5 June just in time to fly their Spitfires on a dawn D-Day beach-head patrol. During their absence, a twin-engine Oxford had been delivered to the squadron to allow all the squadron pilots to practice asymmetric flying.

Whilst the squadron continued to fly Spitfires at an intensive rate in support of the Normandy landings, pilots were withdrawn in groups of five to begin the conversion to the Meteor which was carried out initially at Farnborough. The post of Squadron Commander was upgraded to wing commander and former Battle of Britain pilot Wing Commander Andrew McDowell DFM and Bar, led the first group of five which included a Canadian and a Frenchman. A few days later, the other Flight Commander, Dennis Barry, led the second group and he recorded his impressions of his first flight in a jet:

> 'After an introduction to the aircraft we were briefed for our first flights. We clustered round the cockpit as the Wing Commander (Wilson) went through the drills explaining the instruments and the aircraft's flying characteristics. Next we were told we could take off on our first familiarisation flights. This conversion briefing seemed rather sparse, especially as there were very few Meteors available.
>
> As I taxied out to the end of the Farnborough runway, I ran through the drill as briefed by the Wing Commander and then I positioned the aircraft ready for take off. I held the throttles forward giving maximum power while holding on the brakes, then released them and the jet slowly accelerated down the runway. There was no swing and I held the stick level until 80 mph indicated, then I eased back and lifted off the runway at 120 mph. With the wheels coming up I climbed away while retracting the flaps. The rate of climb was poor at 500 feet a minute. The aircraft was quiet with no engine noise and the visibility was good with no long nose like the Spitfire. The Meteor felt heavy on the controls compared to the Spitfire and especially when full of fuel. After a forty-minute flight it was time to land remembering that by 600 feet we had to decide to carry on and land because of the limited power for an overshoot once we were below the decision height. After landing successfully I returned to my colleagues satisfied with the aircraft except for the lack of power.'

After their first flight the pilots carried out a further four flights and after this short conversion they returned to the squadron as fully qualified jet pilots! This short and rapid conversion from single-engined Spitfires to twin-engined jets is reflected by the entries in the log books of the pilots.

The first two non-operational Meteors arrived at Culmhead on 12 July and nine days later they left with the rest of the squadron for Manston. Five operational aircraft arrived the following day and the Meteor Flight of 616 Squadron was established.

The squadron remained fully operational with two flights of Spitfires but a concentrated period to convert the remaining pilots to the jet commenced immediately. Within a week this programme was complete and one flight was declared operational on the Meteor F1. A few days later the squadron Intelligence Officer captured the mood of the squadron entering in the Operational Record Book the unique line:

> 'Today the Meteors go into operation. History is made! The first British jet propelled aircraft flies in defence of Britain against the flying bomb.'

The privilege of flying the RAF's first operation in a jet aircraft fell to the Canadian Flying Officer W H 'Mac' McKenzie who took off on 27 July for an uneventful patrol near Ashford. Later in the day Watts closed in on a Diver and was ready to register the squadron's first success when his cannons jammed.

The sight of the Meteor over the South East of England in the first few days of August created numerous, potentially serious mis-identifications. One pilot was returning from a patrol when two Spitfires attacked his Meteor. They opened fire, causing serious damage to the elevators, and the pilot had to make an emergency landing using the tailplane trim only. Anti-aircraft gunners also had trouble identifying the Meteors and opened fire on a number of occasions. Identification flights were arranged.

By the beginning of August, eight Meteors had been delivered to the squadron in addition to the two prototypes. Patrols were flown between Ashford and Robertsbridge, usually lasting about forty-five minutes and over the next few days squadron pilots made many more sightings, but problems with the cannons continued to frustrate them. Finally, on 4 August, the squadron achieved its first success. 'Dixie' Dean was flying at 4,500 feet under the control of Biggin Hill when he spotted a flying bomb near Tonbridge and he dived in pursuit. At 450 mph he soon caught the Diver and attacked from dead astern but his four 20mm cannon jammed as he tried to open fire. He accelerated

No 616 Sqn's Meteors at Manston. The nearest aeroplane is a Mk I, distinguished by its hinged canopy, the next two in the line-up are Mk IIIs with sliding cockpit hoods.

and flew level alongside the bomb. Having manoeuvred his wing tip a few inches under its wing, he banked away sharply to send the bomb diving to destruction four miles south of Tonbridge.

Within minutes of this first success Flying Officer Rodger achieved a more conventional 'kill' when he shot down a flying bomb near Tenterden after two two-second bursts. These initial successes were soon followed by others and on 7 August the cannon in 'Dixie' Dean's aircraft worked perfectly and he brought down his second V-1. Flying at 400 mph, he intercepted the Diver near Robertsbridge at 1,000 feet and engaged it at 500 yards firing all his guns. The Diver went down in a shallow dive and the Royal Observer Corps confirmed that it had crashed. On 10 August 'Dixie' Dean completed his hat trick when he shot down a V-1 near Ashford with two short bursts.

By 14 August the last of the Spitfires had gone and No 616 Sqn became an all-Meteor unit equipped with fourteen of the original twenty Meteor F1s, all powered by the Welland engine.

Over the next few days there were more engagements and successes against the V-1. The report of one pilot makes interesting reading:

> 'Control warned me that there was a fast contact south of Canterbury at 1,500 feet and I soon spotted it because there was

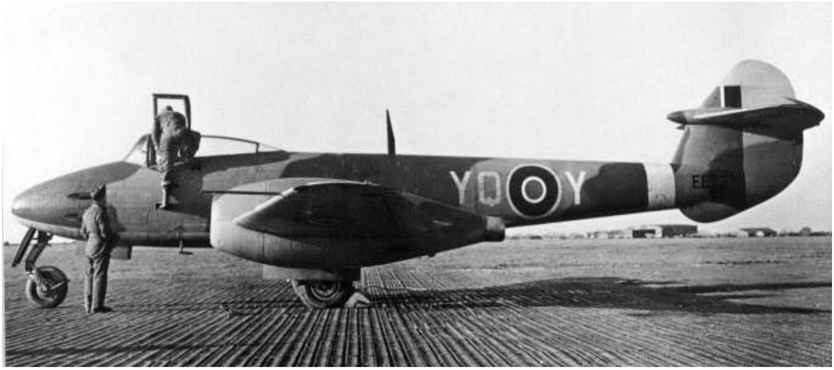
> a Mustang about a thousand yards behind it but not getting any closer. I passed it doing over 400 mph and caught up with the flying bomb. We had been warned not to fly directly behind them. Instead we had to approach to one side and close behind at 200 yards before opening fire. I fired three short bursts at the starboard wing root and it rolled over and blew up on the ground. I could feel the blast rock my aircraft. It was very straightforward and easy. The target was flying straight and level and didn't shoot back, what more could a fighter pilot want?'

On 29 August, 616 Squadron scored its last victory against the V-1 when one was shot one down near Sittingbourne bringing the squadron's total to thirteen. Diver patrols continued but the capture of the launching sites in the Pas de Calais area had greatly reduced the number of flying bombs launched against London.

With the reduced action following the demise of the V-1s 616 Squadron spent much of the time gaining experience of jet operations, flying in formation and demonstrating the new aircraft. A very important task was to train ground crew in preparation for the formation of the next Meteor squadron. During September, six pilots each week attended a Rolls-Royce engine course to be briefed on the Derwent engine which would equip the operational Mark 3 version later in the year. At the end of the month the press were cleared to disclose that jet-propelled aircraft were now being employed with success against the flying bomb.

The Meteor F1 was restricted to flight below 15,000 feet initially and DCAS, Air Marshal Bottomley, decided not to deploy it to the continent but retain it in the UK as 'a flying bomb interceptor and for trials and tactical development'.

A particularly important trial was mounted in early October at the USAAF airfield at Debden. The heavy bombers of the US 8th Air Force had suffered serious losses to the *Luftwaffe* and the appearance of the Me 262 jet fighter had created an increased problem. The CO flew up to Debden for preliminary discussions and a training plan was organised with Brigadier General Jesse Auton, the Commanding General. The exercise was planned to evaluate the combat capabilities of enemy jet fighters and to determine defensive and offensive tactics



Meteor F1 EE227 was delivered to No 616 Sqn on 26 August 1944 and it flew with the squadron until its undercarriage collapsed landing at Debden on 15 October.

for the bombers and their fighter escorts. The 2nd Bombardment Group was to provide B-24 Liberators escorted by P-47 Thunderbolts and P-51 Mustangs.

Four Meteors positioned at Debden on 9 October. The following day a mixed formation of 120 bombers in four boxes joined up with their fighter escort over Peterborough before setting off for the Essex coast. The Meteors, flying at 450 mph, made a number of attacks, and were able to get out of range before being intercepted. Even in a dogfight, the Meteor performed well as long as the speed was kept high. At the debriefing, Lieutenant Colonel Kinnard, who had led the fighter escort, commented, ‘I saw the jets come in across the top of the bombers, but before I could turn into them they had passed through and gone’. Throughout the week, a series of tactical trials continued and by the end the USAAF fighter pilots had begun to devise tactics to combat the jet fighter threat. The de-briefings were described as ‘of inestimable value’. There were also unexpected benefits for 616 Squadron. One aircraft suffered a collapsed undercarriage and another had an engine burn out giving the squadron’s servicing party valuable experience in how to service and maintain their aircraft in the field. This was to prove of great value in the coming months as the Meteors operated from a succession of European airfields.

Throughout November and December, the Meteors were in regular demand by RAF and USAAF bomber squadrons for tactical training.

Many fighter affiliation exercises and formation practices were flown and squadron pilot's practised cine air-to-air gunnery. On 16 December, Colonel Clark from USAAF Headquarters, London visited the squadron and later that day he flew a Meteor on a familiarisation flight. He carried out a second flight two days later. Perhaps he was the first USAAF combat pilot to fly an operational jet?

During December the squadron started to receive the Meteor F3 but the initial batch were still powered by the Welland engine due to the slow delivery of the more powerful Rolls Royce Derwent. The first two aircraft were delivered on 18 December and five more had arrived by the end of the month. The Mark 3 differed in a few aspects from the Mark 1, a new streamlined cockpit hood being the most significant feature.

By mid-January all the Meteor F1s had been exchanged for the F3 version and on 20 January the squadron transferred to 84 Group of the 2nd Tactical Air Force and moved to Colerne, which is where the build up of Meteor units was to be carried out. An advance party of fifty ground crew and equipment left for Melsbroek near Brussels at the end of the month and the first four aircraft flew into the airfield on 4 February to record another first for No 616 Sqn – the first Allied jets to operate from mainland Europe. The aircraft were immediately painted white and flown over Allied lines at appointed times so that troops could become accustomed to the sight of the Meteors and not fire on them in mistake for the Me 262s that were being increasingly used on ground attack missions. Other flights were made to familiarise local anti-aircraft gunners and pilots of other units with the Meteor.

Meanwhile, the rest of the squadron moved to Andrew's Field in East Anglia on 28 February, and in March returned to anti-Diver patrols since the flying bombs had reappeared, air-launched from Heinkel 111 bombers flying over the North Sea.

Back in Belgium the squadron was restricted to flying over Allied territory and the frustrated pilots saw no action. On 29 February the BBC announced in a news bulletin 'British jet fighters – Meteors were in action against the *Luftwaffe*'. The BBC's reference to the Meteors led to widespread publicity in the national newspapers the following day.

Local training flights continued for all the pilots for most of March. On the 26th the Meteor Flight moved to Gilze-Rijen in Holland where

The first Meteors to be deployed on the Continent were painted white.

the bulk of the squadron’s ground crew and equipment had arrived from England. Two days later, seventeen new Meteor F3s, all powered by the Derwent engine and in the standard camouflage scheme, flew in and for the first time for a number of months, the whole squadron was reunited. The new Rolls-Royce Derwent engine of 2,000 lb, static thrust brought a big improvement in performance, and the aircraft gained an extra 85 mph at altitude. The white painted aircraft, together with the F3s with the Welland engine, were returned to Colerne.

From 3 April, two aircraft were permanently on standby by the runway and at 16.50 hrs two red flares were fired from Flying Control and the first Allied jets to be scrambled in the European theatre of operations took off to patrol over Brussels at 15,000 feet where they intercepted two friendlies before returning to base.

The move of the squadron to the continent had released the planned surplus of Meteor-experienced ground crew and they remained at Colerne to form 1335 Conversion Unit equipped with the surplus F1 aircraft. The Welland-engined F3s returning to Colerne from Holland allowed the second Meteor unit, No 504 (County of Nottingham) Sqn, to form on 28 March.

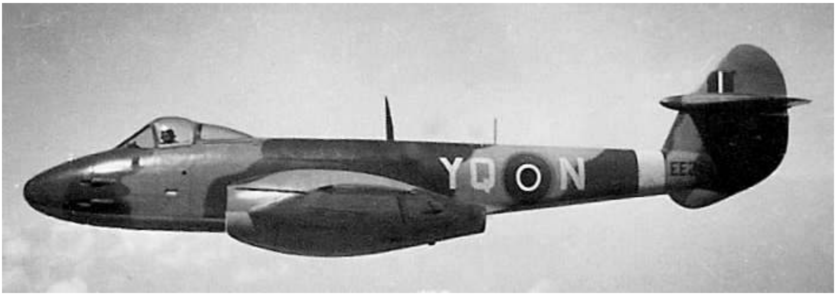
The war now was drawing to an inevitable close and in mid-April the Meteors were finally cleared to operate over enemy territory. On 13 April, ten aircraft left for Kluis near Nijmegen and landed on the single 1,500-yard steel-planking runway. Two aircraft were placed on immediate readiness with the rest of the Meteors assigned to ground attack sorties. The following day the CO briefed all pilots on the squadron’s new task, that of armed reconnaissance. With an operational area in western Holland the Meteors were tasked to attack any rail and road traffic in the area. The first ‘Rhubarb’ was flown on 16 April but no traffic was seen and there was only light *Flak*.

Success came in the following days when over twenty sorties were launched each day with pilots strafing and destroying trucks and armoured vehicles. With the Allied armies advancing at such a pace, the squadron was on the move every few days. On 20 April, it was based on German soil for the first time at Quackenbruck, having joined 122 Wing of 83 Group, and then it was on to Fassberg. The CO led an attack against Nordholz airfield on the 24th when aircraft were shot up, vehicles destroyed and gun emplacements were attacked. Later in the day another sortie was mounted against the airfield with considerable success.

Tragedy struck on 29 April when the long-serving Flight Commander, Squadron Leader L W Watts DFC and Flight Sergeant B Cartmel took off for a reconnaissance sortie at 14.45 hrs. They failed to return and information was received through a radio control centre that Spitfire pilots heard Watts calling Cartmel to come closer as he was going into cloud. Shortly afterwards they saw a large explosion in the air. Both pilots were killed instantly.

The last two weeks of the war provided a great deal of activity with most attacks directed at German Army units as they retreated towards Schleswig Holstein and the Danish border. The formation leader attacked the leading vehicles of a convoy, which created a blockage for those following when they became an easy target for the pilots. On 2 May over twenty vehicles were destroyed and almost a hundred were damaged. The following day saw further successes as the new CO and his Number 2 made a surprise attack against the airfield at Schönberg. The squadron diarist wrote:

> ‘The CO and Tony Jennings strafed the airfield and destroyed two Heinkel 111s, two Junkers 87s and a Messerschmitt Me 109. On the return to base, Tony saw and attacked a Fiesler Storch and he told us how the pilot of the Storch repeatedly and skilfully countered his attacks by turning towards him as he reached firing range so he was unable to get into a good position. As the Meteor turned, the Storch landed and the pilot and a second person got out and ran away. Tony destroyed the



This Meteor III, EE249, was delivered to No 616 Sqn on 7 February 1945 and it was still on charge in August when the unit was renumbered as No 263 Sqn

aircraft but made no attempt to kill the pilot; he was a brave and skilful man.'

This proved to be the last opportunity for the Meteors of 616 Squadron to fight the enemy in the air. The next day was a busy and successful one and more rail and road traffic was destroyed. The CO, Wing Commander Schrader, ran out of fuel at 8,000 feet but managed a successful deadstick landing back at Luneburg. At 17.00 hrs a message arrived grounding all aircraft. Hostilities in Northern Germany had ceased and before the Meteor could be pitted against a jet aircraft of the *Luftwaffe*. The war was over and the squadron moved to its last base at Lübeck the farthest east of the Allied advance. Lübeck was a permanent *Luftwaffe* airfield and, ironically, there were Me 262 jet fighters parked on the airfield – the Meteor squadron's only meeting with its German counterpart.

The end of the war gave an opportunity to relax. Some flying continued in order to display a presence to the local population but air and ground crews were able to take advantage of captured German equipment including two Me 262s. The CO and a test pilot on the squadron flew them but the nose oleo of the CO's aircraft collapsed on landing.

Much of the time at Lübeck was spent on a concentrated training programme for various victory fly-pasts, the most important one being by aircraft of 84 Group at Kastrup airfield on the outskirts of Copenhagen. Others went to Frankfurt where, on 9 June, a formation of twelve Meteors, led by the CO, took part in the victory fly past attended by the Soviet CinC, Marshal Zhukov.

Two months after the events over Copenhagen the sad news arrived that 616 Squadron, the RAF's 'First Jet Squadron', was not to survive the post-war rundown and on 31 August, the squadron was re-numbered 263 Squadron and left shortly afterwards for RAF Acklington in Northumberland. No 504 Sqn, which was ready to deploy to the continent when the war finished, became 245 Squadron.[1]

No 616 (South Yorkshire) Auxiliary Air Force Squadron had had the unique distinction of being the RAF's first jet squadron when it re-equipped with the Meteor F1 aircraft in July 1944. It was the only Allied squadron to operate jets during World War Two. Whilst the pilots rejoiced with the rest of the free world at the cessation of hostilities, celebrations were tinged with slight regret that they had not been able to use the jet to greater effect. The aircraft had been rushed into service, and at a time when much further development was still necessary, not least on the engines and the guns. The pilots had a very short time to convert from the single-engined, tail-wheeled Spitfire before going back into combat in the twin-engined jets. While the Meteor was effective against the V-1s, other commitments prevented it being fully utilised in this arena. In its ground attack role in the hectic final phase of the war, it was not making use of its speed and high ceiling. The real test that the squadron had been waiting for never came, and although the aircraft's successes were relatively few, by the end of the war the Meteor was well established in RAF service and the rapid re-equipment of Fighter Command was possible.

[1] There was a logic underpinning these renumberings. When the AAF had been embodied on the outbreak of war it had, in effect, been absorbed into the RAF and within a relatively short time, few traces of its peacetime 'auxiliary' status remained. Indeed with some of the original squadrons having been re-formed after being wiped out or disbanded, several of the units using ex-AAF numberplates in 1945 had little, if any, association with the pre-war AAF. As early as March 1945, however, the Air Ministry had decided to re-establish a post-war AAF and, in order to recreate the original local affiliations, it needed to regain access to the pre-war numbers. By September all squadrons using nominally AAF identities had been either disbanded or renumbered to permit a new AAF to be set up with recruiting beginning in June 1946. **Ed**

FIT FOR SERVICE – THE ROLE OF SERVICE TEST PILOTS

AVM Alan Merriman

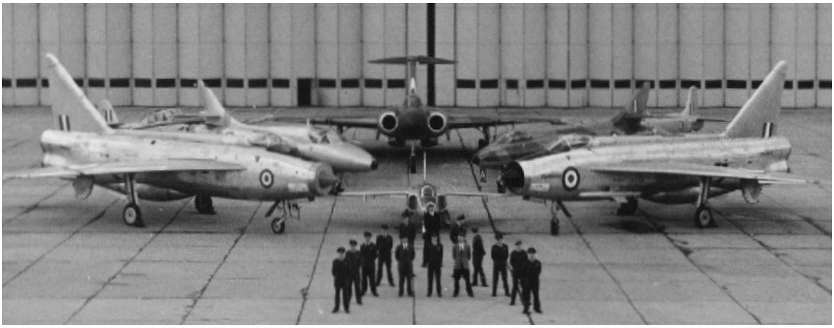
Alan Merriman graduated from Cranwell in 1951 to fly Meteors and Hunters before attending the ETPS and staying on for a tour before moving to the CFE. Among staff appointments he subsequently commanded A Sqn at the A&AEE, RAF Wittering at the beginning of the Harrier era, the ETPS and was Commandant at Boscombe Down. His last tour was as Deputy Head of Defence Sales after which he spent 1984-90 as a Consultant to BAE Systems on the Eurofighter Typhoon

Background

In the 1940s the main British turbo-jet engines in front line service had centrifugal flow compressors. The Rolls-Royce Derwent and the De Havilland Goblin powered the Meteor and Vampire respectively. They differed in that the Derwent had a double-sided compressor while the Goblin was single-sided. Developments of these engines emerged later as the Nene and Ghost respectively.

During the late 1940s, research and development was concentrated on the axial flow compressor in order to achieve higher pressure ratios and a slimmer outer contour. In the early 1950s, Rolls-Royce produced the Avon which in 1951 entered service in the Canberra and was the power unit for the first flights of the Swift and Hunter. At roughly the same time, Armstrong Siddeley produced the Sapphire engine they had taken over from Metrovick soon after the end of the war, when it had been known as the Beryl.

All the main elements of a jet engine – the intake, compressor, combustion chamber, turbine and exhaust pipe – are optimised for the maximum RPM full power condition. This causes problems with starting and then running at low RPM with an acceptable idling thrust. However, the biggest problem of all is to get the engine to accelerate from idling RPM to the full power RPM without surging, which is a breakdown in the gas-flow through the engine. One of the principal causes of surge is a rapid opening of the throttle, so engine acceleration tests featured prominently in every fighter test programme before these aircraft could be considered fit for service. I



'A' Sqn, the A&AEE's fighter test squadron, in 1958. The fleet includes a pair of Lightnings, two Hunters, a Gnat, a Javelin, a Jet Provost and – a Prentice!

gained my 'wings' and had my first flight in a Meteor in 1951, and from 1952-55 I was a Meteor flying instructor at various Advanced Flying Schools. For the next two years I flew with a Sapphire-powered Hunter fighter squadron in the UK before becoming a student at the Empire Test Pilots' School (ETPS) at Farnborough. From there I joined the Fighter Test Squadron ('A' Sqn) at the Aeroplane and Armament Experimental Establishment (A&AEE), Boscombe Down. This talk is based almost entirely on my personal flying experiences at these units.

The Role of the Test Pilots

The main task of the Company test pilots was to demonstrate that their aircraft and its engine met the defined contractual parameters. In the process, they aimed progressively to open up the flight envelope in airspeed, Mach No, altitude and 'g' before handing over the aircraft to Boscombe Down to be flown by Service test pilots, initially for a first look of about 10 hours flying, known as a pre-view, and later for a full acceptance trials programme. Throughout these tests, the Service test pilots and the Company test pilots worked very closely together.

Before any new aircraft types entered service with the armed forces they had to undergo a series of rigorous scientific and engineering trials, mainly in the air, in order to assess the safety, reliability, performance and suitability of the aircraft and their associated systems (armament, communications, navigation, etc) for service use. These trials were conducted mainly at Boscombe Down, and the flying was carried out by Service test pilots recently graduated from ETPS after selection from front line operational squadrons. Relevant copies of their flight test reports were seen by Handling Squadron to assist in the production of Pilots Notes.

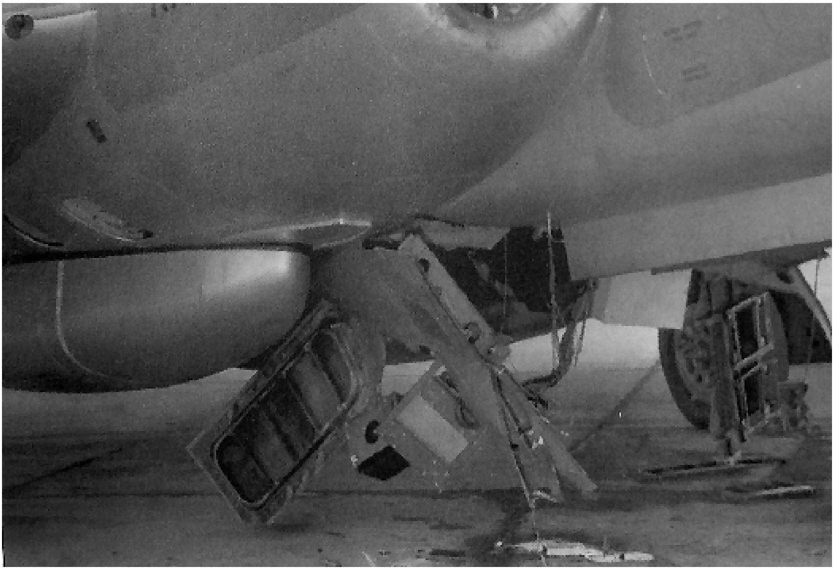
The outlook at Boscombe was to strike the correct balance between an aircraft's safety and its operational usefulness. This meant there were cases where, in order to achieve the desired operational usefulness, it was not possible to achieve the ideally desired safety. In such cases, A&AEE aimed to ensure that higher authorities were fully appreciative of the risks involved. In other words 'Fit for Service, with limitations'. The test programmes took account of the aircraft's role in service, and the flight tests were designed to be as near as possible aligned to the anticipated sorties in the specified operational role. During these flights, particular attention would be paid to the engine handling and performance. So let us first take an overall view of the engine characteristics that the Service test pilot of the 1940s and '50s would be looking out for.

The Engine Test Programme Outline

An important aspect of an air superiority fighter would be the time taken to scramble. This meant a simple starting procedure and a short time to reach idle, something in the order of no more than 10 seconds. Next, fast engine acceleration to full power was required to achieve the shortest possible take off run, followed by stable engine running conditions during the climb to operating altitude. In the 1940s and early '50s this would be around 35,000 feet. Later on this extended to 60,000 feet.

During engagement with enemy aircraft at these altitudes, carefree engine handling, meaning the freedom to open and close the throttles at will with fast response, was essential. The engine should then readily accept a comparatively long period near idle while the aircraft descended and recovered to an instrument approach, at the end of which it should respond quickly to any demand for power to overshoot and possibly divert to another airfield.

A sortie of this nature would be at least 40 minutes in duration. So a feature of the tests would be to ensure that the fuel capacity and endurance of the aircraft were adequate.



Cartridge starting 'could be explosive, as we found with the Sapphire starter on the Javelin.'

Engine Starting

If we examine each element of this sortie in turn, both the Derwent in the Meteor and the Goblin in the Vampire needed an external battery power supply for assured starting. This was a cumbersome and relatively slow procedure and it could be embarrassing if you landed at an airfield lacking such equipment. A more self-contained system with rapid response was sought. The cartridge starter in the early Avon and Sapphire engines proved to be a great improvement. They were self-contained and shortened the start-up time considerably. They also offered multiple starts without reloading. However, they were not without problems. The cartridges did not always fire first time and could be explosive, as we found with the Sapphire starter on the Javelin.

The AVPIN liquid fuel starter fitted to the later Avon engines solved the problem and was lighter in weight. Although misfiring occasionally occurred early on, this was eventually cured and starting became more reliable and safer. Moreover, one fill of the fuel tank offered many more starts.

Compressor stall, or surge, can be quite spectacular, as on this American Airlines Boeing 767.

The Flight Tests

For take-off the pilot would want to achieve the shortest possible take off run. Hence, the pilot should be able to move the throttles rapidly to the full power position, generally known as 'slamming' the throttles, (this term applies to closing as well as opening). However, opening the throttle too quickly is the main cause of surge in both the centrifugal and axial flow compressor. It results from overfuelling, a term used when the increase of fuel in the combustion chambers raises the temperature, and hence the pressure, to a higher value than the output pressure from the compressor. In the extreme, this can reverse the gas-flow giving rise to sheets of flame emerging from the intakes.

The comparative complexity of the axial flow engines makes them liable to surge for reasons other than overfuelling. For example, the flow of air entering the engine can be distorted by the design of the aircraft intake and this can be exacerbated by sideslip or high angles of attack, causing the compressor blades to stall. Or there could be a mismatch between successive stages of the compressor.

The surge can take one of two forms. Sometimes it will be self-corrective and so temporary and transient. But if the surge continues for any length of time there is a high risk of turbine failure due to overheating. With the aircraft on the ground, throttling back to idle will generally cure the problem, or else the engine must be shut down by cutting off the fuel supply. In the air this would necessitate relighting, so tests to establish the optimum relighting conditions were a necessary prerequisite to undertaking extreme engine handling conditions. A failure to relight meant, at best, a landing without power (flame-out landing), or at worst an ejection. It was prudent therefore to practice a simulated flame-out landing before embarking on the higher risk engine handling areas.

The engine flight test technique was to start at relatively low altitude, say 5,000 feet, at a comfortably slow airspeed, and while maintaining straight and level flight the throttles were slammed from idle to full power. This was repeated at a range of increased airspeeds and altitude levels of say every 5,000 feet up to the maximum operating altitude, and the engine performance observed on each run. At the same test conditions, slam closing of the throttles was carried out to check whether the sudden extremely low fuel-air mixture in the combustion chamber could lead to flame extinction. The final test was the demanding hot re-slam. After some 10-15 seconds at full power the throttle is slammed to idle and within 1-2 seconds slammed back to full power.

If an engine passed all these tests satisfactorily, in anticipation of operations in the tropics, the really ultimate test was to repeat the worst cases with fuel at a high temperature. The aircraft would be refuelled from a unique bowser that could raise the fuel temperature to 60ºC which would allow for the cooling effect of the aircraft structure to reduce this to the 45ºC expected in the tropics, on start up.

Flight Test Results

At all times, starting from low RPM, the throttles of the Derwent and Goblin engines needed to be opened slowly if surge due to overfuelling was to be avoided. Once in the middle of the RPM range the engines responded well to throttle movements, both opening and closing. However, these engines could surge when flying at high Mach No and high RPM at high altitude when the air temperature was unusually cold. Under these conditions, the compressor output could reach Mach 1, leading to rough running and loud banging caused by internal shock waves disturbing the gas-flow. Reducing RPM slightly cured the problem. Squadron pilots were briefed and trained on all these circumstances accordingly.

Rapid throttle opening of the early 100-Series Avon engines, such as the RA3 fitted to the early Canberras, led to surge at all altitudes and worsened with increasing height. Clearly this was unacceptable for air superiority fighters such as the Hunter and the Swift. As a result of these early tests, modifications were made to the swivelling inlet whirl vanes, the inter-stage bleeding and the compressor blading. The resultant RA7 engine had greatly improved handling, although surge could still be experienced at high angles of attack, exacerbated by the pitch-up tendency of both Hunter and Swift.

The RA3 Avon, having failed the simple slam open test, never

In its day, the Sapphire was 'the leader in advanced turbo-jet technology.'

reached either the cold or hot re-slam stage of testing, and the RA7 was marginal. Pilots were advised to open and close the throttles cautiously during combat manoeuvres.

As it was known that intake design can affect the performance of the engine it serves, it was thought that the Hunter's wing root intakes might possibly be the cause of the Avon's poor performance. The boundary layer can also be a bad influence. But surge was experienced during runs on the ground test beds and was prevalent on the Avons installed on the Canberra and the Swift, both of which had more straightforward intake designs. It was concluded, therefore, that the Hunter's intakes did not influence the surge problem

The Sapphire

To avoid a national catastrophe if an aircraft failed to come up to expectation, it was standard practice to develop an alternative design with another Company as a safeguard and competitor. The Avon's competitor was the Sapphire which Armstrong Siddeley had taken over from Metrovick. The Sapphire passed the straight and level tests without difficulty and went on to succeed in the most demanding test of all: throttle slamming during high angle of attack manoeuvres through a wide range of airspeeds and altitudes. The Sapphire was shown to be surge free at all altitudes. Undoubtedly, this engine was, at that time, the leader in advanced turbo-jet technology.

Gunfiring

To add to the woes of the Avon, the initial gunfiring tests on the Hunter were, by coincidence, conducted on a Sapphire-powered aircraft and did not seem to affect the engine. Much to everyone's surprise therefore, the first time the four 30mm Aden cannon were fired on an Avon Hunter the engine surged and had to be shut down before relighting.

The Avon-powered Hunter and the Gnat both suffered from early engine problems when their guns were fired.

Analysis revealed that the gasses emerging from the guns were being drawn into the engine intakes. This not only upset the velocity distribution entering the compressor from the intake but the burning of the guns' combustible gasses in the engine caused overfuelling. The Avon's sensitivity to any disturbance, let alone of this nature, inevitably induced a surge.

The answer was somehow to reduce the fuel input proportionately during the firing time. This was achieved on the Hunter by using the electric signal from the control column firing button to partially close off the fuel inlet valve on the engine fuel supply line. Without actually firing the guns, I spent many hours on a prolonged series of trials to determine the correct amount of fuel reduction required at different altitudes and speeds. It was a case of pushing the firing button and recording the drop in engine RPM. This 'fuel dipping' was successfully applied to aircraft powered by the 100-Series Avon engine.

The Hunter was not the only aircraft to suffer surge caused by gunfiring. With complete innocence, the designer of the Gnat fighter had unfortunately located a gun in the lip of each of its side intakes. Gunfiring immediately caused a surge to the Bristol Orpheus engine, which otherwise exhibited superb handling and performance characteristics. The fuel dipping principle was applied and I vividly remember my second ever sortie on the Gnat, firing its guns at 30,000 feet over the middle of Lyme Bay, hoping that the Dowty fuel system modification would be successful. Fortunately it was.

The Orpheus engine of course went on to be the core of the hugely successful Pegasus fitted to the P.1127, the Kestrel and all marks of the Harrier.

The Sapphire was undoubtedly superior to the 100-Series Avon in all respects. It became not only the choice for the Javelin all weather fighter, the Victor V-bomber and the P1A Lightning, but in the form of the Curtiss-Wright J65 it powered many American aircraft, including their version of the Canberra.

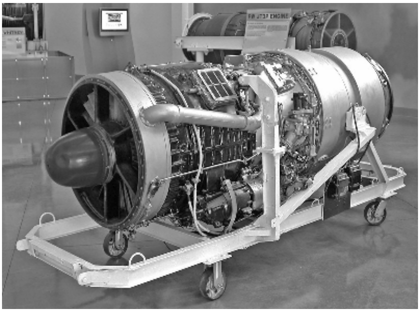
Blade Failures

Centrifugal compressors were robust and rarely suffered from mechanical failure. This contrasted with the early axial flow engines which suffered from compressor blade vibration and fatigue, and eventually blade failures. In many instances this meant complete engine failure. In the worst case, although it is specified that the outer casing of the engine must be strong enough to prevent penetration by a blade that breaks away from the disc, there were many instances of blade penetrations on Sapphire engines. Often this meant the loss of the aircraft. In the mid-1950s the accumulated losses due to engine failure amounted to almost one a month, including aircraft flown by Company test pilots, causing serious injuries to Neville Duke and Frank Murphy.

I experienced two engine mechanical failures with Sapphire Hunters, from which I made successful flame-out landings before being faced with a complete engine break-up while climbing at full power through 12,000 feet. Martin Baker came to my rescue but I had the misfortune of parachuting through the roof of a house in Stowmarket, with my feet entering an upstairs bedroom where a beautiful lady was in bed!

The Javelin was particularly vulnerable if blades penetrated the outer casing because its engines were adjacent to fuel tanks. After the loss of several aircraft, the engines were eventually wrapped in a type of chain mail material as an expedient to prevent the fuel tanks from being ruptured by breakaway blades.

The Sapphire was also prone to failure when exposed to a sudden drop in outside air temperature such as flying into heavy rainfall or snow, or even into cumulo-nimbus types of clouds. This caused the outside casing to contract, bringing it into contact with the compressor blades. The eventual solution was to embody an abrasive coating on the inside surfaces surrounding the compressor blades.



The 200-Series Avon – the RA14.

The 200 Series Avon

Armstrong Siddeley was so concerned about these mechanical problems that they consulted Rolls-Royce and agreed to an exchange of information on their respective engines. As a result, based on Sapphire technology, Rolls-Royce undertook a complete redesign of the Avon and added a more sophisticated version of the Lucas fuel control system. This engine, the RA14, became the first of the 200-Series Avons and made its first flight in January 1954. After an initial turbine blade problem which was cured by derating the engine from 10,500 lbs thrust to 10,000 lbs, it still compared very favourably with 7,500 lbs of the 100-Series and 8,000 lbs of the Sapphire.

Aided, to some extent, by the virtual elimination of pitch-up in the later marks of Hunter, the RA14 and its successor the RA28, passed all the most severe handling tests by Service test pilots, including gunfiring at all altitudes. This engine powered the Hunter F6, which entered service in 1956, and all later marks except the two-seat Mk 7 trainer. Boscombe evaluated the Mk 7 with both the 100- and 200-Series engines and came out decisively in favour of the 200. However, to save money, the 100-Series was adopted for the RAF's trainers, while the Indian Air Force took the 200-Series version.

Reheat (Afterburning)

The principle of burning additional fuel in the jet pipe to achieve higher thrust was applied to the RA7 Avon engine and flown in the prototype Hunter in early 1953 and the Swift the following year. The Hunter was flown by the Company test pilots not so much as an attempt to obtain higher Mach numbers (although Neville Duke did hold the world's airspeed record for a short time) but to improve the rate of climb. However, the project was abandoned because of its extremely high fuel consumption in an aircraft that was already marginal on sortie length.

The reheated RA7 was continued in the Swift with some success

Avon RA14s in reheat.

largely due to the altitude limitations imposed on the Swift because of the aircraft's severe handling problems.

Reheat was also applied to the Sapphire engines which were installed in the English Electric P1A supersonic flight research aircraft. It was a somewhat cheap and cheerful single-stage system making use of the surplus fuel available from the Dowty constant output fuel pump after the main engine's requirements had been bled off.

This system was later fitted to the Mks 8 and 9 Javelins and extensively tested at Boscombe Down. Once the tendency for the necessarily much larger jet pipe to come adrift from the engine and for the rear fuselage fire warning light to come on after every take off, had both been cured, the normal engine handling trials were started. These showed that the reheat was reluctant to light up and could be unstable. And when it did fail to light, the nozzle on the end of the jet pipe remained open, producing a marked loss of thrust until remedial action was taken by the pilot. With development, the system became more reliable and was operable at altitudes up to 60,000 feet. It undoubtedly improved the acceleration of the aircraft when starting

The mildly idiosyncratic reheat in the Javelin which could, under certain circumstances, actually reduce the available thrust.

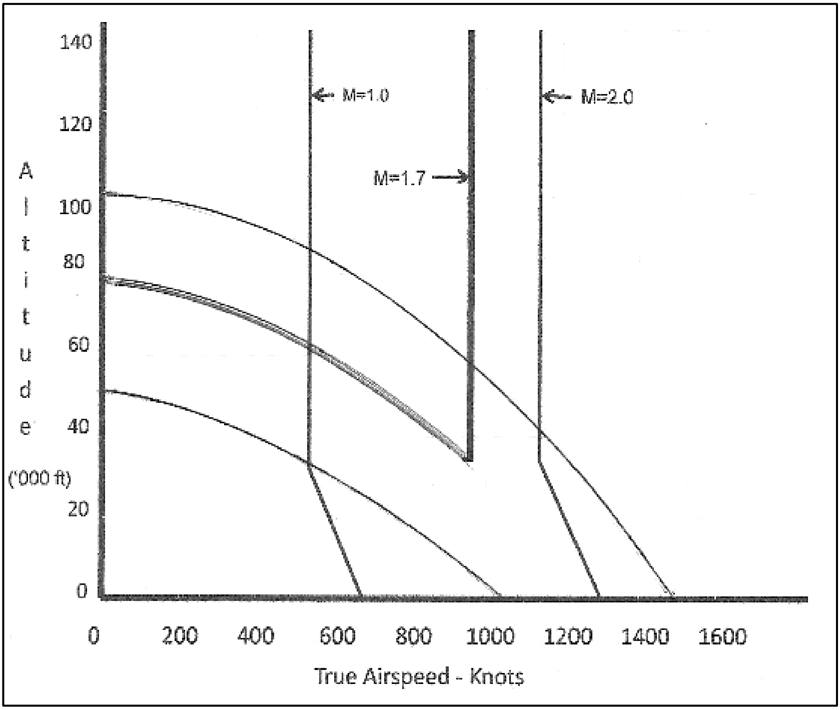
from the lower airspeeds. However, there was no noticeable increase in the attained maximum Mach number. As Reggie Spiers, the Boscombe project pilot remarked, 'The only thing that goes faster is the fuel'.

On the other hand, at full power below about 5,000 feet the main engine demanded practically all the fuel pump output, so this time the use of reheat bled fuel from the main engine, reducing its thrust. In the circuit to land, the total thrust from the main engine plus reheat would be marginally less than the unreheated engine. With the additional risk of light-up failure leaving the nozzle open, pilots were advised not to attempt to use reheat for any overshoot to land, especially on a single-engine approach.

Meanwhile, early tests at Boscombe Down revealed that the reheat system applied to the early RA14 and RA28 Avon engines installed in the P1B, was unacceptably unreliable at all speeds and altitudes. Even when light-up was achieved, it was unstable and frequently extinguished, leaving the jet pipe nozzle open. These symptoms reacted on the main engine causing severe oscillations in RPM and thrust. Once these problems were sorted out, it became apparent that for operational purposes there was a considerable range of speeds between say 0·98M at full cold power and 1·8M in reheat that could not be maintained. Rolls-Royce developed a four-stage system that helped to improve speed control, but it was not the complete answer.

The four-stage reheat proved unreliable and still left speed gaps in the supersonic flight envelope. Eventually, fully variable reheat arrived a year later and was shortly followed by the ability to throttle back the main engine while remaining in minimum reheat. All these steps in the development came about as the result of extensive test flights by Service test pilots at Boscombe Down.

In August 1959 I gave the final service clearance for the engine and reheat after two flights in the Rolls-Royce development Lightning

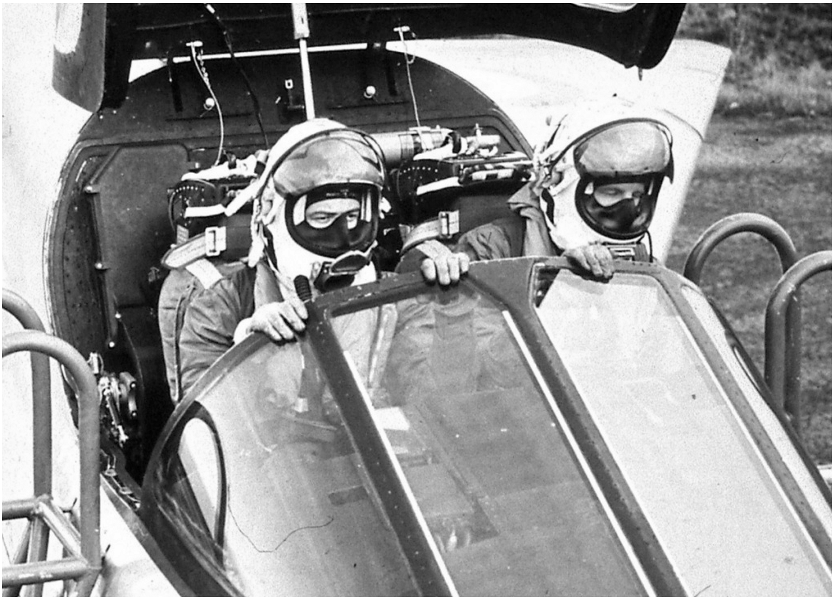


Graph showing that, at 1·7M at 36,000ft, trading speed for height should permit an aircraft to attain about 80,000ft at zero knots.

from their airfield at Hucknall. These sorties involved slamming the throttles from idle to maximum re-heat, then to idle, followed by hot re-slams at altitudes from 20,000 to 50,000 feet at Mach numbers from 0·85 to 1·7. No problems were encountered. At last we thought we had the engine that up to this time fighter pilots could only dream about.

Zoom (Energy) Climbs

It did not stay that way for very long. At the end of 1959 preparations were started for a programme of zoom or, more precisely, energy climbs in order to demonstrate that the Lightning was capable of intercepting any Soviet Union equivalent of the U-2. It was anticipated that these aircraft would be operating at altitudes up to 70,000 feet, compared with the Lightning's level flight ceiling of 55,000 feet subsonic and 60,000 feet supersonic. However, by converting the kinetic energy of true airspeed into the potential energy



Partial pressure suits and helmets were essential for the energy climb programme.

of height, the curves show that 1·7M at the tropopause (36,000 feet) could theoretically be converted to 80,000 feet at zero true airspeed.

In practice, even with a near zero ‘g’ trajectory towards the end of the climb, not only will some residual true airspeed be necessary to provide sufficient airspeed to control the attitude of the aircraft for the subsequent descent, but engine thrust during the climb will not equal drag which the theoretical curves assume. We estimated that somewhere around 75,000 feet would be the most practical altitude that was likely to be achieved.

After fitting out with special high altitude pressure clothing as a precaution against a sudden cabin pressure failure, and undergoing explosive decompression runs in the IAM chamber, in January 1960 Sqn Ldr Geoff Cairns and I started a series of energy climbs, only to find that above 60,000 feet the engine RPM decreased rapidly. This cut off the reheat causing engine instability that threatened a total flame out, meaning we would have to rely upon the engines continuing to windmill in order to sustain the hydraulic pressure for

The writer experienced an alarming case of intake buzz while flying an early F-104 from Edwards AFB.

the flight controls until reaching a practical height of 25,000 feet for relighting.

Rolls-Royce were contracted to cure the problem and soon came forward with a revised barometric pressure controller which proved very successful. In a short series of flight tests thereafter, Geoff Cairns was eventually credited with reaching the greatest height, estimated as 74,000feet. It could only be a calculated estimate because at these altitudes the atmospheric pressure differences with height are not sufficient to operate the mechanics of the barometric altimeter except in jerky steps of some 100 to 200 feet and with considerable lag.

Intake Buzz

Intake buzz is the term given to airflow instability at supersonic speeds when the shock wave at the mouth of the intake is alternately swallowed and expelled at relatively high frequency. It was first experienced on the Lightning at 1·8M when Company test pilot Roly Beamont was opening the flight envelope towards Mach 2, largely for publicity purposes as at that time this was not specified in the Air Staff Operational Requirement.

Buzz causes instability in the engine's compressor which then leads to severe turbine overheating. Until it was eliminated by the combination of a slight modification to the aircraft inlet shock cone and the engine improvements described earlier, a Mach limit of 1·7 was declared for Service Release, and explains the limits for the engine tests previously described. It was raised to Mach 2·0 in the 1960s after the Avon 210 was considerably improved to become the Avon 300-Series which powered later marks of the Lightning.

Buzz was a serious problem to all aircraft operating at high supersonic speeds. My only experience of it occurred at 1·9M at 36,000 feet in a Lockheed F-104 Starfighter prototype flying out of Edwards Air Force Base in 1959. After the onset of an horrendous noise like tearing calico, all the engine overheat warning lights came on and I was compelled to shut down the engine to avoid its disintegrating. I was relieved to obtain a successful relight shortly thereafter at 20,000 ft, for the F-104 was not renowned for its gliding performance and this prototype had a *downward* ejection seat!

Conclusions

The gas turbine jet engine advanced dramatically between 1940 and 1960. In military aircraft the axial flow engine almost completely took over from the centrifugal compressor engine. But the benefit of their greater thrust was offset by difficult handling problems and poor reliability. It took almost a decade to achieve a robust design with the desired carefree handling characteristics; and it came at a great price. Serious accidents due to engine failures were not uncommon in the early 1950s. By 1960, reliability, handling and performance, including the huge boost from reheat, offered an aircraft performance that doubled the speeds and altitudes of the 1940s designs.

Throughout those years, the Service test pilots, working closely with the Company test pilots, were able to expose the engines to their projected in-service operational environments, revealing the deficiencies and advising front line Service pilots, through Pilots Notes, of the limitations to be observed. Although based on the foundations laid by the Company test pilots, it was the role of the Service test pilots ultimately to make the decisions about an engine being ‘Fit for Service’.

THE AVRO VULCAN – MAKING IT WORK

Tony Blackman

Having read Physics at Cambridge, Tony Blackman flew Vampires and Venoms in Germany as a National Serviceman before training as a test pilot. He joined Avros in 1956, eventually becoming Chief Test Pilot, and during his time with Avros/Hawker Siddeley/British Aerospace, he helped develop the Vulcan, Nimrod, Victor K2 tanker and the Avro 748/Andover. He subsequently joined the Aerospace Board of Smiths Industries as Technical Operations Director before becoming the Technical Member of the Board of the UK CAA.

At the conclusion of the Second World War the UK Government decided that it needed an airborne independent strategic nuclear deterrent. An Operational Requirement (OR 229) was issued in 1946 for a bomber with a top speed of 500kt, an operating height of 50,000 ft and a range of 3,350 nautical miles. The OR was refined and issued in detail as B.35/46 and it is an interesting reflection on the defence budget at that time, and on the state of the UK's aerospace industry, that six companies were able to respond and three designs were authorised. Even more impressive was that all three resulted in aircraft that went into RAF squadron service and the two more advanced designs virtually met the Operational Requirement in their Mk 2 versions when the engines had been developed.

Of the three designs chosen Avro's offering, the Type 698, clearly involved the greatest technical risk because there was very little experience, worldwide, of the aerodynamics of such a shape. Interestingly A V Roe, whose company was sold to Armstrong Siddeley in 1928, wrote a letter in 1941 to 'Dobbie', Sir Roy Dobson, Managing Director of Avros at the time, saying:

> 'For a long time I have been of the opinion that the tail unit is an unnecessary appendage, that is the rudder, fin, tailplane and elevators; if these can be eliminated there would be a well worthwhile percentage of structure weight and cost saved.'

We have no idea whether Roy Chadwick, who chose the delta wing

The short-lived Avro 707.

for the Avro response to the OR, ever saw the letter since he was killed, along with the company's Chief Test Pilot, in the 1947 accident involving a Tudor taking-off with its ailerons cross-connected. Chadwick's death clearly increased the risk in developing the Avro 698, later to be named the Vulcan, so it was decided to build one-third scale models of the aircraft to investigate the aerodynamic characteristics of the design; it didn't seem to occur to anybody that money might be saved by just proceeding with two designs. A prototype was built in record time as the Type 707 in a numbering sequence that had started with the Avro 500 in 1912 and had continued unbroken ever since, even after the company had changed hands – perhaps because Chadwick, who had joined A V Roe in 1911, went down to Hamble with the firm during the First World War and stayed with the design office when it moved back to Manchester after the company was sold to Armstrong Siddeley in 1928.

The 707 used parts of existing aircraft, like a Meteor windscreen and an Athena undercarriage, and had a Nene engine. The date of the first flight, 4 September 1949, was significant because Avros always wanted to be able to demonstrate their latest products at the annual Farnborough Air Show and though the 707 was still on the secret list, it was allowed to appear and be shown in the static park. Tragically the aircraft crashed four weeks later near Blackbushe and the pilot, 'Red' Esler, was killed. The aircraft did not have an ejector seat and it was in the days before crash recorders so the reason for the accident will never be known. The controls were manually operated and the

The 'slow speed' Avro 707B.

first few flights of test aircraft at that time were invariably spent getting the right 'feel' for the manual controls and preventing overbalance; in fact the RAE attributed the accident to aileron overbalance after pre-flight adjustment, because the aircraft flew over the airfield rolling from side to side shortly before it crashed, but Avros thought it was due to full airbrake being extended.

A decision was then made to build not one, but two more one-third scale models; the 707B to investigate low speed handling and the 707A with representative intakes to investigate the 'high speed' end. The 707B was ready for the 1950 SBAC Show and at this stage Roly Falk, 'Winkle' Brown's predecessor at Farnborough, joined the programme and did the early development work.

The 707B confirmed that the low speed handling of the delta planform was satisfactory with no sudden wing drops or tendency to spin. It also showed the need for a long nose wheel on the Vulcan to ensure smooth take-offs without the need to pull the aircraft into the air and then immediately having to push the stick forward.

The 707A flew as early as June 1951, rather than September, and this was the aircraft that revealed the shortcomings of Avro's delta wing. The most serious problem was that, at cruising speed and above, buffeting, created extra drag so that the aircraft was unable to meet its performance targets in range, height or load carrying capacity; clearly

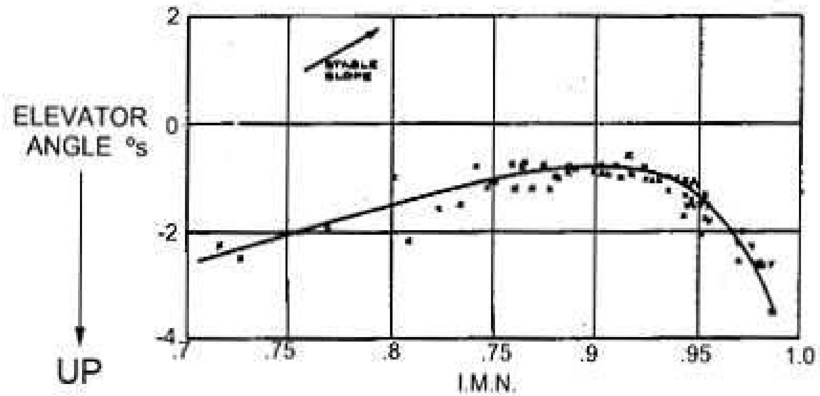


Fig 1. Graph illustrating the way in which elevator deflection changed in order to maintain level flight as speed increased in the transonic region.

unless this buffet could be prevented the aircraft would be of no use as a bomber. However the problem was compounded because, not only did the delta shape have a performance problem, it also had two handling problems. First, it was longitudinally unstable above the cruise Mach number of ·85 IMN, so that the pilot was continually having to pull the stick back to apply up elevator to prevent the speed increasing. By the time that 1·0 IMN was approached the elevators were fully up and if speed was increased further the aircraft dived uncontrollably – not a desirable feature in any aircraft.

Figure 1 records some points I measured at Boscombe Down on the Mk 1 during acceptance tests conducted in March 1956 and it shows increasing instability approaching 1·00 IMN. As speed was increased to about 0·9 IMN more down elevator was needed, indicating that the aircraft was stable. Above 0·9 IMN, however, up elevator was needed to prevent the speed increasing, that is to say that the aircraft was now unstable.[1] On the Mk 1, 1·00 IMN was about ·95 TMN and the Vulcan never went supersonic, unlike the Victor when, allegedly, Johnny Allam let the aircraft get away from him.

[1] I am grateful to Wason Turner for providing both the graph at Fig 1 and the diagram at Fig 2. Wason ran the 'B' Squadron Tech Office when I was at Boscombe Down, later becoming Chief Superintendent; sadly, he died very recently.

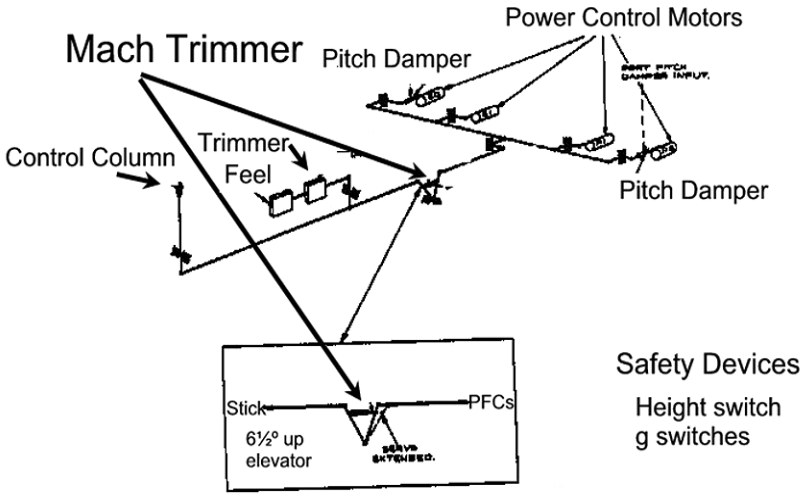
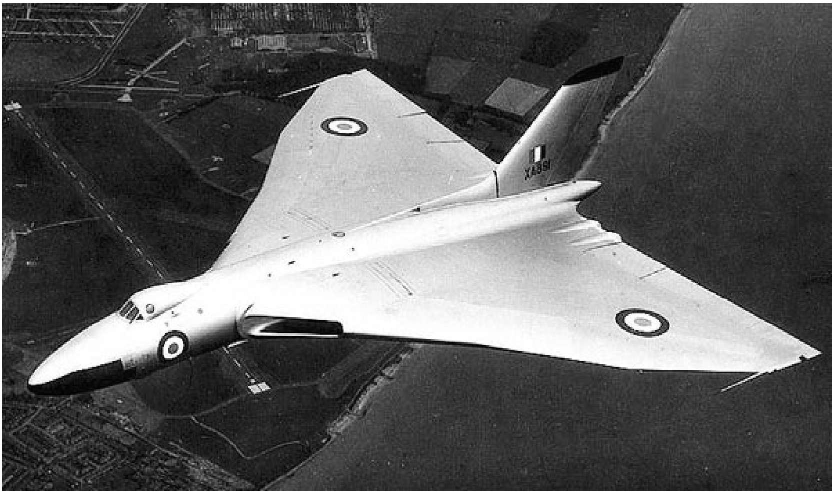


Fig 2. Schematic of the elevator circuit with Mach trimmer.

The other undesirable handling feature of the delta shape chosen for the Avro 698 was that the aircraft exhibited an uncontrollable, although fortunately not divergent, short period pitching oscillation at high Mach numbers. Avros took a brave decision and decided to deal with the handling problems by using artificial stability, which was right at the edge of technical capability at that time. The company involved, presumably recommended to us by the Royal Aircraft Establishment, was Louis Newmark Ltd; they were an excellent firm and their equipment worked well.

Figure 2 illustrates the elevator circuit. Avros had decided that the way to hide the instability from the pilot, and therefore deter him from going too fast and possibly diving out of the control, was to artificially apply up elevator with an extensible servo as the speed increased so that the aircraft felt stable to the pilot. We 'shaped' the output of the servo so that the aircraft was just stable until about ·96 IMN on the Mk 1, ·02 IMN before the maximum permitted IMN for the RAF; then we arranged for the servo to extend rapidly as speed increased so that the pilot noticed a large nose-up trim change which acted as a deterrent to going any faster. Of course, if the pilot ignored this warning and went beyond 1·00 IMN then the servo would be fully extended; the elevators would be fully up and the aircraft would be



A Vulcan Mk 1 with the kinked Phase 2 wing.(BAE Systems)

bunting into a dive. In fact the Mach trimmer proved to be a very effective deterrent as we never lost an aircraft through overspeeding, although we did have two near misses. One involved a Mk 1 on a test flight from Boscombe, the other a squadron Mk 2 doing an air test.

Two pitch dampers were fitted on the Mk 1 but we needed four on the Mk 2 because the pitch damping was forecast to be divergent.

Returning to the aerodynamic drag problem on the aircraft, the solution had to be found by flying the wing itself. The 707A was used as the test aircraft and all sorts of tricks with vortex generators and wing shapes were tried but it wasn't until 1955, by which time there were already several full scale Vulcans flying with straight leading edges, that a fix was found and the production drawings released. The eventual solution was relatively simple and consisted of fixing a drooped leading edge to the outboard section of the wing.

The 707A went on to have a remarkably lengthy career. Owned by the Ministry of Supply, when Avros had finished with it, it went to the RAE and then, later, through the aegis of the Commonwealth Aeronautics Advisory Research Council, it was shipped to Australia where it was flown from Laverton by the RAAF's Aircraft Research and Development Unit on, *inter alia*, boundary layer and flow separation tests. When that programme ended, the aircraft was sold to

The second Avro 707A while engaged in aerodynamic studies undertaken by the RAAF at Laverton in the 1960s.

a Mr Geoffrey Mallett in 1967 for A$1,000. Mr Mallet kept it in his back garden until the RAAF Museum at Point Cook eventually decided that they ought to have the aircraft and a deal was struck in 1999. The 707A is now in the Museum but, sadly, not currently on display, although it is undergoing restoration. However, in 2008 I was lucky enough to be able to see the aircraft which still features the crucial kinked leading edge, without which the Vulcan would probably not have been a practical proposition.

The first full scale Vulcan flew in 1952 – just in time for Farnborough week. The blanking plates on the undercarriage legs blew off on the first and subsequent flights, so the aircraft was demonstrated at the SBAC Show without them. The prototype did not have Olympus engines so it was unable to fly high enough to help the 707A sort out the buffet problem and the Mach trimmer shaping; it was used instead for developing the various systems – electrics, hydraulics, fuel, flying controls and so on.

The original flight deck of the first prototype had a wheel and only one pilot seat for the first flight. It was agreed that for such a small flight deck a wheel was not required and with a stick and four small throttles it felt just like a fighter so we had to make the artificial feel work to prevent the pilot inadvertently damaging the aircraft.

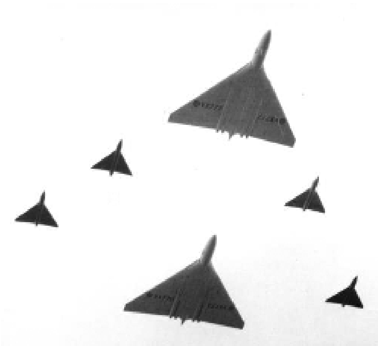
From a flying control view point the aircraft was way ahead of its time. The controls were all fully powered, unlike the Valiant, but

The prototype Vulcan at the SBAC Show in 1952.

instead of being driven by hydraulic systems piped all round the aircraft, each control surface had its own electrically powered hydraulic pump. A failure of the electric motor or pump would just result in a trailing surface and some loss of control effectiveness; however it was necessary to have a control surface indicator so that if there was a failure and/or warning lights came on it was possible to determine whether the warning was genuine or not.

This system meant that the Vulcan was an 'electric aircraft' in that, without electricity, there were no hydraulic pumps and that meant no flying controls. The Mk 1's electrical system was 112V DC, like the Valiant and the Victor Mk 1, which was not very satisfactory since, in the event of a total electrical generation failure, the batteries could only keep the aircraft flying for about twenty minutes – and they had to be new to achieve even that. The Mk 2 was a far better prospect. It had a 200V 400-cycle constant-frequency AC system with a Ram Air Turbine and an Auxiliary Power Unit so that, in the event of an electrical generation failure, there was always enough power to drive the flying controls. The Mk 2 also had elevons instead of separate ailerons and elevators which meant a vast improvement in flying qualities and precise control.

The Vulcan's fuel system consisted of fourteen tanks, divided into four groups, one for each engine. In order to keep the centre of gravity in the right place, the fuel had to be fed in turn from each tank and this was done by fuel proportioners. In the event of a failure the fuel could be controlled manually and a slide rule was provided to work out the



The famous six-delta formation at the 1953 SBAC Show.

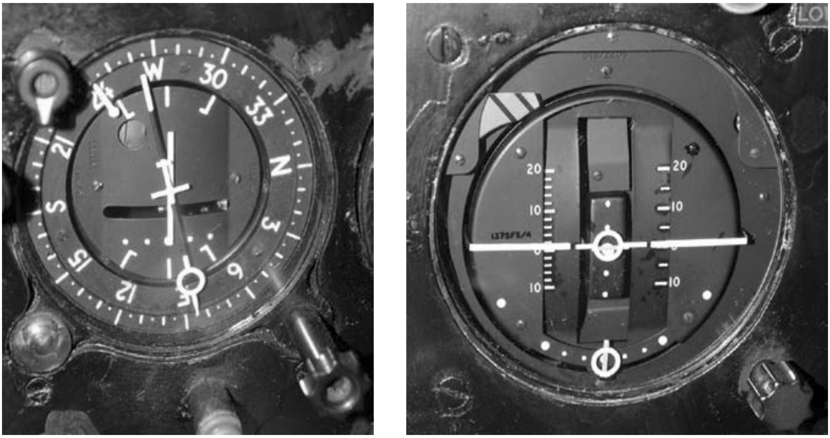
CG. On the Mk 2 a CG indicator was fitted which was a great help, as trying to work out the CG by feeding fourteen tank readings onto the slide rule was a very hit and miss procedure; there was a fuel transfer pump on each side to adjust the fuel CG.

The second prototype Vulcan flew a year after the first one, again just in time for Farnborough and by this time there were four 707s, the original 707A and 707B having been joined by a second 707A and a twin-seat 707C. How Roly was able to organise the famous six-delta formation flight in such a short time was amazing; apparently it needed all the resources of Aeroflight, still at Farnborough in those days.

Looking back I find it interesting that there appears to have been no hesitation in ordering not only an extra 707A but four 707Cs, although it was later decided to build only one two-seater. In the event, neither of these aircraft contributed a great deal to the Vulcan programme, although both had useful careers, the second 707A being used by the BLEU to develop auto-throttle and the 707C was used by the RAE for fly-by-wire development. I never flew the 707C but I did fly the 707A and all I can remember was what a very unpleasant aircraft it was to fly.

It would seem that developments and changes, even extra aeroplanes, could be approved on a ‘nice to have’ basis in those days. At Avros we certainly found that, if we thought things could be improved, but were not absolutely essential, we often got our suggested changes agreed. During my years as a test pilot attitudes steadily changed, however; the rules became stricter and we had to be far more cost effective in everything we did. As an illustration, the Vulcan was developed on a ‘cost plus’ basis while, by comparison, the later Nimrod programme was completely fixed price.

Roly was a great salesman and knew how important it was to convince the decision makers that the development programme was going well. He even managed to get the Prime Minister, Anthony



The Vulcan's Smiths Military Flight System was not as user-friendly as some.

Eden, to fly in the aircraft while it was under development. How times have changed!

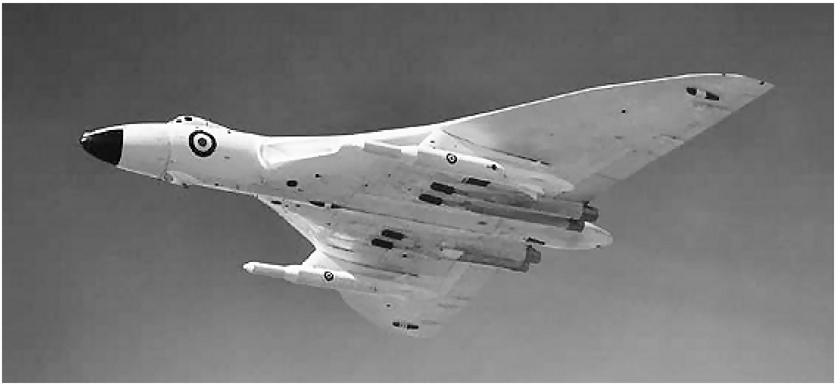
The Vulcan 1A had an enlarged back end to house the Electronic Counter Measures equipment. It retained the Mk 1's revised leading edge but the thrust was increased from the original 11,000lb per engine to 13,000lb.

When the available thrust was further increased to 17,000 lb and later to 21,000 lbs, however, there was no way that the Mk 1 wing could fly at the increased altitude and lift coefficients which that permitted without buffeting. Authorisation was therefore given for a further development of the aircraft with a new wing (and the new electrical system) which became the Vulcan Mk 2. We did the development work on the Mk 2 using Mk 1 airframes and the second prototype, VX777, which was fitted with the new wing..

The aircraft was probably the first RAF aircraft to have a 'flight system'; it was the Military Flight System (MFS) which was made by Smiths – and left a lot to be desired. The heading was shown on a moving pointer for some reason best known to Smiths, unlike Bendix, Sperry, Collins *et al* who all used a conventional moving card showing the heading. It was necessary to look hard at the instrument to find out what direction the aircraft was going in! It wasn't much better in pitch. To fly a glide slope the pilot was invited to put the attitude pointer over the glide slope pointer and all would be well; but of course it wasn't, because the ILS glide slope is conical and the gearing gets tighter the lower the aircraft goes. As result, as it approaches the touch-down point; the aircraft would become unstable long before any sensible decision height was reached. Smiths did a 'kludge', non linearising the glide slope deflection, after we told them what was wrong with their system and it worked reasonably well on the Mk 2, which was a much nicer aircraft to fly on the approach than a Mk 1. We moaned like mad about the system but we got nowhere, particularly as the civil equivalent SFS (Smiths Flight System) was already flying in some Comets and the Vanguard. Pilots are very adaptable, of course, and they get used to poor designs and even praise them. However it was difficult to see why any airline bought the system when there were much better ones available, and also difficult to fathom why Smiths designed the system the way they did; the result unfortunately was that the firm were no longer credible in the flight system market.

The Mk 2 had an automatic landing system designed by the Blind Landing Experimental Unit at Martlesham Heath, who were meant to be the world's experts at the time. The Vulcan was originally delivered to Avros with an automatic throttle control with just a speed sensor to control the engine power; it was pointed out that it was necessary to have a pitch term to give phase advance to open the throttles because of the slow response time of the jet engine but, incredibly, they actually argued and said it worked on the Varsity. BLEU asked for different pitot static systems to be tried, wasting flying hours, but they finally gave in and let Smiths provide a pitch rate sensor. After that, and after we had redesigned the pilot interface so it was safe to operate, it worked beautifully!

The other thing BLEU got wrong was the directional control on the runway. They decided that it would not be possible to do automatic landings with just a localiser and said that leader cables would be required on either side of the runway approach lights and the runway. The system worked but it put the cost up so much on airfield installations that the programme was cancelled. Worse than that, all of Bomber Command's localisers were offset so that the touchdown point was approached at a slight angle and the Vulcan had the localiser antenna in the wing tip so it was impossible to do a straight



Vulcan B2, XH537, with two dummy Skybolts circa 1962. (BAE Systems)

approach in bad weather without the aircraft having to be turned to line up with the runway at the decision height. Incidentally I don't think I was BLEU's favourite pilot because, when I did the first automatic landing at Bedford with the aircraft, they reported me to MOD for not asking them first. In fact we did have a problem on landing due to longitudinal dispersion of the touch down points caused by the Vulcan's ground effect; we cured that one by varying the approach speed with headwind component and we eventually delivered the aircraft to Boscombe for clearance just as the programme was cancelled.

Some of you may remember the Douglas Skybolt ALBM programme. The programme was cancelled eventually but not before most of the Vulcan Mk 2s were strengthened to take the missile on pylons underneath the wings which had the beneficial effect of extending the aircraft's fatigue life in the low level role.

We did radio trials at Edwards and I was very fortunate to be able to fly the B-47 with its spectacular view – compared with the Vulcan. I also flew in formation with the remarkable B-52, which first flew in 1952, the same year as the prototype Vulcan. It is said that the pilot who will fly the last B-52 hasn't been born yet!

Avros of course built the Blue Steel with its rather unpleasant hydrogen peroxide/kerosene engine. It had a range of something over 100 miles when launched at altitude but half way through the acceptance trials at Woomera the Vulcan's role was changed to low

B-52/Vulcan formation over Edwards AFB.

level and the range was reduced to something over 50 miles.

We were very fortunate at Avros as we got the contract to develop the Victor tanker. In many ways the Victor was a superior aircraft, not least in that it could carry a lot more fuel than the Vulcan – it always disappointed me that with the Vulcan's thick wings it did not carry all that much fuel, because, of course, the fuel was in bags. The Victor had a much nicer cabin, permitting the crew to see the pilots instead of being cooped up in a dungeon. The view on the approach was also a bit better than from the Vulcan. On the other hand, the Vulcan was much stronger at low level and much, much nicer to land – loads of drag after touch down so there was no need to stream the chute or brake hard at all.

I mentioned Farnborough at the start of this talk and so it is appropriate to close by mentioning that in 1958 with the Mk 1 developing the engines for the Mk 2 with 16,000lb thrust per engine it was possible to do two rolls off the top, one after the other after from a standing start and then land in 3 minutes and 19 seconds. A glorious way to spend a week.

THE COMET IN TRANSPORT COMMAND

Wg Cdr Basil D'Oliveira

Basil D'Oliveira joined the RAF in early 1946 and subsequently flew Hastings (at the end of the Berlin Airlift), Dakotas, Valettas, Ansons and Devons in the UK, Egypt and the Sudan before becoming a Comet 2 captain in 1957. Thereafter his career was closely linked with that aircraft, including a stint as OC 216 Sqn 1969-72 and he was instrumental in the introduction of the Comet 4. Basil had captained more than 650 VIP flights before leaving the RAF in 1976 to become Operations Director for the CAA and, latterly, serving as aviation advisor to the Secretary of State for Transport.

Wg Cdr D'Oliveira was unable to be at Hendon so his paper was read by Gp Capt Richard Bates.

After Cranwell, Richard Bates flew Meteor night fighters in Germany, instructed at Oxford UAS and was an ADC in Coastal Command. He spent the next fifteen years in the transport world, initially on Argosies followed by a secondment to the Kenya Air Force to fly Beavers and Caribous. After a tour as OC 24 Sqn (1970-72) on Hercules he had an exchange posting with the USAF on the C-141 Starlifter. On returning home, he commanded RAF Brize Norton in the wake of the 1975 Defence Review and later headed the Intelligence Branch at HQ Strike Command before joining Rolls-Royce.

My talk will cover both the Comet C Mk 2, the first jet aircraft to be operated by Transport Command, and the C Mk 4 in Royal Air Force service. The Comet era lasted from 1956 until 1975 – and could have gone on much longer had the squadron not been prematurely disbanded.

'Two-sixteen' was not the first military jet transport squadron, as is often supposed. This honour goes to the Royal Canadian Air Force who beat us to the post by using two Comet 1XBs from early 1953, so the title of being '<u>the first</u>' military jet transport squadron goes to the

A Comet C Mk 2.

Canadians.

I first encountered the Comet at Khartoum in April 1950 as a result of a chance breakfast meeting with John Cunningham. The prototype Comet had just arrived for hot weather trials but the programme had been upset by crew sickness. In my capacity as OC Flying Wing, I was able to assist John in solving some of his problems. Although I could not have known it at the time, of course, the Comet was to play an important part in my life. It was 1955 before I would encounter it again, but this time it would be for keeps.

The tragic accidents involving civil Comet 1s led BOAC to cancel its order for Comet 2s. This presented the Royal Air Force with the opportunity to enter the jet era and it acquired ten aircraft, with appropriate modifications to cope with pressurisation, for service with Transport Command (and three unmodified examples for use by No 51 Sqn[1]).

The Comet 2

The first RAF Comet (XK670), configured as a trainer, was delivered to No 216 Sqn at Lyneham on 7 June 1956. It was closely followed by a second, XK669, which also arrived in June. As originally delivered, the trainers lacked the reinforced floor of the transports but, after initial use for crew and route training, both were later brought up to the same standard as the C2s.

The selection of Comet crews set very high standards, most of the pilots being very experienced in long range transport operations with a minimum of 3,000 to 4,000 hours of flight time. The powers that be decided that the pilot training sequence should be as follows:

- Twenty-five hours on Meteors with the All Weather Jet Refresher Squadron at Strubby.
- A short spell on Canberras at Bassingbourn (later deemed to be unnecessary and omitted)
- A one month ground school course on airframes, at the De Havilland Technical School at Hatfield, and on engines with Rolls-Royce at Derby.
- A one-week course on aircraft performance.

Personally, I was very glad to have had the opportunity to attend the Performance Course as it threw a lot of very necessary light on the many graphs and how to use them, not least those for calculating take off and landing parameters – something we could have used to great advantage in the past, had they been available. When taking off from Negombo in a Hastings on a hot and humid day, for instance, I had often pondered take-off performance as we approached the coconut trees in the overshoot – although we always managed to clear them in the end.

During the initial squadron work-up on the T2s there were frequent delays in the conversion programme due to limited aircraft availability, poor weather and the crowded circuit at Lyneham. So, in order to speed up the process, it was decided to detach crews to El Adem for initial type conversion. This was very successful from our point of view, although it was a bit of a culture shock for the folk at El Adem who were not used to big jets doing circuits and bumps 24 hours-a-day with crews requiring meals at random, day or night. Nevertheless our hosts did everything possible to make our stay both enjoyable and a great success. Crews needed, incidentally, to have 75 hours on type before they were permitted to carry passengers.

In acquiring the Comet the RAF had, in effect, made an off-the-shelf purchase of civil aeroplane so they arrived at Lyneham fully certified to British Civil Airworthiness Requirements (BCARs) – the first military aircraft to meet that standard. As a result, the squadron operated its aircraft in accordance with civil procedures and practice. This had many advantages when compared to the way in which

Transport Command operated its conventional piston engined aeroplanes and it enabled us to maximise the aircraft's operational capability.

HQ Air Support Command (the new name for Transport Command from 1967) and De Havillands jointly issued an excellent booklet of aircraft scheduled performance notes for aircrew which helped us to have a quicker and better understanding of the complex problems involved.

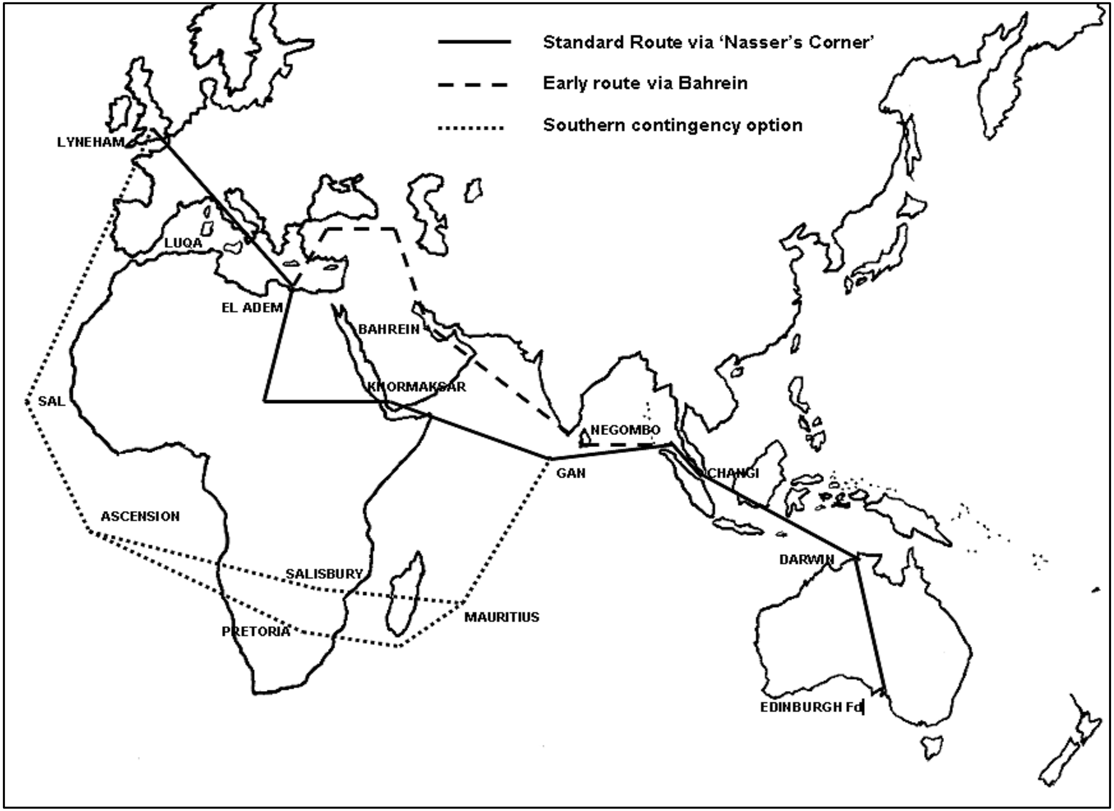
The squadron establishment was calculated on the number of crews needed to run a daily slip service to Changi, with a twice weekly extension to Kai Tak and a once a week extension to Edinburgh Field near Adelaide. That worked out at a minimum of twenty-four crews. A Comet crew consisted of a captain, co-pilot (or second pilot – there is a difference), navigator, air signaller, air engineer and, to look after the passengers, an air quartermaster. Co-pilots were routinely qualified as first pilot-on-type and could expect to graduate to captain as and when vacancies occurred. A second pilot was not qualified on type and would therefore move on to other types of aircraft.

The first operational VIP flight took place on 23 June 1956 from Heathrow to Moscow (Vnukovo) for the Soviet Air Day celebrations and to show off the new Comet. The aircraft carried a number of British VIPs, including the Secretary of State for Air, Mr Nigel Birch, Air Mshl Sir Harry Broadhurst, Air Chf Mshl Sir Ronald Ivelaw-Chapman, and Air Mshl Sir Thomas Pike. The Soviet VIP passengers included Marshals Zhigarev and Konev.

It was originally intended to give a demonstration flight for Soviet officials but this had to be postponed because of a battery failure which meant that we were unable to start the Comet's engines. To save face, the aircraft subsequently returned to Moscow on 3 July, gave its demonstration flight, and flew back to Heathrow and Hatfield the same day.

The Eastabout Route

The Eastabout route to Australia was, initially, Lyneham to El Adem, Bahrain, Negombo, Changi, Darwin and Edinburgh Field. The daily scheduled service from Lyneham to Singapore began in early June 1957 with the extensions to Kai Tak and RAAF Edinburgh Field (to support activities at Woomera) being added a little later. Slip crews



The Eastabout Route.

were pre-positioned at El Adem, Bahrain, Karachi and Singapore. When Gan opened up, the route to Singapore became Lyneham, El Adem, Khormaksar (via Nasser's Corner), Gan, Changi.

Planned turnaround time at each staging post was set at either 1hr 30mins or 2 hrs, depending on the ground facilities available. Turnaround time at Changi was either 10hrs or 12hrs, to allow for weight and performance limitations due to high temperatures, little surface wind, and Changi's shortish runway.

The accuracy of navigation was such that we occasionally encountered separation problems on the Khormaksar-Gan sector with the westbound Comet from Gan conflicting with the eastbound Comet from Khormaksar. On this sector both aircraft used cruise-climb techniques, rather than cruising at a fixed flight level, and it was surprising how often the aircraft passed uncomfortably close to each other in the middle of the Indian Ocean! We eventually imposed a lateral separation, all aircraft flying 60 miles to the left of the direct track so that they would be a notional 120 miles apart when they passed each other.

The spares holdings pre-positioned at the staging posts in the early days proved to be insufficient to support a regular slip service, which meant that aircraft were often grounded awaiting spares. These delays could cause problems, especially with providing accommodation for passengers stranded along the route. This situation improved, of course, once additional spares pack-ups had been deployed.

In view of the Comet's previous history, an incident that occurred on the first passenger schedule to Singapore caused some considerable concern. Whilst flying between Bahrain and Karachi, the aeroplane was still cruise climbing between Flight Levels 410 and 420 when, just as it was approaching its top of descent, there was a loud bang and the aircraft pitched into a 30° dive. The captain was able to regain control and the aircraft landed safely at Karachi where it was discovered that the port elevator and mass balance were missing. This clearly alarmed both crew and passengers. The repair at Karachi took about four weeks to complete.

Emergencies like that were rare, of course, but we did experience some less dramatic situations. A problem that we encountered fairly regularly was intermittent freezing of the pitot/static pressure lines, which affected all the pressure flight instruments such as the ASI, altimeters and VSIs which, when the freezing occurred at high altitude, could cause some confusion.

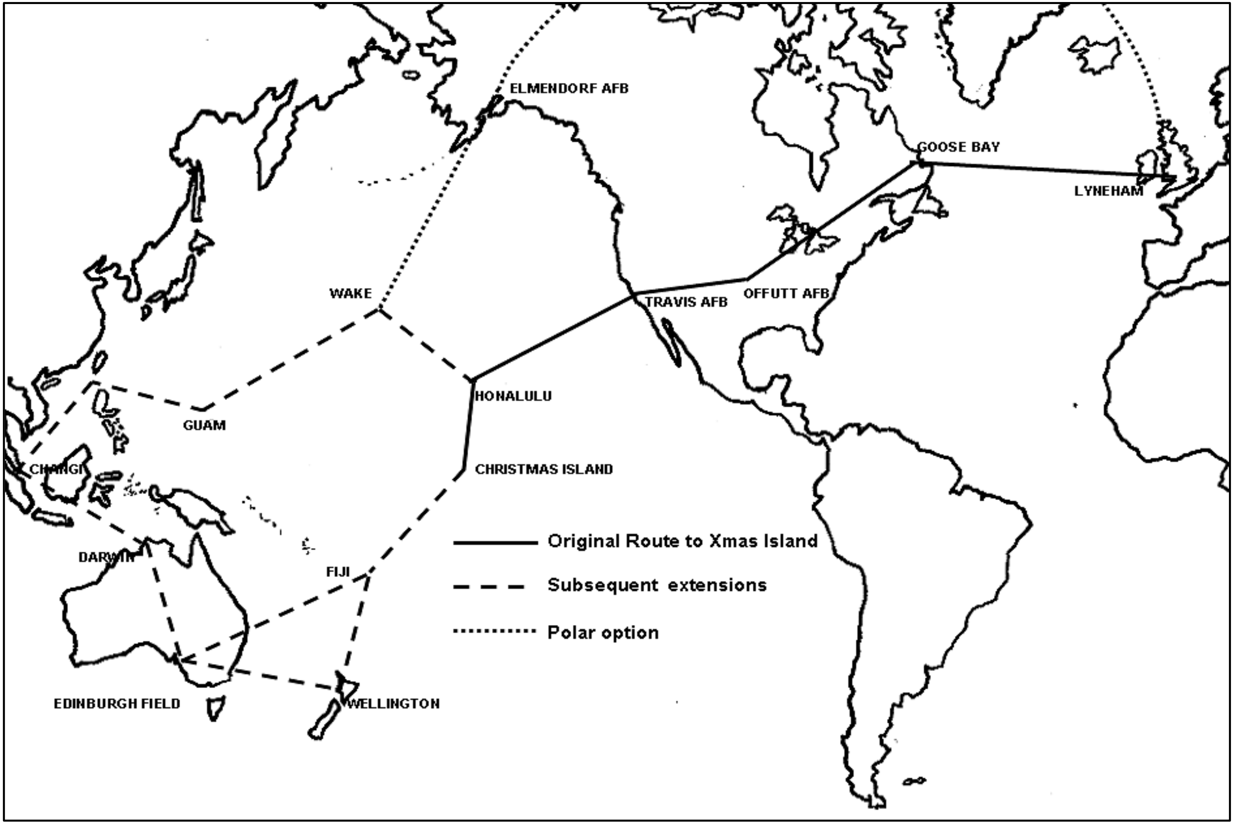
Cloud Warning Radar

Another significant hazard arose from the lack of a Cloud Warning Radar. The Air Ministry did not consider it necessary and Transport Command did not know enough about the problem to back one side or the other. At the time, the Met Office's views were unhelpful because, in their opinion, encountering cloud at 45,000 feet was not possible! When we did finally get our radar we regularly encountered cloud tops above 50,000 feet, that is to say, as much as 15,000 feet above the level we might be cruising at. The danger, of course, was that, when flying in thick cirrus, we could blunder into the core of a tropical 'cunim', so the provision of a Cloud Warning Radar (CWR) was, we maintained, essential.

On 10 November 1958 the AOCinC Transport Command, Air Mshl Sir Andrew McKee, set off on his global inspection tour. At the press conference held at Lyneham before take off, the subject of CWR was raised, but even our own CinC was unconvinced by the arguments put forward. On the Changi-Darwin sector, however, his Comet was flying at Flight Level 450 in thick cirrus cloud when it ran into the top of a cumulo-nimbus and encountered severe air turbulence leading to a partial loss of control and frightening everyone on board. At his press briefing on arrival at Darwin, the CinC announced that 'all my Comets will have Cloud Warning Radar'! Appropriate wiring was already available, so it did not take long for the whole fleet to be equipped. The bonus was that we also acquired a useful map painting facility and, at the same time, the autopilot was modified to incorporate a speed lock.

The Westabout Route

In 1957, with the scheduled slip service to the Far East now running like clockwork, the Air Ministry decided to run one passenger flight a week to Christmas Island. The so-called 'Westabout Reinforcement Route' (WRR) eventually ran from Lyneham to Goose Bay, Offutt AFB, Travis AFB, Honolulu (Hickham AFB), Wake Island and Andersen AFB, on Guam, to Changi. Slip crews were pre-positioned at Goose, Travis and Hickham. Initially, however, the route turned south after Hickham to terminate at Christmas Island.



The Westabout Route.

In the early days we found that Air Traffic Controllers around the world were not very keen to allow the Comets to use cruise-climb techniques, even though there were very few, if any, other aircraft operating at FLs 350 to 450. It took a lot of liaison work with the various ATC authorities on the Eastabout Route before cruise-climb techniques were universally accepted and adopted.

The situation on the Westabout route over the USA and Canada was very different. Clearance to cruise-climb was very rarely granted, so we had to adopt level cruises with step climbs of 4,000 ft when the aircraft weight allowed. Unfortunately, these rigidly imposed 4,000-foot steps meant that the aircraft was often flying 3,000 ft from its optimum operating height, which inevitably incurred a significant penalty in terms of fuel consumption.

The other thing the FAA did was to insist on piston-engined 'island holding' fuel reserves on arrival overhead Honolulu. The sector from Travis to Honolulu is affected by strong headwinds and/or jet streams. This often resulted in a lot more fuel being used than had been planned for, so that the aircraft eventually arrived over Honolulu with less fuel than the authorities demanded. It was not uncommon for the FAA to dip our tanks on arrival – this constraint applied to all aircraft, incidentally, not just Comets.

Extraneous Tasking

Although the Comets were never intended for VIP flights, once the full complement of ten aircraft became available, it was inevitable that such a prestigious aircraft would be employed in the VIP role. Comet C2 VIP flights ranged all over the world. Notable personalities carried included British Prime Ministers, Harold Macmillan and Alec Douglas-Home for instance, the President of the USA, the Australian PM, Bob Menzies, and Lord Mountbattern to name just a few. It was regarded as something of a *coup* that our PM could arrive for a UN Conference in a jet airliner whilst the Russians came by sea!

Another of the tasks assigned to the Comet fleet was trooping flights in response to an emergency. The high speed movement of the Army Strategic Reserve was always given high priority and in June 1958, for instance, the squadron's main effort was devoted to moving troops to Cyprus.

One of the more unusual tasks undertaken by 216 Squadron was

The Comet 2 represented a huge advance in CASEVAC facilities.

the provision of route flying experience on jet aircraft to the first six pilots selected to become BEA Training Captains. This came about because the Chairman of British European Airways, between 1949 and 1964, was Marshal of the RAF Sir Sholto Douglas who had approached the Chief of Air Staff and the government with his request which was quickly approved.

The first six were Captain Geoff Greenhalgh, who was Flight Manager (Comets) and Captains Tony Angus, Les Alexander, Jimmy Munro and Alan Green. They were each allocated to one of our RAF captains with whom they did at least two trips to Singapore, while also participating in our routine monthly continuation training exercises. The exchange was mutually beneficial and both parties learned a great deal from this experience.

Casualty Evacuation

The Comet was ideally suited to the casualty evacuation role, of course, because of its speed. Using older piston-engined aeroplanes, a CASEVAC from Singapore could take a week; a Comet could do it in 24 hours. But that aside, the Comet could fly at more or less any altitude, although we would normally fly above the weather which was a great boon to the comfort of seriously ill patients. The aircraft could be pressurised to a cabin altitude of 7,500 feet, or even lower if required, and it had a humidifier which could maintain 30% relative humidity, or less, in the cabin,

Casualty evacuation was the second priority for Comet 4 tasking. All of the facilities offered by the Mk 2s were available in the Mk 4, but there was more of it and it was better designed for the job. For example, the Mk 4 carried six two-tier stretcher racking and supports internally at all times, so in the event of a medical emergency, the aircraft could be re-roled very quickly.

The Comet C Mk 4.

The Comet 4

Following the success of Comet operations between 1956 and 1960, the Air Staff decided to order five Comet 4Cs to augment the Mk 2s. The Mk 4s were required to be in service as soon as possible, or not later than the third quarter of 1961, with the Ministry of Aviation signing the formal contract with De Havilland on 24 August 1960.

On 3 October 1960 I was appointed as the Project Liaison Officer with De Havillands at Hatfield. My small project team consisted of: Flight Lieutenants Jack Boucher (a navigator); Tim Ware (air engineer); Joe Wright (co-pilot); Whalley Slade (AEO) and Gerry Pengelly (Equipment Officer). Although a Comet 4C crew was not going to include an air signaller, I had asked Transport Command to include an AEO in my team because of the huge amount of work that would be involved in drafting new route flying documentation, and briefing crews on the aircraft's electrical and radio systems.

The first of the Mk 4s was delivered to the squadron at Lyneham on Thursday 15 February 1962. The biggest obstacle that had to be overcome in the early days was probably popular misconception. In spite of the Project Team's repeated warnings, many people believed that the Comet 4 was merely a stretched Comet 2 and that it could, therefore, be stitched seamlessly into the existing system. They could not have been more wrong.

Any new aircraft coming on strength for the first time – and the Comet 4 was in many respects a new type – needs a vast amount of work to be done before it can be used operationally. Technical inventories have to be checked; Government-supplied equipment needs to be fitted and tested; ground crews have to familiarise themselves with the aircraft and the procedures for refuelling and so on and – needless to say – aircrew have to be trained on type. In the case of a transport aircraft, of course, similar procedures have to be implemented at all the regular staging posts and diversion airfields likely to be visited and proving flights have to be made to establish what special-to-type ground equipment needs to be deployed along the route. All of this has to be done before operational flights can take place.

Type conversion training began in February 1962. Training flying was limited by having only one aircraft available until 14 March when the second arrived. Route training and route familiarisation flights had to be delayed until all the necessary ground equipment had been deployed along the route, eg ground power units, passenger and crew steps, refuelling units, toilet and water trolleys, liquid oxygen and, not least, where to deploy the spare RA29/Avon 350 engines.

The first five familiarisation flights to Luqa took place with new crews during March and April. Further route training flights went to Luqa and Gander. By this time enough specialist ground equipment had been deployed along the Eastabout Route to allow the first proving flight to take place. It left Lyneham on 14 May and the trip lasted fourteen days, staging through El Adem, Khormaksar, Djibouti, Gan, Changi, Kuala Lumpur, Kai Tak, Changi, Gan, Nairobi, El Adem and finally back to Lyneham. There was a ground crew instructional team on board who were able to provide any specific training required by local personnel and/or to supervise and advise on the turn round procedure. To allow for this, extra time for the turn rounds had been planned within the itinerary.

The Comet 4, and other aircraft, would eventually have a very satisfactory radio fit, but that might not have been the case. When the Mk 4 specification was being drawn up in 1960 the Ministry was pressing for the HF radio to be provided by Marconi, using a set that was being developed for the TSR2. This was not ideal, however, as Marconi’s radio had been designed for high power at low level under icing conditions at relatively high latitudes.

A far more appropriate HF radio was the Collins 618T, but in order to get the specification changed from the Marconi, it was necessary to appeal to VCAS. A demonstration was laid on at Hatfield using a Collins KWM2A brief case-sized portable transceiver. This was a great success and VCAS was suitably impressed. He told me he would support the change, although, since each 618T set cost $9,800, he was concerned about finding the necessary foreign exchange, this problem being exacerbated by the fact that he aimed to provide a common radio fit across the whole transport fleet. Nevertheless, Vice-Chief was as good as his word, and authorisation to change the specification came through relatively quickly.

As a result, the RAF's Comet 4Cs had very sophisticated communications facilities with an HF single side band (SSB) radio that was way ahead of that fitted to most other aircraft, both military and civil. In addition to twin VHF and UHF radios, our Mk 4s eventually had two Collins 618T-3 HF transceivers operating in the 2 to 30 MHz band. Each receiver had its own SELCAL.[2] Space had also been provided to permit the fitting of a third HF radio to be located in the passenger compartment for use on VIP flights, rather than passengers having to interfere with the operational sets on the flight deck. This idea was just a little too gold-plated for the MOD, however, and it never came to pass.

The only controversial issue was my insistence on having a long wire antenna extending from midway along the top of the fuselage to the fin, instead of a notch, or slot, antenna which tended to make communications directional. Many aircraft fitted with notch or slot antennas had to alter heading in order to receive transmissions.

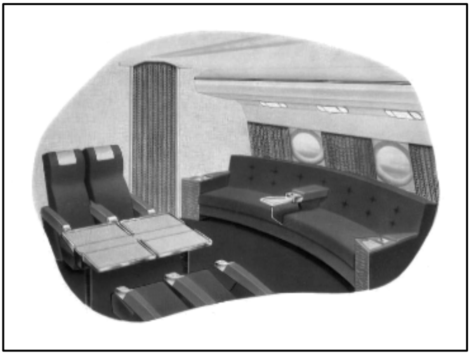
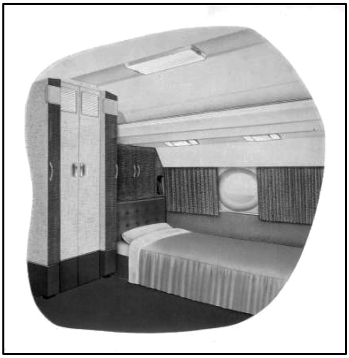
This was early days, of course, but when all of the SSB ground facilities had been deployed the result was instantaneous, crystal-clear, 24-hour global communications cover which represented a vast improvement in the handling of all types of messages – including phone patches – to any destination so equipped. In other words, all radio traffic, including long range communications, could now be handled by voice, making the use of Morse redundant. That meant that there was no longer any need for a crew to include a professional 'communicator' so the air signaller gradually disappeared from the flight decks of transport aircraft, which represented a significant saving in manpower.

Perhaps surprisingly, the Radio Flight Log was, in my opinion, probably the most important piece of paper on the flight deck. The initial design was done by the Comet 4C liaison team at the factory, the aim being to produce a layout that would permit the flight planning staff at Lyneham to fill in all the information relevant to the flight – radio frequencies, navigation aids, ATC changeover boundaries, etc – in advance, while the crew could use it to record details in flight, for instance the weather conditions encountered and which navigational aids were being used. Since the Comet had twin VORs[2] and dual ADF[2], there were four options, any two of which could be displayed on either of the two RMIs[2]. To keep track of what was being displayed where, the pilot selecting a new facility would annotate the frequency in the log with ADF1, ADF2, VOR1 or VOR2, as appropriate, and circle it when it had been positively identified. These selections triggered magnetic indicators on the instrument panel to provide a visual indication of what was being displayed on which RMI.

The Comet aroused great interest wherever it went, especially at airfields where it had not been seen before. I experienced an incident of this kind at Wayne Field, Detroit in August 1971. I had just checked in on the approach frequency as Ascot 2850 when the controller said, '*Say your aircraft type.*' I told him, '*Comet.*' '*Is that a De Havilland Comet?*' '*Yes,*' I said. In the meantime we had changed to the radar approach frequency. I was then asked if I could slow down to 200 knots, and then to 180 knots. ATC then started to vector us for the final approach. Finally the Approach Controller said, '*Continue approach. You are cleared to land. You probably won't believe this, but you are Number Two to a Spitfire!*' This story doesn't end with our touchdown, because behind the scenes, the Ramp Controller was busy re-arranging all the parking slots so that the Comet and Spitfire could be parked together. Finally, he arranged for local TV and radio to meet us – this was all done within a space of about 15 minutes at one of the busiest airports in the USA.

VIP Flying

Every VIP flight requires extensive, detailed preparation. When all the data had been collected HQ Transport Command would issue an

Left, one of the twin-bedded compartment and,
right, the lounge in the Comet 4 VIP-fit.

Operation Order dealing with the particular flight. This Order was then sent to a large number of commercial concerns, civil and military organisations and individuals. These documents usually ran to about 20 pages but they could be much longer – the Queen's State Visit to Brazil and Chile had about 80 pages and was published in three languages.

One of the VIP flights of some historical significance occurred in December 1962 when the squadron flew the Prime Minister, the Rt Hon Harold Macmillan, and the Foreign Secretary, Lord Hume, and other VIPs to Nassau for the Skybolt talks with President Jack Kennedy. A couple of days before the flight I was surprised to receive a phone call from the Prime Minister himself. He wanted me to buy four crates of champagne and see them loaded on the aircraft before departure. He would give me his personal cheque on the aircraft. Just before departing Heathrow I was handed a shoe box by one of the BOAC Traffic Staff who said they were for the PM's breakfast. I asked what was in the box and was told 'gulls eggs'. I passed on the box to my chief AQM, who was normally very *au fait* with such requests, but on this occasion he was completely thrown. We eventually got hold of the BOAC Catering Manager on the company frequency who advised that the eggs were 'normally eaten raw with champagne'. During the flight our biggest problem was keeping the champagne cold. We filled up all five sinks on the aircraft with ice cubes and champagne bottles and just about kept up with the consumption!

The best thing that happened during the Comet 4 era occurred in May 1970 when the squadron became autonomous. Its revised priorities were defined as:

- VIP Operations
- Casualty Evacuation
- Troop moves
- Scheduled flights – which now included a weekly trip to New York/JFK

To carry out these tasks, the squadron establishment was increased by approximately 100 technicians and it became directly responsible for much of its own servicing, the aim of the squadron's engineers being to keep *every* aircraft ready to fly day or night.

The result of this major policy change was that the standards of maintenance improved dramatically. Morale went sky high. Airmen took much greater pride in what they were doing, with the result that aircraft serviceability got better and better. We were often able to put all five aircraft in the air at the same time, with the fifth aircraft undertaking short range trooping flights instead of going out to civil charter. Four sectors per day became quite normal.

To wind up, I want to stress how successful the Comet C4 had been as a VIP aircraft. It was certainly a considerable improvement over what had gone before. I recall my early days of VIP flying around Europe in a Valetta, with inadequate radio equipment and a box of crystals for the PTR175 balanced on my knee. The final indignity was being obliged to park our tail-dragger next to John Foster Dulles' Super Constellation or the only slightly less impressive aircraft of one of the European leaders. I am a great believer in 'National Status' and there is a clear need for a suitable VIP aircraft to 'sell' the UK. Chartering from British Airways is simply not the answer. The Comet did this with distinction – we really do need to reinstate that facility.

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This has all been Basil D'Oliveira's account, of course, but perhaps I (*Dickie Bates*) could add a brief coda myself. When the time came to disband 'Two-Sixteen' in 1975 I was the Station Commander at Lyneham. The Squadron Commander at the time was Wg Cdr Roy King. He was planning to include a church service in the proceedings and, with a twinkle in his eye, he suggested that this should include Hymn Number 216. Everyone concurred, but when I checked in Hymns Ancient and Modern I found that the first line is 'Rejoice, the Lord is King.' Nice one!

Notes:

1 The unmodified aircraft could be distinguished by retention of the original square windows. **Ed**

2 It may be helpful to demystify some acronyms. **Ed**

a. SELCAL (Selective Calling) was a remarkable innovation when it was introduced in 1957, just as the Comet was entering service. In short, it relieves the crew of the need to maintain a listening watch on the radio, ie they can turn the volume down. Every aeroplane in an operator's fleet has an individual four-letter identification code (eg CEKL) and when a ground operator wishes to contact that aircraft he enters that combination into a SELCAL encoder which triggers a 'bing bong' tone in the headphones of the crew, alerting them to an incoming message.

b An ADF (an Automatic Direction Finder) is a radio-navigation device, conventionally associated with a radio compass, that automatically and continuously points towards a selected facility, eg a radio broadcast station or a navigation aid, such as a non-directional beacon (NDB). This information can be presented on the flight deck in several ways, often via an RMI.

c. An RMI (a Radio-Magnetic Indicator) is a dial on the instrument panel, that displays a constant read out of aircraft heading and, via one or two needles, the bearing to/from one or two selected radio navigation aids.

d. VOR (VHF omnidirectional radio range) is a ground radio station. Oriented (conventionally) with respect to magnetic north, if, as is often the case, a VOR is sited to establish a waypoint on an airway, a specific bearing, or 'radial' will define the centreline of that airway. On the flight deck, the actual bearing of an individual aircraft from the facility will be displayed on an RMI.

THE INTRODUCTION OF RAF JET AIRCRAFT - ENGINEERING AND SUPPLY ISSUES

AVM Graham Skinner

Graham Skinner entered the RAF via its Technical College at Henlow in 1963 and graduated in Aeronautical Engineering at Bristol University. After early experience with helicopters at Odiham and Sharjah, he worked on Lightnings at Coltishall before tours at No 60 MU, No 5 MU and, in 1983-85, as OC Eng Wg at Valley. The inevitable stints at MOD, Strike Command and Logistics Command culminated in his appointment as the last AOCinC of the latter. Since retirement from the RAF in 2000 he has held a number of posts within the aviation industry, with Cranfield University and with The Worshipful Company of Engineers in the City of London.

Background

Although the jet engine represented a major breakthrough in aircraft propulsion – opening up substantial increases in aircraft speed and altitude performance – its introduction into RAF service was remarkably smooth from an engineering and supply perspective with the related challenges being progressively resolved during the first decade of introduction.

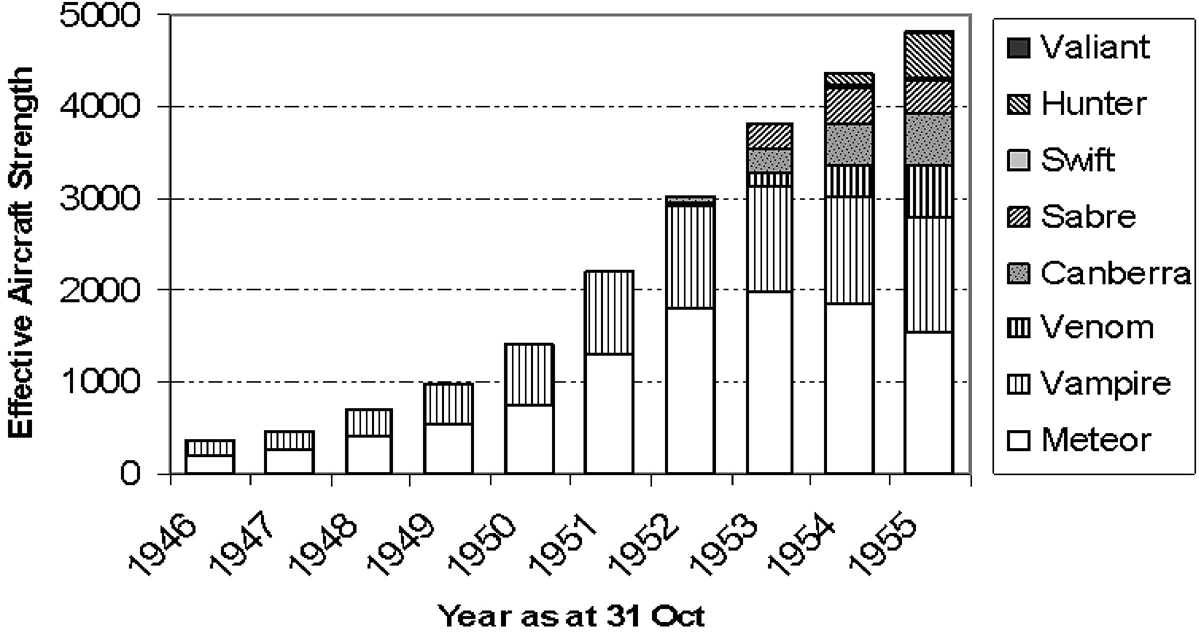
In general terms, for any air force, the engineering and supply issues of in-service aircraft are a function of their quantity in use, as defined by the fleet size and each type's intrinsic reliability and maintainability characteristics. When jet aircraft were introduced into the RAF in the decade following the Second World War they were funded, because of Governmental financial constraints, only for a slow build-up in relation to a steeply reducing piston-engined inventory and the few jet aircraft types procured were small fighters which had been designed with sound engineering judgement and recent operational experience. The result was that there were relatively few issues requiring radical in-service engineering or supply solutions to be deployed.

For the RAF any changes in supporting process or procedure from that of piston-engined types that did occur derived from one of three reasons: the nature of the jet engine itself; the higher all-round performance of jet aircraft; and the greater depth of technological skill required in the maintenance and supply organisation. This paper explores these categories of influence against the build-up of jet aircraft in the period.

Build-Up of Jet Aircraft from 1944 to 1955

The quantity of jet aircraft in-use and their relative proportion compared to the overall inventory can be estimated from contemporary Air Ministry Monthly Effective Strength statistics for all types and Commands at home and overseas. The Gloster Meteor entered service in July 1944 and by the spring of the next year there were 22 Meteors operating, compared with 55,469 aircraft on the strength of the RAF at the end of the Second World War. Engineering and supply issues were dominated by the demands of piston-engined equipments and would remain so, even during the following ten-year build up of jet aircraft. These were predominantly two aircraft types only – the Meteor, with two of Rolls-Royce's Welland and then Derwent jet engines, and the Vampire with its own single de Havilland Goblin. A total of 362 Meteors and Vampires in late 1946 had reached 1,409 by 1950 but this still represented only 15·7% of the whole of the RAF's effective strength of powered aircraft at this time. In 1951 the combined fleet of Meteors and Vampires was 2,257 when they were joined by the first new types with two Venoms and twelve Canberras; the latter type produced as a 'Jet Mosquito' replacement against the RAF's first post-war operational requirement (OR199 which was released in January 1946 with B.3/45 to cover it drafted in November 1945).

By 1953 there were: 1,971 Meteors, 1,147 Vampires, 162 Venoms, 249 Canberras, plus 293 Canadair CL-13 Sabres which had arrived via US-funds under the Mutual Defense Assistance Program (MDAP) as a stopgap swept-wing jet fighter as part of RAF expansion in response to the Korean War pending production delivery of Hunters and Swifts. Thereafter the initial Javelins, some early Valiants and the first few Jet Provosts arrived but in numbers insufficient to register visually near the end of any chart showing the chronology of the build-up of



The introduction of jet aircraft into the RAF 1946-55.

effective strength in the first decade of RAF jet aircraft introduction.

The optimism of the future RAF fleet make-up was shown during the Coronation Review on 15 July 1953 at RAF Odiham which involved 640 aircraft with 440 jets, including the first prototype Victor, second prototype Valiant, first prototype Vulcan, third prototype Javelin, first production Hunter, and a flight of Swifts. In reality, two years later, in 1955, the total jet aircraft on the RAF effective strength was 4,832 comprising: 1,548 Meteors, 1,235 Vampires, 578 Venoms, 461 Canberras, 361 CL-13 Sabres, 23 Swifts, 488 Hunters, 32 Valiants, three Javelins and two Jet Provosts. These jets totalled 57%, over half for the first time, of the 8,464 aircraft that constituted the RAF's effective strength at the end of 1955.

Clearly, although there remained in the inventory plenty of piston-engined types (some of relatively recent introduction such as the Shackleton, Neptune, Hastings, Varsity, Provost and various helicopters) to balance the jet engines' particular support needs from an engineering and supply perspective, by the mid-'50s the RAF was getting closer to its aim of a multi-role combat force of predominantly jet aircraft. These had inevitably posed some particular issues but, although the jet engine was a discontinuity in propulsion technology, its overall introduction in the previous ten years was a progressive ramp up with an orderly, realistic expansion of aircraft roles which allowed the engineering and supply issues to be managed.

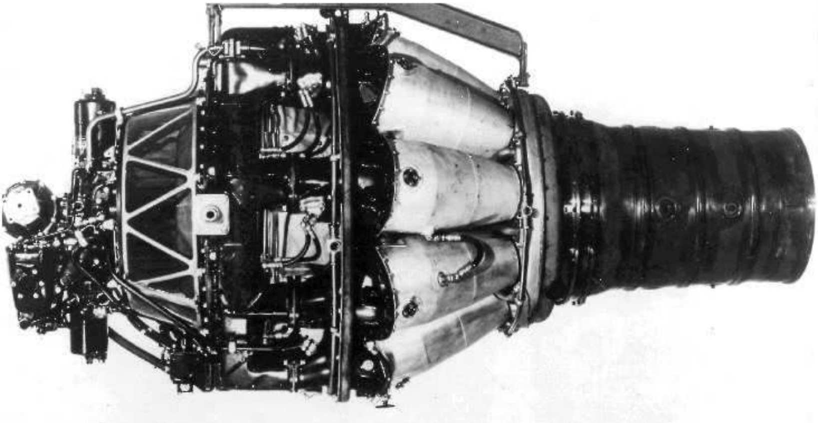
Jet Engine Issues

In contrast to a piston engine, a jet engine ran on a new type of fuel, required a different form of starting, invariably constrained the airframe designer to configure the aircraft and its systems in a specific manner but, most importantly, despite its relative infancy, the jet engine was a more reliable and maintainable source of motive power.

Jet Engine Maintenance Characteristics

At the time of early jet engine development, piston aero-engines in general were approaching their ultimate potential and were becoming increasingly complex in order to deliver relatively small improvements in performance. Their technology had probably reached an extremity of the envelope and complexity was overwhelming maturity. From a maintenance point of view, a periodic inspection on a piston engine involved considerable work on the airscrew, constant speed unit, cylinders, exhaust manifold, magnetos, carburettor and controls, cowling gills and controls, and engine and airscrew controls. With the exception of the engine controls, the jet engine has none of these components and only a few high-velocity rubbing surfaces, such as pistons, although there are a large number of hot surfaces. So there were items in the jet engine requiring inspection such as the combustion chambers, flame tubes and burners as well as the compressor and turbine. Fortuitously, the jet engine had a relatively small number of moving parts to become worn, and vibration due to rotational forces was relatively low. Furthermore, only a few adjustments were possible, principally those associated with the fuel supply system, temperature sensing and instrumentation. However, suitable checks were relatively straightforward, consisting, in the case of the turbine area, for example, of aural observations as engine revolutions slowed on close down, followed by visual checks, taking only a short time, with simple clearance confirmations of the blade tips. To quote contemporary experience, the average time to complete a Daily Inspection (DI) on a reciprocating engine power plant could take an experienced crew 3½ man-hours whereas a DI on a Derwent installed in a Meteor produced an 83% saving on this figure. Additionally, it was also noted that it was quicker to change a jet engine than to rectify any major problems in situ. Time-study investigations of engine changes revealed that there was a significant saving in labour costs compared to a piston engine. For the Meteor an engine change consumed 48 man-hours which compared most favourably with the Tempest which took 105 man-hours (or 75 man-hours if the engine was pre-dressed). Sir Frank Whittle recorded that a feature of his Whittle W2 and W2B design was the very simple engine mounting and that it was intended from the first that the engine change should be a straightforward operation.

Jet-engine systems were also relatively robust and the installed life of these early engines was, by 1946, already considered to be up to 180 hours with predictions that it could ‘soon’ reach 1,000 flying hours without difficulty. Deeper inspections, such as for the Derwent V, were scheduled at 50 flying hour intervals for minors until a major at 200 flying hours. The Goblin went quite rapidly to a Time Between Overhaul (TBO) of 600 hours in 1949 but with an



Typical of the first generation of jet engines, a Rolls-Royce Derwent, its chunky appearance being dictated by its centrifugal compressor; de Havilland's Goblin and Ghost looked broadly similar.

intermediate combustion chamber change at 300 hours. Overall, in general terms from an engineering perspective, the early jet engines were welcomed by the RAF support staffs for their relative simplicity, robustness and their savings potential from improved maintainability.

Early RAF Jet Engines Experience.

RAF jet aircraft in the first half of the decade were 100% Meteor or Vampire until 1950, 96% still in 1952 and only by 1955 had this balance fallen to 59·5% principally from the introduction of the CL-13 Sabre and Canberra. Until the first axial flow engines (the Sabre's General Electric J47-GE-13 turbojet and the Rolls Royce Avon of the Canberra, Hunter and other second generation jet types) came into service with their particular teething problems, the earlier introductory period was dominated by the engineering and supply characteristics of various marks of the centrifugal Derwent and Goblin.

The Derwent, with its single-stage, dual-entry, two-sided impellor, was based on the Whittle W2 which became the RR W2B/23C, then the RB23 Welland and this type powered the Meteors in their initial introductory decade and owed much to Sir Frank Whittle's pioneering designs. The Derwent V, whilst retaining the double-sided impellor, was significantly modified with a Rolls-Royce diffuser and straight-through combustion chambers and was an 85% scale down of the

Nene to the same volume envelope of the Derwent I to power effectively the Meteor F4 and its onward marks.

The de Havilland Goblin in the Vampire was designed by Major Frank Bernard Halford who, when first approached, was 'much in ignorance' of Whittle's work. But the de Havilland team were immediately given the full co-operation of all concerned at Power Jets, the Royal Aircraft Establishment (RAE) and Glosters and were able to start work with a full understanding of what had already been achieved. Whilst the design of the Goblin's single-sided compressor, bifurcated intake, long tubular drive shaft and improved combustion flow differed fundamentally from Whittle's engine, it is possible that much of his aerodynamic design went into the compressor and turbine.

It is interesting to learn that, unlike Britain, in Germany there was an engine altitude test chamber in Munich and when it was captured intact in May 1945 plans were rapidly made to test the British jets inside it and the first Goblin ran there in August. After the first runs the German technicians asked if they should open up the cell so the engine could be inspected; the de Havilland team declined and started the next tests. After these the Germans asked again because they had never met a jet engine which could run more than 5 hours without something being replaced. The Goblin ran, simulating altitudes up to 43,000 ft, for 42 hours in that cell without any maintenance. A simple configuration, the availability of good materials such as nickel, and a sound design by a small experienced team in Britain had achieved much in terms of longevity in comparison to the German jet engine programme. In fact, because the de Havilland turbojets were so reliable, one of the dubious results was that they were given no means of airborne relight following a flame out. In due course, the operational confidence in these early British designs is well illustrated in the first East-West crossing of the North Atlantic by six RAF Vampire F3s flying via Iceland and Greenland on 14 July 1948.

Overall, the reliability and maintainability of the early jet engines in RAF use was extraordinarily good with no endemic technical problems evident. This is attributed in no small part to the influence in every part of their design by Sir Frank Whittle. He was personally well-trained with significant practical hands-on experience of the operational requirements of the Service. His RAF apprenticeship as an aircraft mechanic in the new trade of rigger for metal aircraft was

Air Cdre Frank Whittle, whose practical 'engineer's' approach to the design of his jet engine ensured that its introduction to service. would be relatively trouble-free.

followed by flying training at Cranwell and operational tours including test flying at the Marine Aircraft Experimental Establishment at Felixstowe and the role of station Armament Officer. His higher education included the Officers Engineering Course at the Home Aircraft Depot at Henlow with a six-month interlude as the Officer i/c Aero-engine Test Benches in the Engine Repair Section pending his posting to Peterhouse College, Cambridge which resulted in a Mechanical Science Tripos with First Class Honours in 1936. He subsequently noted that he had been trained to think as an aeronautical engineer in terms of very low weight and great precision and his experience had given him a clear picture of the special problems of an aircraft power plant. He also said that he saw these things through the eyes of a pilot, as well as through the eyes of an engineer. All of this personal experience was fed into every aspect of the Whittle engine's design which, together with a Power Jets' team comprising strong Service associations, including serving airman on detachment, resulted in a very robust and maintainable product.

This sound foundation for engine design was in turn liberally dispensed to the other contractors engaged by the Air Ministry for volume production, further evolved by Sir Stanley Hooker at Rolls-Royce, and developed by de Havilland in their own independent jet engine. As Sir Frank's direct role in manufacture diminished he was appointed the Technical Advisor on Engine Design and Production to the Controller of Supplies (Air) in June 1946. On balance, it is a fair deduction that the relatively smooth introduction of jet engines into RAF aircraft from a supporting engineering and supply perspective can be attributed to the extraordinary talents of our most accomplished Engineering Officer, Sir Frank Whittle, who, in a pivotal role, had an embedded and intrinsic understanding of the requirements at all levels of utility for his invention to the subsequent benefit to all those who flew or supported his engine designs.

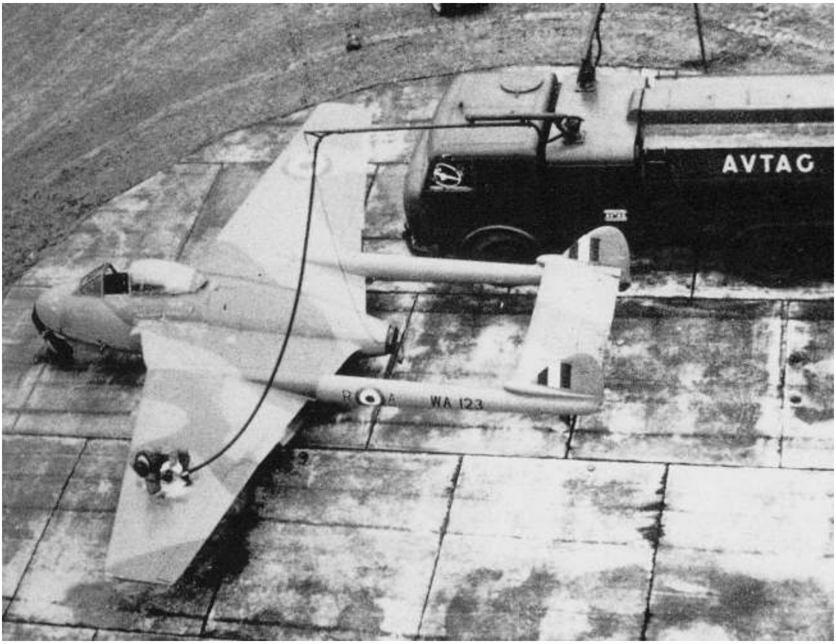
Jet Aviation Fuel and Engine Lubrication

Jet aircraft engines required a new form of fuel and their main drawback was that they were relatively inefficient, especially at lower altitudes. One senior RAF officer who was allowed to fly the experimental Gloster Whittle E.28/39 remarked that it was the first ever aircraft he had flown where you could actually see the fuel gauge needle moving while the engine was running. As far as the early Gloster Whittle aircraft operations were concerned it required a Lancaster bomber fitted with a large tank of kerosene to accompany it wherever it went because there were few airfields with a supply of aviation kerosene. Therefore, for an RAF wanting to introduce extensive jet operations their fuel availability problem needed to be addressed as an urgent supply issue.

Jet Fuel.

Apart from the requirements of bulk storage and volume distribution of a fuel with markedly different characteristics from petrol, an early decision was required to determine the standard of jet fuel to be specified. As well as calorific value and specific gravity defining the fuel load, properties affecting ‘pumpability’ (such as viscosity, deposition of water, corrosion, vapour locking, and high temperature degradation) and fire hazard needed to be considered.

Soon after the first flight of the Meteor F1 in 1943, the Ministry of Aircraft Production issued RDE/F/KER/210 describing conventional lamp-burning kerosene with a -40°F freezing point. The next year, DERD 2482, based on domestic lighting and heating kerosene, became the first of a series of improving narrow-cut jet (AVTUR) fuel specifications. However, only 6% of a barrel of crude oil could be used for AVTUR and a wide-cut alternative produced at a rate of 30% convertibility was developed. This was called AVTAG and by 1951 a wide-cut kerosene specification, DERD 2486 was issued to cover this and fuel similar to US JP-4. But AVTAG/JP-4 in trials showed some



A Vampire FB5 being refuelled with jet fuel (kerosene) as distinct from petrol (gasoline) – both of which needed to be available in large quantities while the air force was operating substantial numbers of both piston- and jet-engined aeroplanes.

problems with vaporisation (which required pressurised tanks), lower calorific value (which reduced range), and issues to do with governing the speed of the engine near max rpm. Additionally, it was shown that narrow-cut kerosene (AVTUR) was, generally speaking, a safer fuel than wide-cut AVTAG/JP-4 in all aspects of operation, crash landing and fuelling.

The debate on the relative use of AVTUR (and its aircraft carrier borne AVCAT – DERD 2488 – equivalent) and the crude-oil efficient, more widely available AVTAG, both almost 100% technically satisfactory, continued well past the first decade of jets. However, in RAF service safety considerations took precedence, thus favouring the use of AVTUR, along with selective additions of Fuel-System Icing Inhibitors to prevent the formation of ice in the fuel and reduce the chances of fungal growth. This practical operating experience, and an internal reorganisation within the MOD resulted in the RAF effectively becoming the custodian of the Defence Standard for jet aviation fuel and setting world-wide jet fuel specifications based on DEF STAN 91-91.

Jet Engine Lubrication.

Most early jet engines were lubricated from 1944 with existing petroleum suitable oils such as those to specification DTD 44D. However, for the higher internal temperature limits and lower ambient starting temperatures involved, it was clear that special lubricants would be necessary to meet the internal demand of the higher powered jet engines. In 1947-48 work began on synthetic lubricants – Esso lubricant (EEL-3) and Esso Aviation Turbine Oil 35, which was a blend of high viscosity complex esters. The result in 1949 was the issue of DEng RD 2487 as the basis for synthetic oil lubricants. In due course the RAF managed these lubricant specifications and, apart from occasional over-heating of the plain bearing on the early Welland engines, the fact that there were few jet engine bearing- or lubrication-related failures reported in service testifies to the quality and suitability of the oils that were employed.

Ground Handling

To ensure that air intakes were not blanked at low speeds, and to minimise any scorching damage to the runway from jet efflux, jet-engined aircraft had to be designed with a nose-wheel undercarriage. Furthermore, because the jet engine offered no airscrew slipstream over the tail surfaces to provide directional control it was necessary to make the nose-wheel steerable. This combination not only provided excellent visibility for the pilot, and precise manoeuvrability on the ground, it also offered major advantages to ground handling both on the flight line and in the hangar. Nose wheel towing was much safer, with positive directional control by the tractor driver via a tow bar attached directly to built-in points on the nose wheel itself. In due course the strength of the nose wheel assembly was increased to allow tractors to push aircraft rearwards, as well as pull them. For lighter aircraft the Land Rover proved a useful towing vehicle and flight line personnel could be licensed to do this, thus saving on the establishment of MT drivers endorsed to handle specialised tractors – a useful consideration in the enforced economies of the post-war

While the absence of a whirling propeller reduced the hazards associated with traditional engines, jets introduced others, like a wet start.

years.

Starting

Jet engines need to be spun up to around 40% of their maximum revolutions in order to provide a sufficient volume of air for self-sustained running and to allow fuel to ignite without the risk of an excessive temperature rise in the combustion chambers and turbine. For electrical starting the number of batteries required is greater than for an equivalent piston engine and their charge needed to be maintained. On an overseas flight line this did present significant problems, because high ambient temperatures could, and frequently did, lead to overheating of the batteries in trolley accumulators.

New starters to supersede the trolley accumulators were developed; first known as Ground Power Units (GPU) and later as Electrical Servicing and Starter Trolleys. Before they came into almost universal use the cartridge starter had a brief period in use, as did AVPIN, which was the Service name for iso-propyl nitrate (or IPN); a highly volatile liquid to feed a starter system with blazing gases from which a prudent starter crew sheltered behind the Houchin ground power unit. Additionally, pooling of fuel from leaks into the jet pipe to be ignited on first start-up also produced some spectacular sights and required anticipation by attendant fire crews to add to the flight line issues.

Flight Line Operating Hazards

As well as the hazards of starting, jet aircraft presented further new issues to technical tradesmen on first line duties. As well as the obvious ones from hot exhaust gases, there was the pervasive and distinctive noise of the jet engine turbine which could easily result in high-tone deafness from prolonged exposure. Ear guards or defenders became regular features of RAF flight line attire from the early days, especially against the high pitched scream of the Goblin, and one-

Tradesmen working on a Vampire – note the one-piece overalls.

piece boiler suits were recommended as ideal clothing for personnel to mitigate any suction hazards. This was highlighted in service by the first ground ingestion incident. This occurred in January 1943 when Michael Daunt, Gloster's Chief Test Pilot, was standing looking into the port nacelle for fuel leaks in the H1-engined Meteor F2 prototype. When the engine speeded up he was swept off his feet and sucked head first into the intake. The throttle was hastily chopped and Daunt (allegedly not a small man) was extracted, badly bruised, but otherwise unharmed; thereafter ground running guards were used – known as 'anti-Daunts'.

Small items that were sucked up during ground running and taxying were not generally a problem to the robust impellors of the early centrifugal compressors of jet engines but as axial flow compressors became prevalent at the end of the decade a whole new area of awareness and discipline around the flight lines and hangars became a major issue. These problems were mitigated through anti-FOD (Foreign Object Damage) campaigns, comprising 'FOD walks' with any loose items being picked up by hand, through to elaborate runway sweeping machines with sophisticated brush sweeps and magnetic bars. Additionally there were, within the maintenance areas, significant improvements in the engineering and supply practices of tool issue and control to minimise the potential hazard represented by loose articles.

Armament Gas Ingestion.

Designers had always needed to ensure that the armament installations on aircraft caused no adverse effects on the engine and airframe, such as damage arising from ejected cartridge cases, and that stores, particularly rocket-powered weapons, separated cleanly. This was really no different for the newer jet aircraft apart from the additional need to minimise the ingestion of gases into the intakes to avoid surging and flame-out. This was not a particular issue with the early centrifugal flow jet-engined aircraft but the Hunter with its axial flow compressor of the early Avon RA7 (Mk 115) was at significant risk of surge when its 30mm Aden cannon were fired at high altitude. A partial redesign of the intake was required for the 157th Hunter F4 onwards, plus a modified Avon Mk 121 with an instantaneous minor interruption in engine fuel flow on firing, known as 'gun-dip', to avoid over-temperatures in the combustion chambers when the supply of air was diluted by weapon propellant gases. The Hunter F4 was also the first variant to be fitted with ammunition link containers under the nose to minimise the chance of them being sucked into the air intakes during gun-firing resulting in foreign object damage.

Issues Arising from Higher Performance Jet Aircraft Flight

Most jet-engined aircraft were destined to fly higher and faster than their piston-engined predecessors. This meant improvements to aircraft system and aircrew protection and these needed revised and expanded in-service technical and supply support.

Aircraft Systems.

In the earlier jets Mach meters had been introduced and there were many improvements in the sensitivity of aircraft instruments to counteract their inherent lag in true indication and the limitations of pressure-driven instruments at altitude. Likely prolonged exposure to the cold, and reduced pressures at higher altitudes, also meant that electrical equipment needed to be better insulated. Trials at high altitude on the Meteor F4 by the Central Fighter Establishment showed a greater tendency to unserviceability, problems arising with pressurisation, hydraulics and instrumentation.

Flying control systems, using hydraulically servo-assisted powered flaps, dive-brakes and flying controls to keep the aerodynamic forces manageable by the pilot, became commonplace with the second generation fighters. In due course the improvements in manoeuvring performance and low-level operations at speed meant the 'g-loadings' on an airframe required recording, initially to ensure that overstressing had not occurred in the short term, but, after the analysis of the Comet failures, to estimate the progressive build-up of fatigue damage on the airframe. These issues in turn meant additional activities on the flight line and expanded second line engineering hydraulic bays and the Electrical and Instrument (E&I) Sections at stations operating jet-aircraft, with tradesmen becoming increasingly specialised in particular equipments within each of the aircraft system categories.

Pressure Cabins and Aircrew Flying Clothing.

Air Ministry Specification F.4/40 for a high altitude fighter had raised serious consideration of pressurisation and aircrew protection by designers in 1940. Four marks of Spitfire had such a cabin as a result of work between the RAE and Supermarine during 1940-41 and, although it never reached squadron service, the Westland Welkin had a cabin that had been designed in collaboration with Gloster. However, pressure cabins were not commonplace in RAF service and although the 51st production Vampire onwards had one, this was not the case with the early Meteors. However, a lot of high-altitude test work was carried out with Meteor F4s by the Aircraft and Armament Experimental Establishment at Boscombe Down during 1947-48 with the result that pilots sustained only by oxygen and pressure waistcoats reached 15,300m (50,200ft). Nevertheless, in general service use, pilots were not permitted to fly above 35,000ft and then for no more than ten minutes. This was a serious operational limitation and to utilise the intrinsic performance of jet aircraft properly the general use of aircraft cockpit pressurisation, albeit to the possible detriment of engine compressor and fuel efficiency from air bleeds, was necessary; additionally, improved aircrew flying clothing, including the use of g-suits and the delivery of oxygen, under pressure, was essential. This standard of personal support was introduced progressively, the later marks of Meteor having a fully operational pressurised cockpit with air being bled from the engine compressor casings. These facilities were provided from the outset on later types, such as the Canberra, which had a pressure cabin designed by W E W ‘Teddy’ Petter, who had been Westland’s Technical Director at the time of the Welkin and had subsequently joined English Electric in early 1945. With cabin pressurisation becoming an increasingly common feature of jet aircraft operation, this drove the development of associated maintenance

The first ejection seat training rig was installed at Chivenor in 1948.

procedures, demanding a high level of integrity on the part of airframe tradesmen, and the evolution within the Service of new specialised skill sets to deal with the issue, fitting and maintenance of 'aircrew flying clothing'.

Aircrew Assisted Escape Systems.

Before ejection seats, bailing out from an early Vampire was considered to be problematical and there was only one known successful bale-out from a Meteor without an ejection seat. Well before this, as jet-aircraft speeds had built up, it had become obvious that an automated and practical means of emergency escape was essential. Despite outstanding design work started by the Martin Baker Aircraft Co Ltd as early as 1944 and subsequent successful dummy and live ejections in 1946, it was not until June 1947 that it was decided that all British military jet aircraft should be fitted with Martin-Baker seats. This was because the Air Staff were initially reluctant to show support because, almost without exception, the aircraft manufacturers claimed that an ejection seat could not be fitted without major structural alterations in the cockpit area, and there were also some exaggerated claims regarding the costs and disruption to aircraft availability schedules associated with the necessary modifications. Additionally, there were reports that some pilots would be reluctant to fly with an explosive cartridge attached to their seats.

However, by February 1948 a rig had been erected at Chivenor for training in the whole process. The Mk 1 seat was introduced and in various versions was fitted to the Meteor, Canberra, Venom and Hunter; this was used successfully on over fifty occasions. However, a

A new standard of discipline and awareness was required to ensure the safety of tradesmen working on aircraft fitted with live ejection seats.

significant portion of ejections proved fatal because these early seats did little more than lift a pilot clear of the cockpit. Thereafter, he still needed to free himself from the seat and a fully automatic sequence from initiation to a developed parachute was required. The solution was the Mk 2 automatic seat, with its scissors shackle and a clockwork time release unit plus other improved features, which became the standard fit. There was also a retrospective programme, approved in August 1953, under which Mk 1 seats were modified to the Mk 2 standard. Further improvements followed to supersede the less than wholly effective thigh guards on the earlier seats, the Mk 3 being provided with positive leg restraints to prevent legs from hitting the instrument panel and then flailing on egress from the aircraft. The Mk 3 seat also employed the more powerful, 80 foot per second telescopic ejection gun, that was necessary to clear the higher tails of Javelins and V-bombers.

During this introductory period new disciplines were developed between aircrew and flight line groundcrew to manage ejection seat pins. Additionally, ejection seats with their explosive cartridges required new engineering procedures in the hangar for the storage of seats and the definition of rules for working in the cockpits with 'live' seats still fitted. Crash recovery aspects also needed consideration and any individuals who might find themselves involved in the rescue of a crew needed to be provided with appropriate training. The armament engineering trades were expanded to take on the specialised work of seat removal and fitting, with in-depth maintenance of the intricate timing devices and seat structure being provided alongside the more traditional weapons in the armament and gun bay sections on RAF stations. These armourers worked closely with the evolving trades of

Airwomen working on a Meteor T7 to minimise the blemishes in its surface finish. Again, note the one-piece overalls.

the safety equipment specialists, because of the intimate parachute, oxygen, g-suit and flying clothing interfaces with their equipment. A higher standard of cleanliness was deemed necessary in ejection seat bays and specialised procedures for quality control and independent supervision were also introduced to protect against maintenance failures in this vital task. It was also not unusual to find aircrew visiting the armoury and taking a welcomed, close interest in the overall working arrangements in these areas.

Aircraft Surface Profile.

Compared to what was to come later, the early jet aircraft were relatively underpowered, with the Meteor requiring two engines (the Derwent 1 gave 1,640lb static thrust) and the smaller Vampire faring better with its single Goblin 1 producing 2,700lb thrust. To obtain the predicted higher performance from these aircraft required a reduction in parasitic drag, thinner wings and a cleaner profile of the airframe itself. On the other hand**,** in-service operational aircraft need frequent and speedy replenishment of fuel, oils and oxygen as well as of expended stores, usually in harsh environmental conditions. A good designer, with in-service feedback, would take care over this detail and, for example, ensure that, even after prolonged in-service use, replenishment and servicing access points would always return flush to the aerodynamic surfaces. However, this ideal was not always achieved and from the early days of the introduction of jet aircraft, airmen working on the flight line needed to become more aware of the issues of reduced tolerances in aircraft surface finish and skin structure, since any blemishes could potentially degrade the performance of these newer types.

Effective Strength	1947	1948	1949	1950	1951	1952	1953	Average Fleet Rate
Meteor (%)	7·97	5·75	6·83	6·11	6·79	8·53	7·46	**7·07%**
Vampire (%)	0·90	3·70	5·22	7·01	7·33	7·26	7·67	**5·58%**

Table 1. Annual % Cat 5 per aircraft type.

In-Service Engineering and Supply Organisational Issues

General Support Aspects.

As has been already pointed out, the number of jet aircraft in service during the decade was a low percentage of the overall RAF inventory which continued to be dominated by the demands of the more numerous piston-engined types. Fleet management issues are affected by attrition rates but for the early jet-engined fleet these were in-line with the peacetime rates of comparable piston-engine fighters. In 1950 the annual Category 5 write-off rate for all causes, as a percentage of the Effective Strength, for Spitfires was 6·2% whereas, between1947 and 1953, the equivalent rate for the new jets straddled this figure with the Meteor averaging just over 7% and the Vampire rather less at 5·6% (*see Table 1*).

Nevertheless, those percentages represented the loss of 515 Meteors and 317 Vampires in just seven years and this did bite into the financial resources available to restore strengths to establishment. This had a consequential effect into ranging and scaling on each fleet's supply of spares even though, at the time, a Meteor F4 cost a mere £30,468 (equivalent to about £700,000 today) and a Vampire FB5 only £22,000 (about £500,000 today).

For in-service maintenance costs, contemporary reports in open literature show that the overall rectification man-hours per 1,000 flying hours of a piston-engined day fighter was of the order of 1,200 with the majority of effort split evenly between airframe and engine trades. In contrast, a jet-engined day fighter consumed three times that amount with around 3,700 man-hours per 1,000 flying hours with two thirds of that extra effort being absorbed by airframe trades along with a significant increase in electrical and instrument rectification.

These increased demands on manpower in a period of drawdown required improvements in planned flying and servicing with aircraft 'pooled' to smooth expected fluctuations in opportunity and embryonic arrangements for 'centralised' servicing were developed. The Air Ministry Servicing Development Unit at Wattisham, which had been formed from the Air Ministry Manpower Research Unit at the end of 1944, played a leading role in the scientific approach to aircraft maintenance, especially for the new generation of jet aircraft. This unit provided sound practical guidance and innovative techniques to both the manufacturer's design teams and to RAF tradesmen working at all levels of in-service maintenance.

New Airman's Trade Structure for the Jet-Age.

It was not until 1948 that a Trade Structure Committee was formed for reasons which included: the increasing complexity of aircraft and ancillary equipment; it was neither practical nor economical for one person to be trained to look after all aspects of mechanical or electrical maintenance; aircraft maintenance now called for teams of specialists backed by highly skilled individuals. Up to this stage and for a considerable time earlier there had been 100 or so RAF trades classified into four pay groups: A, B, C and D, with Group A carrying the highest rates. Whilst these overloaded trade groups had been thought suitable for propeller-driven aircraft and the very early jets, they were now considered to be inadequate, not least because they involved lengthy initial training courses, covering too wide a field, incurring significant training overheads and high wastage rates. Furthermore, the skills acquired were insufficient for the increasingly specialised engineering areas required to support the more sophisticated aircraft entering, and planned for, service.

Overall, a new trade structure was required to produce tradesmen better adapted and trained for the intended jet-orientated air force. The Committee's proposal to remedy these deficiencies became the 1951 Command/Technical Scheme of twenty-two compact trade groups leading off, for aircraft support, with Aircraft Engineering, Radio Engineering, Armament Engineering, Electrical & Instrument Engineering, and General Engineering. Each of these Trade Groups embraced a spread of technical competence ranging from completely unskilled, through semi-skilled, to skilled and advanced trades; each covered the whole range of pay. The new scheme, controversially, separated the 'command' and 'technical' pathways to future promotion and this was visible through the use of inverted chevrons on uniforms for the first time. Beneficial revisions were made to this structure again in 1955 after complaints received from serving tradesmen but this overall Trade Structure philosophy lasted until the next revision in 1964 by which time the jet-age had truly arrived in the RAF.

Conclusion

The introduction of the jet engine into regular service use was probably the greatest single advance in the operational aircraft inventory of the RAF. It transformed aircraft performance in the air and gave rise to new procedures on the ground. However, given such an advance it might have been expected to have spawned many difficult problems in the first ten years, problems that would need to be tackled from engineering and supply perspectives before jet-engined aircraft could become practical and well-supported operational weapon systems.

As this paper has tried to demonstrate, those issues all turned out to be manageable against a background of support of the existing piston-engined fleet during the progressive build-up of jet aircraft which was dominated for the whole of the period by the Gloster Meteor and the de Havilland Vampire. The technical challenges presented in-service were much more related to the higher speeds and altitudes that these aircraft and their more sophisticated second generation successors could achieve, together with their increasing complexity of associated operational equipment. Issues of a new type of fuel and lubricants, flight line hazards and handling, aircraft support and aircrew survival systems, trade skills and technical organisation did arise, some with useful organisational by-products, but all were resolved with manageable engineering and supply solutions.

However, as far as the jet-engine itself was concerned, the early centrifugal compressor models in the vast majority of the jet aircraft in the first introductory decade of RAF service proved to be remarkably reliable and trouble-free with significant benefits from their simplicity in terms of maintainability. This is believed to be due in no small part to the extraordinary talents of our most accomplished Engineering Officer, Sir Frank Whittle, whose Service background and understanding of the practical needs of an operational air force influenced his invention's development fundamentally.

Overall, the relatively few in-service engineering and supply issues brought into play by the introduction of jet aircraft meant that by the end of the first decade the RAF was well-placed in support arrangements to achieve its plans, accelerated by increasing concerns of the Cold War, of an expanded multi-role force of jet-powered aircraft.

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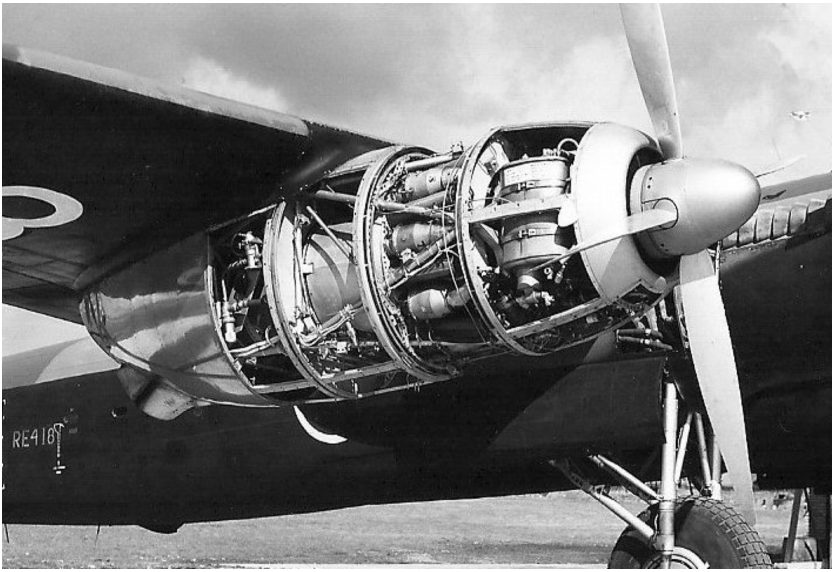
THE LINCOLN THESEUS EXPERIMENTAL UNIT

Gp Capt J D 'Jock' Heron

Some eight years before Royal Air Force Transport Command introduced the Comet as its first jet transport aircraft the Service had pioneered the operation of the gas turbine in transport aircraft with the Lincoln Theseus Experimental Unit (LTEU) based at RAF Lyneham.

The world's first turboprop powered aircraft was the Trent-Meteor which flew for the first time on 20 September 1945 from Church Broughton. Its two Rolls-Royce Derwent II engines were adapted to drive small bladed Rotol propellers through reduction gearboxes. The Trent was a straightforward adaptation of the Derwent and each provided about 750 bhp plus 1,000 lbs thrust. The 7' 11" diameter of the propeller was determined by the available ground clearance and this had the effect of limiting the power that could be supplied to the propeller and perhaps explains why there was so much residual jet thrust. As a prototype installation the major shortcoming was that the single-stage turbine had insufficient power to drive both the compressor and the propeller when it was in fine pitch but the Trent-

The Trent-Meteor with one of its 7' 11" diameter propellers feathered. These were later cropped to just 4' 10½", resulting in a power output of 350 hp and 1,400 lbs of thrust.



The starboard Theseus in Lincoln RE418.

Meteor went on to fly some 47 hours and served its purpose, which was to demonstrate the validity of the turboprop concept.

Although the principle was first examined by Roy Fedden and his team at Filton in 1924 and later with Whittle in 1931, Bristol's first experience of gas turbine technology was the Theseus turboprop. It appeared later than the Trent and was designed from the outset to drive a propeller so it incorporated several innovations. The engine had a two stage turbine which drove a combined axial and centrifugal compressor whilst the propeller was driven by a separate turbine through an epicyclic reduction gearbox, a principle now described as a free turbine. The compressor consisted of nine axial stages in tandem with a single centrifugal unit giving an overall compression ratio of 5:1 at 300 kts at 20,000 ft. Satisfactory bench testing resulted in the Theseus being awarded the first type test certificate for a propeller-turbine engine on 28 January 1947 rated at 2,180 bhp plus 600 lbs thrust.

The Avro Lincoln was selected for flight testing at Filton because it had good performance at altitude. It was also a mature airframe with a high ground clearance, so that a fully representative propeller could be fitted, and a capacious fuselage for the carriage of flight test observers and their associated instrumentation. The outboard positions were chosen for the Theseus installation because the modifications were simpler and the inboard Merlins provided power for the aircraft ancillaries. Retaining the Merlins meant that the fuel system had to be modified to accommodate both petrol and kerosene. The cockpit retained the standard Merlin engine controls and included single throttle levers for each Theseus whose travel was arranged to match the Merlins' position for closed, idling, cruise and take off, thus ensuring that throttle handling, feathering and other controls would be uniform throughout.

The No1 engine (port outer) was fully instrumented while the No 4 on the starboard wing carried sufficient instrumentation for safe operation in flight. Instrumentation was repeated on a panel in the fuselage. The flight test programme was designed to calibrate the engines at various heights and speeds up to the aircraft's ceiling. The first Theseus Lincoln, RE716, made its first flight on 17 February 1947 with Bill Pegg, Bristol's chief test pilot, at the controls and within some 15 hours full calibration of the engines had been achieved, up to 20,000 feet and 300 knots. Further proving flights were conducted to gain experience up to 30,000 feet within a total flight time of 50 hours. Suitable modifications were made to the engine controls and to accelerate flight experience the Ministry of Supply asked Transport Command to assist by accepting two Lincolns, converted to a similar standard as the flight test aircraft, to be manned by the RAF and operated on a suitable Transport Command scheduled route with a representative payload. Two additional Lincolns, RE339 and RE418, were converted, each to be fitted with a pair of engines from an experimental production batch of six Theseus. This work was carried out at Filton in early 1947.

As a bomber, the Lincoln had a normal crew of seven but because of the different nature of the transport role this was reduced to four servicemen plus a Bristol engine specialist who acted as the flight engineer. In addition to the Theseus conversion, other modifications were introduced such as the fitting of long range bi-fuel tanks in the bomb bay, removal of armament, fitting Transport Command radio and navigation aids and the installation of a floor in the fuselage to

The somewhat Spartan conditions provided for passengers privileged to experience a flight in one of Transport Command's Lincolns.

carry freight. Also there was space for seven passenger seats all equipped with oxygen, parachutes and dinghy stowage.

The first route flight took place on 7 May 1948 when RE339 took off from Lyneham at 0900 hrs and landed at Luqa in Malta just before 1500 hrs after an uneventful flight at 10,000 feet. On 8 May the aircraft flew on to Fayid in Egypt with a flight time of less than four hours and the following day it returned to Malta, although the onward flight to Lyneham was delayed until 15 May by a combination of bad weather and the need to check oil consumption during an intermediate stop at Istres in France. As service experience was gained the crew schedule settled down to the following routine:

Day 1 Lyneham to Malta
Day 2 Malta to and from Egypt
Day 3 a rest day
Day 4 Malta to Lyneham.

The trial lasted until 31 July 1950 when, having served its purpose, the LTEU was disbanded. In the words of one of the pilots 'Flying the Theseus Lincoln was just like operating any other four-engined aircraft' and the final report stated:

RE418 – one of the pair of Theseus-Lincolns operated by Transport Command.

> ‘That more than 1,000 operational engine flying hours in two aircraft during a selected period of eight months have been completed successfully on an entirely new form of power unit in the hands of RAF personnel operating under service conditions, is a very strong recommendation in itself. During this period the performance of the Theseus has been exceedingly satisfactory and it has given virtually no trouble whatsoever. Furthermore the extremely small maintenance claimed for this type of engine has been well substantiated during the course of these trials.’

Servicing records show that the servicing man hours for the Theseus were about 60% of those for the Merlins but that the rectification man hours were understandably higher due to the prototype and trials nature of the installation.

While the design of the Theseus looks clumsy today, it nevertheless pioneered the use of the turboprop in the RAF. Experience from its operation with the LTEU taught Bristol a number of valuable lessons and gave the RAF confidence in a concept which was to be put to good use in its future transport fleet.

The assistance of Alan Baxter of the Bristol Branch, Rolls-Royce Heritage Trust is a acknowledged in the preparation of this short paper.

HIGH DUTY ALLOYS AND THE JET ENGINE

Tony Buttler

The talks which formed the core of the Society's seminar focused, quite rightly, on the main players and the biggest problems that had to be solved and hurdles that had to be cleared. But making the jet happen also needed the efforts of many other smaller organisations and personalities, often specialists in a specific field who could devise and develop new materials and techniques of manufacture to match the unique requirements of the jet. One such company was High Duty Alloys, or HDA, a forging and casting firm specialising in aircraft and engine components.

Readers familiar with British aviation history will be aware of how many of the pioneer companies were created by powerful individuals such as Geoffrey de Havilland, Frederick Handley Page and Charles. Rolls and Henry Royce. High Duty Alloys came into being through the efforts of another dominant personality, Colonel Wallace Charles Devereux who, from the late 1920s, became one of the most important names in British industry. Born in March 1893, Devereux first became involved in the aircraft business in 1922 when he was appointed Works Manager to Peter Hooker Limited at Walthamstow. This firm was learning how to forge aluminium alloys having gained experience with aero-engines during the First World War. Hookers closed in 1927, but 'Dev' acquired much of its equipment and, with the backing of John Siddeley, set up a factory at Slough on 5 January 1928 under the name High Duty Alloys. Every major British aircraft built since that date has used some parts produced by HDA's factories.

Wallace Devereux at the opening of the Fulmar Research Institute on 2 April 1947. (RAeS)

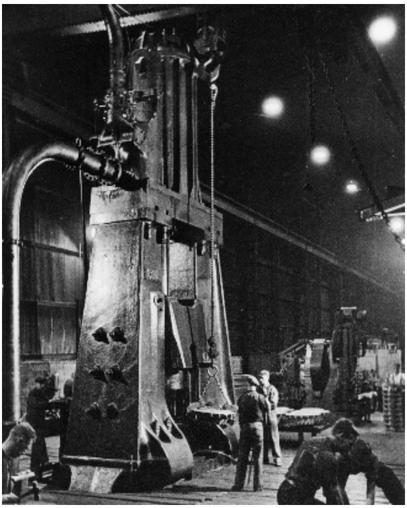
As aluminium steadily replaced wood in aircraft, the manufacture of cast and forged components began to expand. Through strict laboratory control and the inspection of his firm's products at each stage of manufacture, Devereux introduced high standards of quality control in the development, production and metallurgy of light alloys. Indeed, until HDA established a comprehensive research facility adjacent to the Slough works, forging had been a virtual black art with no technical supervision whatsoever.

Within a year Devereux had acquired the world rights to a series of Rolls-Royce alloys which became known as the Hiduminium RR range. In the early days, HDA's production was limited to the use of 'Y' alloy and Duralumin but in the late 1920s Rolls-Royce was finding that the available alloys were just not good enough to withstand the greatly increased stresses in its high speed aero-engines, so development work began on some alternatives. In 1928-29 the first new alloys in the RR series were announced and HDA was chosen as the organisation most worthy to produce them on a commercial basis. The slogan 'Hiduminium makes the most of Aluminium' quickly became known world wide! Probably the first occasion when HDA hit the headlines was the famous 1931 Schneider Trophy contest won that year, for the third time in succession, by Great Britain. All of the aluminium parts in the winning Supermarine S6B's Roll-Royce R engine, including the supercharger casing, cylinder blocks and crankcase, were manufactured in Hiduminium RR 50.

The Build Up To War

Several times during the 1930s Devereux visited Germany with Roy Fedden and so became aware more quickly than most of that country's expansion of its military and its preparation for war. German factories were far bigger and busier than those in Britain, but persuading the Government of the day to heed the warning signs proved difficult, Devereux being described by one Cabinet Minister as 'a bloody scaremonger'. At very much the eleventh hour the need for rearmament was acknowledged and huge orders for aircraft followed, but this needed a big increase in manufacturing capacity, leading to the building of new facilities under the so-called 'Shadow Scheme'. High Duty Alloys was to get its own 'shadow factories' at Distington in Cumberland and just north of Redditch in Worcestershire. Construction work began at Redditch on 18 October 1938 and a huge

Above, the HDA propeller shop at Slough in 1937. Below, the 29 ton Erie hammer at Redditch. (HDA)



460 ton hammer, the largest of its type in the world, with a 29 ton falling weight, was ordered from Erie in America specifically for this facility. High Duty Alloys, Redditch, was formally opened on 16 August 1939 in a ceremony attended by many important people from the world of aviation, including: the Secretary of State for Air, the Rt Hon Sir Kingsley Wood, who actually set the giant hammer in motion; Oswald Short and Arthur Gouge of Short Brothers; W E W Petter of

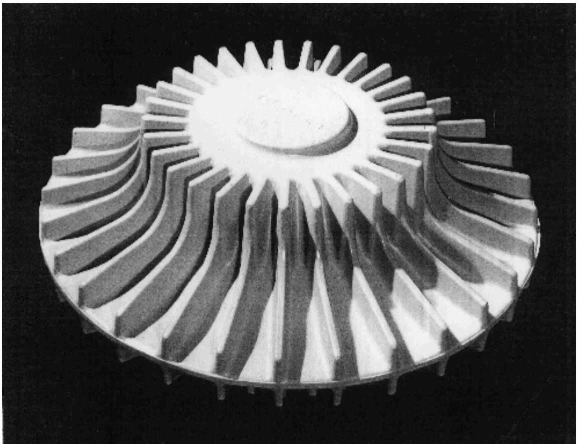
Westlands; Frank Hearle of de Havillands; Roy Fedden from Bristols; Robert Blackburn representing his own company and Ernest Hives from Rolls-Royce.

Redditch became responsible for the great majority of forged and machined aero-engine pistons produced in Britain during 1939-45, the final total exceeding 10 million, plus a great many other forged components such as crank cases, cylinder barrels and supercharger impellers – and the V-shaped spars that enabled Lancasters to carry bouncing bombs to the Möhne and Eder Dams. The power of the Erie hammer eventually wrecked its own foundations and in 1941 it was moved to the new factory at Distington, being replaced at Redditch by an 18 ton hammer which remained in use until the early 1990s. Devereux did not actually own High Duty Alloys; the firm was one of the founder members of Hawker Siddeley when it was formed in 1935 along with Armstrong Whitworth, Avro, Gloster and Hawker Aircraft. Devereux left at the end of the war and founded the Fulmar Research Institute but died suddenly at Ascot races on 22 June 1952, worn out by his efforts during those six years of conflict.

Jets

The development of the jet engine would have the most profound effect on High Duty Alloys. HDA made the first centrifugal impellers for Frank Whittle's pioneer engines in two of the new Hiduminium alloys – RR 56 and RR 59 – but, despite being the best available at the time, these materials were incapable of surviving the operating temperatures and speeds experienced inside the new powerplant. Bursting problems were encountered with RR 56 impellers during running which were overcome by using RR 59 parts specially heat-treated after pre-heat-treatment machining. This procedure reduced the residual stress within the impeller to acceptable levels but a better alloy was needed. Diffuser blades (simple aerofoils of constant section) for early Whittle units were also made in RR 56.

Once the firm's metallurgists and engineers had been allowed to learn what the application was (Whittle's creation was, of course, Top Secret), they got to work preparing a new alloy with good tensile, creep-resisting and fatigue properties at operating temperatures up to 200-250°C. It was called RR 58 and was based on RR 59 but with a much lower silicon content, and the first impellers to be manufactured



An Impeller disc for an early Whittle engine made in aluminium alloy by HDA.(National Archives)

in this new alloy were to be used by the engines that powered the early Gloster Meteors. After the war this alloy was patented in the name of two metallurgists, one from Rolls-Royce and one from HDA.

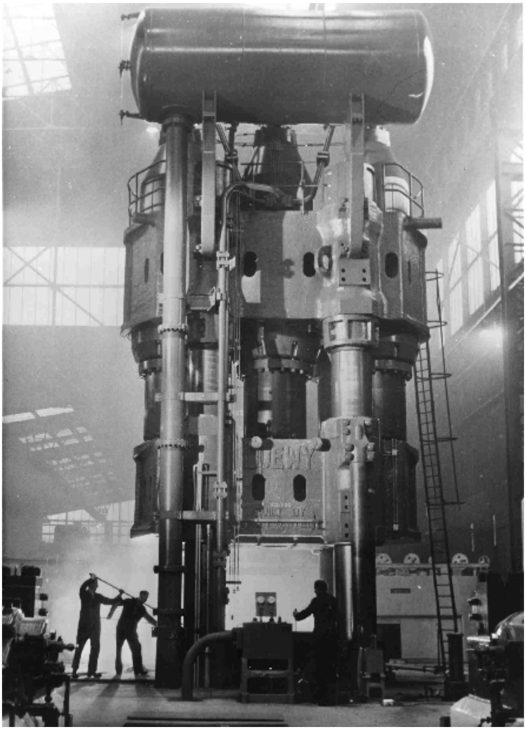
Frank Whittle also wanted blades for the turbine section of his engine made in a nickel alloy developed by Henry Wiggin at Hereford called Nimonic 75. But Nimonic 75 proved to be such a tough material to work that real problems were encountered when machining it to produce the required final shape or form. The solution, introduced in 1942, was to forge 'close to form' on a 20 cwt drop hammer at Redditch.

It would be the development of the axial jet, however, that brought the biggest change to HDA. The firm's first work with compressor blades came in 1939-40 on the axial flow engine developed by RAE Farnborough which later became the Metropolitan-Vickers F.2, first flown in a Meteor prototype in November 1943. The Slough works produced the first forged aluminium compressor blades in 1941 in RR 56, but this metal was very susceptible to intercrystalline corrosion cracking which gave rise to a high rate of rejection, despite attempts at control during manufacture. Later blades were made in RR 59 before Rolls-Royce switched to RR 58 for Avon compressor blades. The Bristol Engine Company stayed with RR 59 until 1959 when it switched to blade manufacture in an alloy called RR 57, a material also used by Armstrong Siddeley for compressor blades in its Sapphire, Mamba and Viper engines.

When the axial engine became politically and technically the more favoured over the earlier centrifugal arrangement the need for vast quantities of blades of complex design and shape suddenly became critical. Prior to 1950 a section of the HDA Redditch works had been set aside for blade production but that year, under a Ministry-sponsored scheme, a dedicated blade making facility was set up with much greater manufacturing capacity. This has been known ever since as the 'Blade Forge', with the original part of the factory renamed the 'General Forge'. In its first fifteen years of operation the High Duty Alloys Blade Forge produced over 25 million precision forged blades, many in RR 58, using a 'close-to-form' compressor blade stamping technique pioneered by the firm. There was some early controversy as to whether to machine the blade aerofoil from an oversize casting or to forge it from the outset to what was termed 'precise to form'. HDA vigorously followed the latter route but it is understood that for many years the Americans generally preferred blade aerofoils forged oversize which were then machined to the correct dimensions. From the forging operation point of view the American approach was cheaper and easier, but involved a high rate of metal wastage.

Due to increasing operating temperatures, the early 1950s saw the start of aluminium being superseded by titanium in jet engine compressors and HDA helped pioneer the forging of this very new and expensive 'wonder metal'; indeed HDA's association with titanium dates from about 1952. In the early years the material quality was, to say the least, rather inconsistent and there was a steep learning curve involved in all aspects of handling and fabricating this metal, but the situation improved after Imperial Chemical Industries had begun to produce titanium stock in the UK. Forging unlubricated titanium to make compressor blades proved to be very difficult so efforts were directed towards improved lubricants which eventually allowed the successful production of Avon compressor blades in IMI 314C.[1] Requirements followed for improved alloys, Bristol opting for Hylite 50 (which was subsequently retitled IMI 550 and was much used in Pegasus compressor discs made at Redditch for the Harrier) and Rolls-Royce for IMI 679. Titanium airframe parts soon followed and the metal was first used in quantity on the Lightning.

The advances made possible by jet propulsion brought a need for ever bigger forgings and HDA's board eventually took the decision to install a 12,000 ton hydraulic press which entered service in February



HDA's 12,000 ton press which produced aluminium propeller blades, torpedo bodies, and titanium engine discs. (HDA)

1953. This could make forgings bigger than anything in the USA (although the Americans quickly responded and soon had presses of 50,000 tons capacity). Primarily used for large aluminium forgings such as undercarriage legs, the 12,000 ton press was also employed on making large titanium compressor discs.

Other post-war HDA airframe work included the manufacture of: under-carriage forgings for the Bristol Brabazon; a large 'farmyard gate'-type forging that fitted between the wing roots of the English Electric Canberra; propeller blades for Avro Shackletons and de Havilland Doves; huge propeller blades for hovercraft (some of the biggest parts ever made at Redditch); and many components for the BAC TSR2. The range of aviation products also stretched to ejection seats and guided missile fins and HDA was heavily involved in the development of the Concorde supersonic transport. In fact, in a marathon effort, RR 58 was developed into a form suitable for manufacture in large quantities as sheet which proved to be a major factor in Concorde's construction. The company also did its share of non-aviation work, one of the most noteworthy being the aluminium wheels produced for Richard Noble's 'Thrust' supersonic car which broke the sound barrier in 1997.

By 1975 patents on the RR series of alloys had run out and many were no longer in use, having been replaced by modern equivalents;

consequently the name Hiduminium was dropped. In 1973 a 10,000 ton screw press was acquired for the manufacture of very large blades and missile fins at Redditch. The original Slough site, which for many years had concentrated on castings and research, was closed in 1981 while Distington was sold in 1979. The deep recessions that affected the British aircraft industry in the 1990s forced a period of consolidation and the workforce became concentrated at Redditch in 1991. The name High Duty Alloys finally disappeared when the company was taken over by Mettis Aerospace in September 2000, but at Redditch the company still manufactures aircraft and jet engines parts in large quantities.

A titanium alloy compressor blade for an RB.199 engine. Forged-to-size, after the excess metal (flash) has been removed and the root block machined, it will be ready to fit. The pips at each end help with the machining operation. (HDA)

[1] IMI stood for Imperial Metal Industries, an offshoot of ICI

BOOK REVIEWS

Note that the prices given below are those quoted by the publishers. In most cases a better deal can be obtained by buying on-line.

A Bucket of Sunshine by Mike Brooke. The History Press; 2012. £12.99.

Fifty years ago – Ye Gods! That's when this story starts – early 1962, when the author entered training at South Cerney, before moving on to Leeming, then Swinderby, and via Bassingbourn eventually to Laarbruch. In those fifty years all but one of those stations has gone out of RAF use, along with all the aircraft involved. But that's history for you, and the Historical Society readership will I'm sure find much in this book to enjoy. It has certainly been a pleasure for me to re-live my almost exactly parallel existence all those years ago.

One typically telling early detail is beautifully recalled by 'Noddy' Brooke (he reveals his nickname's origin, too): that strange ritual on Day 1 of any ground-school phase when the issued Air Publications have to be amended. As he tells it [and I hope he's right about the AP or editor CGJ will add his own footnote to this review[1]], the handwritten amendment to AP 1234, Pt 4, Chap 6, Page 3, Line 7 was to be thus: "For 'heliocopter' insert 'hicopleter'". Even to this day, he notes, you can tell someone who joined the RAF as aircrew in the early 1960s through the fact that they will invariably refer to those whirling dervishes of aviation as hicopleters!

The heart of this 224-page book (a little surprisingly, a paperback) is in the sub-title: Life on a Cold War Canberra Squadron. It's all there, starting with the basic challenge of negotiating the successive phases of flying training and operational conversion. Noddy gets through with only minor upsets, although having the airfield lights turned off as he made a night approach to Bassingbourn with electrical

[1] I too recall having to incorporate that notorious AL, but I share the reviewer's reservation – the amended publication was not AP 1234, which was (and may still be) Air Navigation. Not sure about the specific page and line, but a change to the text relating to helicopters would have been to AP129, Vol I, Pt 1, Sect 1, Ch 16. **Ed**

failure seemed a little over the top as a training method. Two days after his twentieth birthday he's declared fit for purpose and starts his journey to Laarbruch and the meat of the story.

Step by step, Noddy and his navigator (to whom the book is dedicated) work their way to operational status. They perform endless practice LABS manoeuvres, then start dropping practice bombs at the various North West Europe ranges – especially Nordhorn. They fly the different profiles – Hi-Lo-Hi, Hi-Lo, Lo-Lo, by day and night. They learn all there is to know about the primary weapon system – the Mk 7 1,650 lb nuclear bomb – euphemistically known as the 'bucket of sunshine' of the title. And after all the build-up, they eventually win the prize: their first stint on QRA. The first of many, and the feature of life on a Cold War squadron that comes most readily to the top of the memory pile. There are, too, exotic departures from that Germany regime: the detachments to Cyprus, Malta or Libya for more weapon training, including role change to conventional weaponry. RAF Germany Interdictor Canberras – the B(I)6 of 213 Squadron at Brüggen, and the B(I)8 of the other three squadrons at Geilenkirchen, Wildenrath and Laarbruch – could be transformed into gun-firing, dive-bombing variants. Great sport! Neat idea, and proven to be useful, when the call came for RAF Germany squadrons to rotate through Kuantan and Tengah to boost the Far East Air Force as the Malaysian-Indonesian 'Confrontation' brewed up in the mid-'60s. And to ensure that crews could operate anywhere else they might be sent, there was the need to practise getting there and looking after yourself. So it was that a first-tourist crew could set off confidently to fly to Salisbury, Rhodesia (as was). A bit of duty-free shopping in Aden on the way back, with calls in at Bahrein or Sharjah to spice up the journey still further. Halcyon days. Apart from TACEVAL!

But, although Noddy recalls the 'busy happiness' of life and work on 16 Squadron, he reflects that there have to be doubts about real operational effectiveness. Would they get through Warsaw Pact defence arrays? Would they find the target at low level at night even if they penetrated those defences? Would they survive an ejection into the North Sea without immersion suits if caught short during a Hi-Lo-Hi trip to a UK range? Worth remembering, too, the interesting lay-out of the Canberra B(I)8, with no ejection seat for the navigator (default arrangement for too great a proportion of the RAF's nuclear fleet). Although equipped with a special flying suit with integrated parachute harness, in emergency he would still have to find the parachute, clip it on, jettison the door, and roll away from the doomed aircraft. It was done, twice, but too many RAF Germany Canberra losses took the lives of all on board – usually involving collisions with the ground, more often than not via disorientation during LABS or other weaponry manoeuvres. Fifty-one B(I)8 aircraft in total were taken on to the inventories of the three squadrons (No 59 re-numbered as 3, No 88 later becoming 14, and No 16): twelve were lost with fifteen aircrew dead. Even worse was the loss rate of the B(I)6, used only by 213 Squadron: of nineteen issued to the squadron, eight were lost. With the three-man crew of this variant, that brought twenty fatalities.

Sobering numbers. Nevertheless, I enjoyed this book enormously. It captures perfectly a slice of RAF history that is – already – far removed from anything today's airmen will experience. Worth recalling, too, that while we are 50 years on from that nuclear posture, it was itself 50 years on from the foundation of the RFC. Time really flies, and symmetrically.

But I'll let Noddy have the last word. Like others after the end of the Cold War, he had an opportunity to visit the former enemy. During a Staff College visit to Poland, he found himself watching an air display at the airfield that had been his primary target. As he reflects: 'I was so glad that the Cold War had thawed out and that we hadn't had to go and throw a 'bucket of sunshine' after all.'

Air Cdre Phil Wilkinson

Wings of the Malvinas - The Argentine Air War over the Falklands by Santiago Rivas. Hikoki Publications, 2012. £34.95

Wings of the Malvinas is a weighty tome in every sense. It is essentially a work of reference, rather than a bedtime read or a book offering much by way of information or analysis above Squadron or Wing level. Santiago Rivas describes in great detail the ORBAT and day-by-day operational employment in the Falklands campaign of elements of the Argentine Air Force (*Fuerza Aérea Argentina* – confusingly shortened to FAA), the Naval Air Arm (*Comando de Aviación Naval Argentina* – COAN), and Army Aviation (*Comando de Aviación de Ejército* – CAE), drawing on war diaries and personal recollections. In passing, he touches on support flights by two airlines, the state owned flag-carrier, *Aerolíneas Argentinas*, and *Austral*. He also describes a range of operational support tasks flown by the shadowy *Escuadrón Fénix*, which included diversionary radar saturating sorties, radio relay, maritime reconnaissance and SAR, using aircraft such as the Learjet and HS 125. Intriguingly, Rivas names two British ex-RAF pilots among the 110 civil pilots 'on the books'.

The format of *Wings of the Malvinas* is that of a unit by unit, sortie by sortie narrative of operations giving a very clear picture of the courage and determination of the crews involved. It recognises a capacity for improvisation and technical innovation that in many ways mirrored activity in UK at the time. As fits were urgently cobbled together on RAF stations to install Omega navigation equipment, Radar Warning Receivers, Shrike anti-radiation missiles, Sidewinder AAMs or even air-to-air refuelling equipment, so in Argentina, similar work was being undertaken, with some significant successes. Improvised chaff and flare dispensers for the Canberra (which had already been modified to carry a mapping radar), Multiple Ejector Racks (MER), capable of carrying six 500 lb bombs and a sighting system from the Pucara for the C-130 and Omega for a number of types were all trialled and put into service. Most significant of all, Exocet was incorporated in the Super Etendard fit, with no help from the manufacturers and crews trained, with dire consequences for HMS *Sheffield* and the *Atlantic* Conveyor. Had more of this aircraft/weapon combination been available to the COAN, the fate of the British carriers might have been decided less ambiguously than is suggested in this book's account of attacks on HMS *Invincible*.

These examples of improvisation and flexibility are impressive, but the book is silent about higher level decision making and very largely about logistic and other support for operations. However, those critical of the support tail associated with contemporary RAF off-base operations need only consider Rivas's chapter dealing with Pucara operations in the Malvinas, to see the reality of attempting to operate without sufficient support – engineering, supply, Sapper or Force Protection. Pebble Island offers many lessons. Again, reading between the lines, the outbreak of war is not the time to be learning new tactics or roles, beguiling though such adaptability might seem.

Running to 383 A4 pages, with maps, diagrams and more than 500 colour and b/w plates, *Wings of the Malvinas* is a well written and a valuable reference source, besides giving a flavour of the operational environment into which Argentine crews were launched and from which they did not flinch. It is comprehensive and clearly exhaustively researched and will lie well alongside many books by British authors who cannot have had the benefit of such detail from The Other Side of the Hill.

AVM Sandy Hunter

Imperial Outpost in the Gulf (The Airfield at Sharjah (UAE) 1932-1952) by Nicholas Stanley-Price. Book Guild Publishing, 2012. £17.99.

In the 1920s and '30s establishing air routes from Britain to the outposts of Empire was a high priority for both the RAF and civil aviation. One link in the chain to India and beyond passed over what was then known as the Persian Gulf. The Gulf lay between Persia and Arabia and Britain had much better relationships with the latter – particularly the Trucial States which from 1892 had been quasi British protectorates – because the trading contacts which had grown up offered good prospects for successful negotiations with local Shaikhs (the author's spelling throughout). The coast was rich in inlets and sheltered bodies of water which were useful for the RAF's flying boats and proved valuable later when the Empire Flying Boats came along. Between Kuwait and Sharjah several landing grounds were established, of which Sharjah was by far the most important. This book is a detailed study of that airfield in which the author also aims to make a contribution to the history of the United Arab Emirates. He is well qualified to make such a contribution since he has had advisory roles to the Ministry of National Heritage and Culture of Oman and to the Sharjah Museums Department in the UAE.

The book explains the problems posed for the British in dealing with the local Shaikh who had personal difficulties in coping with neighbouring Shaikhs, and members of his own family, as he dealt with British requirements for access to his territory. Successful negotiations led to the establishment of a staging post for the RAF and Imperial Airways at Sharjah, a coastal town on the northern side of the Trucial State of Oman. The climate in the region was hostile to

Europeans with temperatures commonly around 100°F and humidity levels to match. Imperial Airways flew its passengers in ponderous, but luxuriously appointed, Handley Page HP42s and conditions provided at their staging posts had to come up to similar standards. The answer at Sharjah was the construction of the Rest House – to which the author devotes a chapter and a lot of discussion. It was designed on the rectangular pattern of a desert fort with an enclosed courtyard, later extended to incorporate two courtyards. The construction was such that it could be defended from possible hostile action by local dissidents whilst inside it contained high quality passenger accommodation. However, an RAF posting to Sharjah was a hair shirt deal because of the climatic conditions and the primitive living conditions provided by the Service. In his book about Masirah, an island off the Arabian Sea coast of Oman and sharing Sharjah's kind of climate (which I reviewed in *Journal* 25) Colin Richardson records the opinion of a BOAC captain that a posting to Masirah must have been the reward for some spectacularly bad behaviour. He could certainly have said the same about Sharjah!

The 20-year history of Sharjah in the title breaks down into three periods; 1932-39 when the airfield served as an Imperial Airways overnight stop and an RAF staging post; 1940-45 when it was a wartime airfield for UK and USA military operations and for civil flights and finally l946-52, a period which is described as its quiet years, as an RAF and civil field. In Chapter 4, dealing with the first of these periods, the author quotes extensively from a 1937 Paul Rotha film, *Air Outpost*, which is a detailed visual source for life and facilities at Sharjah in its earliest years. That chapter provides a lot of information about the operation of the airfield and also notes significant changes in Sharjah's role in the late 1930s. One arose from the increased range of civil aircraft with HP42s being upstaged by more modern types, such as Armstrong Whitworth Atlantas and Ensigns. That was coupled with an increase of night flying so that not so many overnight stops at Sharjah were needed. The second factor was the acquisition by Imperial Airways of the government contract for carrying international mail which became the Empire Air Mail Scheme (EAMS). Imperial's decision to use the Empire Flying Boats in 1935 was very significant. These new four-engined aircraft were faster than the HP42s, and sacrificed none of their passenger creature comforts. Sharjah's creek was not suitable for landings, which were made at Dubai, but Sharjah's Rest House was easily accessible for those wanting a night sleeping ashore.

During the war Sharjah played an important staging role in military movements to the Far Eastern theatres and later for the return of repatriated troops, casualties and refugees on the conclusion of hostilities. RAF Sharjah was established in 1942 providing a base for anti-submarine patrols, reconnaissance and shipping protection. In wartime a number of squadrons visited Sharjah but only No 244 Sqn had any firm base there. It arrived with Vincents in 1940 and later received Blenheim IVs and the dreadful Mk V (Bisley) version, leaving for Masirah in November 1944 equipped with Wellington XIIIs. The aircraft were not in top class condition and an Australian pilot recalled those whose guts 'had been beaten out of them over Europe'. In 1944 the USAAF established an Air Transport Command unit at Sharjah for ferrying duties to India, Burma and China. BOAC had replaced Imperial Airways in 1940 and dealt with both service and civilian transit passengers. Sharjah did not play a glamorous role in WWII but a useful one nevertheless.

The post-war years saw a gradual rundown of the airfield. BOAC withdrew its services in 1947 as aircraft with longer ranges became available but the RAF retained a foothold there. That enabled it to operate jet aircraft and to provide support in the Buraimi dispute of 1952-54 and in operations in the Jebel Akhdar war of 1957-59. The presence of Canberras was a useful influence in the Kuwait crisis of 1961 and the airfield's facilities were aids to squadrons involved in the hasty withdrawal from Aden. RAF Sharjah closed in 1971 and the Sharjah International Airport was set up in 1977. The site for that was not on the original airfield because its proximity to the growing town of Sharjah prohibited the kind of expansion required.

In Chapters 6 and 7 the focus changes to the people who passed through Sharjah and to description and discussion of the town and its relationships with the airfield. There is a lot of interesting detail here. So far as the role played by Sharjah and its airfield in the history of the Emirates is concerned I think the meat of the author's case is to be found in those Chapters. In particular he draws attention to the ways in which the arrival of the airfield in 1932 opened up Sharjah to the

Western world in ways which were not experienced by the other Trucial States. The airfield and the Rest House (it now houses the Al Mahatta Museum) were the property of the local Shaikh who received regular payments for the use of both. However, the social mixing which took place between airfield and town seems to have been under rather formal control from both sides, friendly on the whole but on a pragmatic basis. The emergence of the prosperous modern UAE of course owes most to the discovery of hydrocarbons in the area.

The question to be posed at this point is should you buy the book? The answer depends on what you want to know about the history of an important staging post in the development of air routes to India, the Far East and the Antipodes, in peace and in war. Also how much do you want to know about the history of an Emirate within the latent UAE – an important Western-friendly region of the Middle East? Here we have a well researched and lucidly written account which throws light on those histories. (Incidentally, I do not know why the subtitle suggests a study ending in 1952 when the discussion of the airfield carries on for nineteen years after that date.) The book is well presented and indexed, has useful appendices, comprehensive endnotes and includes a decent selection of photographs.

Dr Tony Mansell

First In The Field by Guy Warner. Pen & Sword; 2011. £30.00

Guy Warner has done much to record the development of aviation in Northern Ireland, embracing, *inter alia*, the histories of some of the units that have had a particularly close association with the province, notably Nos 72 and 230 Sqns RAF and now No 651 Sqn AAC. Of these, No 651 Sqn is a relatively late arrival, having become a permanent resident, at Aldergrove, as recently as 2008, but it had previously had an on/off presence at flight strength 1957-62 and 1972-85 and as early as 1942.

To fill what amounted to a gap in RAF capability that had developed between the wars, the Army needed to re-establish the dedicated gunnery control facility that had been provided by the BE2s and RE 8s of the corps reconnaissance squadrons of the RFC. The eventual solution was a force of jointly-manned RAF squadrons with the parent service providing the technical personnel and the Army, the pilots and support services. No 651 Sqn was the first such unit and, as such, it led the way in devising the necessary techniques and was the first to employ them in the field when it was sent to North Africa in late 1942 – Operation HUSKY. It spent the rest of the war in-theatre, fighting its way up the Italian peninsula and by the summer of 1945 it had reached Austria.

The squadron survived the early post-war cull and over the next ten years its Austers saw service, often operating as detached elements, in locations as widely dispersed as Palestine, Egypt, Iraq, Libya, Cyprus and Eritrea. Disbanded in 1955, it was promptly re-formed in the UK (by renumbering the erstwhile No 657 Sqn) to operate helicopters – initially Sycamores and Skeeters – and two years later the RAF relinquished its stake in the business, transferring its assets to the newly created Army Air Corps. Since then No 651 Sqn has continued to play a leading part in the evolution of Army aviation, spending time as a 'line squadron' in Germany providing Air OP, and later anti-tank, facilities for BAOR, and seeing service in Northern Ireland, the Falklands and the Balkans. It spent 2000-03 as a trials unit introducing the very sophisticated Apache attack helicopter and, since 2004, it has been back in the fixed-wing game operating the Britten-Norman Defender to provide ISTAR facilities in Iraq and Afghanistan.

So what of the book? I spotted a couple of typos eg Saraf, for Sarafand (p63) and Sire, for Sirte (p66); the Lysander-like Hs126 was not a biplane (p162); there are a number of acronyms, eg AGRA, ATGW, CRA and PSNI, that may be familiar to some but really ought to have been included in the Glossary, and, in that context, there is some confusion on p206/7 between COMAARC and COMMARC (which really ought to be COMARRC). Those minor issues aside, it is evident that the story has been researched in some depth and that the author has clearly established a rapport with the squadron, and its association, permitting him to make extensive use of personal anecdotes. These help to keep the narrative flowing, although readers who are accustomed to RAF organisation may occasionally get a bit lost in what seem (to me) to be the Army's somewhat fluid arrangements, as its AAC units often tend to exchange identities, operate as semi-autonomous detached flights or as subordinate elements of numbered regiments, so you do need to pay attention.

In short, *First In The Field* is a well-written, generously illustrated, 300-page hardback that does credit to a unit with a remarkable history.

I suspect that many ex-RAF folk may well still think of the AAC as relatively small beer, albeit with its puddle-jumping Austers replaced by helicopters. For them, this book will be an eye-opener. The Defender is a hi-tech surveillance platform and the Apache is a quite fearsome beast. What is really interesting, is that in 2010 No 651 Sqn's total establishment of sixty-five personnel included fifteen pilots and fifteen crewmen, but only seven officers. So, in sharp contrast to the RAF and RN, both of which operate a 100% officer pilot policy, the Army seems to be able to manage with at least half of its pilots as sergeants. So how do they do that? Or perhaps we shouldn't ask.

CGJ

Fighter Operations in Europe & North Africa, 1939-1945 by David Wragg. Pen & Sword; 2012. £19.99.

The title of David Wragg's most recent book suggests a comprehensive and ambitious analysis of fighter tactics on both sides of the conflict and how these developed during the course of WW II. However readers will be disappointed because, to meet the challenge of chronicling such a comprehensive subject within 182 pages, the author has responded with an amalgam of personal observations, detailed extracts from authentic sources and some sweeping generalities which don't do full justice to this enormous subject. For his research the author acknowledges the extensive material transcribed from the Imperial War Museum sound archives, from which he quotes extensively, and the sizeable bibliography which lists several authoritative sources such as Johnson's *Wing Leader* and Lucas' *Five Up*. It is surprising however that many other pilots who have written authoritative accounts of their experiences in fighter cockpits including Clostermann, Bader, Duke and, more recently, Geoffrey Wellum have not been cited as original source material. From the German standpoint two books, namely Cajus Bekker's *The Luftwaffe War Diaries* and Heinz Knoke's *I flew for the Fuhrer*, are both quoted widely in the text to describe *Luftwaffe* operations, mainly in the west. Operations over the Eastern Front are covered by extracts from these books but there is little mention of the Soviet Air Force and its significant influence on the air war.

He begins with the emerging threat to Britain, the nation's belated preparation for war caused by the War Cabinet's conclusion of 1919 (and renewed annually from 1928 onwards) that there would be no major conflict for ten years (sounds familiar?), and the consequent expansion of the RAF. He provides illuminating detail on the orders of battle of the many participants, before describing the air fighting campaigns from the Spanish Civil War in 1936 to the end of the war in Europe.

The first two chapters describe the changing organisation of the RAF to meet the challenge and include several interesting historical snippets which emphasise the lack of preparedness in Britain compared to Germany's methodical planning for operations by the *Luftwaffe*. He reminds the reader of the haphazard procurement decisions in the early 1930s that led to some squadrons being equipped with more than a single aircraft type and the puzzling rejection of monoplane fighters in favour of the Gloster Gladiator biplane as the new fighter for the RAF. Although he describes in some detail the organisation of the Service he does not attempt to address the uncertainty over the roles and concepts of operation for the new fighters which were being conceived during the expansion. While the Defiant is criticised, with some questionable blame being levelled at Churchill for trying to persuade the RAF that its fighters should have rear turrets, it is surprising that the Blenheim receives no mention, although it too was used unsuccessfully as a day fighter before its debut as one of the first RAF night fighters in 1940. Fortunately more enlightened and timely arguments had led to the Hurricane and Spitfire and these types feature prominently in his accounts of fighter operations from the third to the final chapter by which time the first jet fighters had entered service on both sides.

Much familiar territory is covered and predictably the first of the great air fighting encounters, the Battle of Britain, justifies an entire chapter but not surprisingly little new material is uncovered. The disagreements between Park and Leigh-Mallory over fighter tactics are repeated as are reminders of the importance of the Chain Home radar network and the Dowding command and control organisation. His narrative include the familiar and well-documented phases and the use of numerous individual aircrew accounts from the Imperial War Museum sound archives add valuable authenticity to the combat reports.

In the remaining chapters he goes on to examine the extended use of fighters in offensive sweeps across the Channel, bomber escort duties and as fighter bombers in the relevant theatres of operation. Each begins by setting the scene before the author goes on to describe the appropriate developments in aircraft, armaments and tactics. His observations, sometimes detailed but often superficial, are considered from both sides of the conflict but where European air operations are listed extensively the campaign in North Africa is covered in just one chapter and a mere twenty pages, some of which are devoted to air operations in Greece. This is surprising in the light of the significant lessons learned from allied fighters in the ground attack role over Egypt and Libya although there is a brief mention of the air/land co-operation which emerged from the extensive experience of the Desert Air Force. Operation TORCH receives greater attention, as does the siege of Malta, which justifies a chapter on its own with some good detail about the crucial reinforcement of the island by RAF fighters flying from aircraft carriers. Operations over Sicily and Italy are covered well and include several interesting snippets about Fleet Air Arm fighter activities. Perhaps the book should have been given the more appropriate title *Fighter Operations in Europe & the Mediterranean, 1939-1945*.

He closes with a brief personal analysis in a chapter entitled 'What Might Have Been' which examines theoretical situations, not wholly restricted to fighter operations. However questions such as 'What if the RAF had lost the Battle of Britain?' and 'What would have been the significance of the *Luftwaffe* being equipped with longer range heavy bombers armed with the equivalent of RAF Tallboy bombs?', although interesting, are hardly relevant in this account of fighter operations. Neither are his comments that the P-38 and P-47 became the F-38 and F-47 as these changes did not come about until the formation of the USAF in 1947.

Despite the shortcomings, this is a well illustrated and useful hardback which contains several interesting and perceptive observations. The book's 215 pages include a very comprehensive index and a useful eighteen-page annex providing a calendar of those significant events from the WW II which had a bearing on fighter operations. Nevertheless, I would hesitate to rate it as an authoritative work of reference.'

From Gloster Gladiator to Gloster Meteor would be an appropriate sub-title for David Wragg's book which is recommended as a good extended holiday read rather than being absorbed in snatches as a book at bedtime.

Gp Capt Jock Heron

***Luftwaffe* Emblems 1939-1945** by Barry Ketley. Flight Recorder Publications; 2012. £12.95.

Among those who study the RAF of WW II, there tends to be a corresponding interest in the opposition. There are the more obvious aspects, of course, like the characteristics of the enemy's aeroplanes and the ways in which they were employed, but there are more esoteric issues that can also fascinate. One of these is *Luftwaffe* heraldry. Unlike the RAF, which, from the mid-1930s imposed a very rigid system (a stylised role-related badge frame enclosing the squadron's motif, the suitability of which had to have been formally endorsed by the College of Heralds), the *Luftwaffe* adopted a far more casual approach, but it still served to identify an aeroplane as belonging to a particular unit.

Policy within the wartime RAF was even more restrictive, confining the identification of a unit to its allocated code letters. Nevertheless, it was sometimes difficult to suppress the atavistic desire to display something more colourful, more individual. This could be seen, for instance, in No 26 Sqn's exploitation of the (pre-1942) broad central white stripe of the tricolour on the fins of its Tomahawks to display its gazelle's head motif; similarly, No 601 Sqn used the same space to sport its winged sword on Hurricanes and Airacobras.

In marked contrast to British conservatism, the Germans gave full rein to the expression of unit pride and, as the author, puts it 'Almost anything served as a source of inspiration for the unit artists.' Such emblems ranged from the heraldic arms of a town to a cartoon figure, like Mickey Mouse, taking in a variety of characters from folk tales, death's heads, lightening bolts and so on, along the way. A little surprisingly, however, and in marked contrast to the trend among the equally testosterone-fuelled young aviators of other air forces, there were very few instances of bare naked ladies. Some of these emblems were relatively permanent, others could change, for instance, when a new CO was appointed. The picture is further complicated by the *Luftwaffe's* three-tier *Geschwader*, *Gruppe*, *Staffel* structure which often resulted in an aeroplane wearing more than one emblem.

Since this system was so flexible and informal there was little (if any) attempt to document these markings at the time. That led post-war historians to embark on, what amounted to, a treasure hunt, to seek out photographic evidence of these emblems and to identify the units concerned and the relevant dates. The pioneer in this field was Karl Ries whose findings were published between 1963 and 1972 in his four-volume *Markierungen und Tarnanstriche der Luftwaffe im 2 Weltkrieg*. The next major advance was *Luftwaffe Emblems 1939-1945* by Barry Ketley and Mark Rolfe which appeared in 1998.

In the book under review here, a slightly less than A4-sized, 190-page softback printed on high grade paper, Ketley has brought the story up to date. It features more than 1,000 emblems, about 150 more than in the previous edition, provides new insights and corrects previous errors. It embraces units of all kind, from the mainstream day- and night-fighter, bomber and ground attack outfits via the less familiar reconnaissance, maritime and transport formations, to training schools and relatively obscure courier units. All of the badges are rendered in colour and many are supported by well-captioned photographs, some of these also being in colour, illustrating the emblem as applied to a particular airframe.

This is, of course, a somewhat arcane subject but for those with an interest in the *Luftwaffe* it represents the state of the art and, as such, I would rate this book as an essential addition to the library of a true enthusiast – and, considering the high production quality, it is a bargain. There are many aviation softbacks out there that are half the size, twice the price and offer far less colour.

CGJ

ROYAL AIR FORCE HISTORICAL SOCIETY

The Royal Air Force has been in existence for more than ninety years; the study of its history is deepening, and continues to be the subject of published works of consequence. Fresh attention is being given to the strategic assumptions under which military air power was first created and which largely determined policy and operations in both World Wars, the inter-war period, and in the era of Cold War tension. Material dealing with post-war history is now becoming available under the 30-year rule. These studies are important to academic historians and to the present and future members of the RAF.

The RAF Historical Society was formed in 1986 to provide a focus for interest in the history of the RAF. It does so by providing a setting for lectures and seminars in which those interested in the history of the Service have the opportunity to meet those who participated in the evolution and implementation of policy. The Society believes that these events make an important contribution to the permanent record.

The Society normally holds three lectures or seminars a year in London, with occasional events in other parts of the country. Transcripts of lectures and seminars are published in the Journal of the RAF Historical Society, which is distributed free of charge to members. Individual membership is open to all with an interest in RAF history, whether or not they were in the Service. Although the Society has the approval of the Air Force Board, it is entirely self-financing.

Membership of the Society costs £18 per annum and further details may be obtained from the Membership Secretary, Dr Jack Dunham, Silverhill House, Coombe, Wotton-under-Edge, Gloucestershire. GLI2 7ND. (Tel 01453-843362)

THE TWO AIR FORCES AWARD

In 1996 the Royal Air Force Historical Society established, in collaboration with its American sister organisation, the Air Force Historical Foundation, the *Two Air Forces Award*, which was to be presented annually on each side of the Atlantic in recognition of outstanding academic work by a serving officer or airman. The RAF winners have been:

1996	Sqn Ldr P C Emmett PhD MSc BSc CEng MIEE
1997	Wg Cdr M P Brzezicki MPhil MIL
1998	Wg Cdr P J Daybell MBE MA BA
1999	Sqn Ldr S P Harpum MSc BSc MILT
2000	Sqn Ldr A W Riches MA
2001	Sqn Ldr C H Goss MA
2002	Sqn Ldr S I Richards BSc
2003	Wg Cdr T M Webster MB BS MRCGP MRAeS
2004	Sqn Ldr S Gardner MA MPhil
2005	Wg Cdr S D Ellard MSc BSc CEng MRAeS MBCS
2007	Wg Cdr H Smyth DFC
2008	Wg Cdr B J Hunt MSc MBIFM MinstAM
2009	Gp Capt A J Byford MA MA
2010	Lt Col A M Roe YORKS

THE AIR LEAGUE GOLD MEDAL

On 11 February 1998 the Air League presented the Royal Air Force Historical Society with a Gold Medal in recognition of the Society's achievements in recording aspects of the evolution of British air power and thus realising one of the aims of the League. The Executive Committee decided that the medal should be awarded periodically to a nominal holder (it actually resides at the Royal Air Force Club, where it is on display) who was to be an individual who had made a particularly significant contribution to the conduct of the Society's affairs. Holders to date have been:

Air Marshal Sir Frederick Sowrey KCB CBE AFC
Air Commodore H A Probert MBE MA

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Oxon
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GL12 7ND
Tel: 01453 843362

TREASURER
John Boyes TD CA
70 Copse Avenue
West Wickham
Kent
BR4 9NR
Tel: 0208 776 1751

EDITOR and PUBLICATIONS MANAGER
Wg Cdr C G Jefford MBE BA
Walnuts
Lower Road
Postcombe
Thame
OX9 7DU
Tel: 01844 281449