Article

The RAF's Leading Role in the Development and Application of Synthetic Training Equipment

By Dr Trevor Nash

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Abstract: The Royal Air Force has long been recognised as one of the leading proponents of Synthetic Training Equipment (STE) for aircrew training. Along with other mature STE user nations such as the US, Australia, Germany and France, the modern RAF invests heavily in simulation and sophisticated training devices to fulfil a number of training ambitions. These include better preparing aircrew for time spent in the air, enhancing safety, saving money, undertaking mission rehearsal and more recently, reducing the Service's carbon footprint. It was also found during its early adoption that STE provided a repeatable and scalable training medium that enabled more efficient 'training transfer' when compared with purely flying training. Much of this STE expertise was gained in the run-up to, and during the Second World War with Bomber Command at the innovative leading edge.

Introduction

In discussing the use of Synthetic Training Equipment (STE) to enhance training within the RAF, there has been a tendency for historians to mention the ubiquitous Link Trainer in passing and ignore other training systems or training methodologies that used STE.[1] The importance of the Link Trainer should not be underestimated and it certainly was not by the former RAF Director of Training, and later RCAF Chief of Air Staff, Air Marshal Robert Leckie, who said that '[t]he *Luftwaffe* met its Waterloo on all the training fields of the free world where there was a battery of Link Trainers'.[2] But it was not all about the Link Trainer, as by 1942 'no less than 200 training devices had been invented and put into use' by the RAF with some of the most sophisticated of these being used by Bomber Command.[3]

As well as the invention and development of these training systems, the RAF was making significant intellectual investment in examining how STE could be used to improve operational training at the individual and collective training levels; the latter being especially important in considering the seven-man crew of the heavy bombers that begin to enter service from 1941. As will be seen below, the adoption of what were considered by some as unproven technologies to improve training and assist in taking pressure off an increasingly overworked training pipeline were, with few exceptions, broadly accepted by the Air Ministry and the operational Commands. The aim of this paper is to highlight the role that STE played in enhancing operational training by considering how it assisted in closing a number of training gaps and provide an innovative training medium that was repeatable, scalable and safe. The paper will also argue that the use of STE marked a major evolution in the way organisations such as Bomber Command conducted operational training and, as such, was one of the key drivers in developing new training methodologies that had a long-lasting impact on the RAF's approach to training. The paper will firstly consider the context of STE and then examine how STE policy was developed, how STE was procured and managed, and how synthetic training devices were used by Bomber Command to support operational training before concluding that simulation was a key element that helped to drive the overall success of operational training in Bomber Command.

Returning to the Link Trainer, the great misconception surrounding this device is that it was the first ground-based training simulator that was ever used for pilot training. Baarspul described the Sanders Teacher and Eardley Billings training devices of 1910 as 'aircraft attached to the ground' and mounted on a 'universal joint' to enable pilots to experience the effects of elevator, rudder and aileron or wing warping control.[4] The problem with these early devices was that they were reliant on wind strength to make them function and therefore their use was limited. Later in 1910, this limitation was overcome by the French Antoinette trainer that featured the pilot sitting in a cockpit that had been crafted from a half wine barrel fitted to a swivel mechanism.[5] A horizontal bar was located on the front of the cockpit and, through the use of his controls, the pilot had to keep the bar on the horizon as instructors on the yaw, roll and pitch axes moved the cockpit by means of poles to alter the status quo. What the

Link Trainer did achieve during its development between 1927 and 1929 was to provide a pneumatically operated 'efficient aeronautical training aid' that could be operated by a single instructor and the student, which was not dependant on wind strength.[6] Patented in 1930 by the Binghamton, New York-based Link Company, the Link Trainer's 'roll, pitch and yaw movements were initiated using pneumatic bellows for actuation. The various control valves, operated by the stick and rudder, were fed by an electronically driven suction pump, mounted on a fixed base'.[7] The Link Trainer formed the basis for a number of different training device variants that were used for operational training but in its basic form, the device was used for elementary and intermediate flight training as well as continuation training. One example of the latter saw a device installed at HQ Bomber Command to allow pilots carrying out staff functions to retain key airmanship skills.[8] The Link Trainer's importance is that when it entered service with the RAF it was at the forefront of simulation technology and subsequently provided the catalyst and inspiration for the Service's further investment and interest in STE following the adoption of training systems in the period before the Second World War.

STE in Context

Before considering the policy, procurement and management, and application of STE within Bomber Command and the wider RAF, some terms and parameters need to be defined; primarily, why the use of STE became so prevalent? This can be mainly attributed to the increasingly technical nature of the modern bomber, the roles that it had to undertake, the shear throughput of students that required training and logistic issues. Addressing training issues facing the US Navy in 1941, but no less applicable to the RAF and Bomber Command in 1938 and beyond, Dawson said that 'the traditional training methods…were incapable of providing the thousands of newly trained personnel…' that were required due to a lack of training aircraft and other resources such as airspace, airfields and ranges.[9] Rolfe and Bolton reinforced the 'shortage of training resources' argument for the growth of STE when they stated that: 'By 1940 the pattern of the war in the air was such that difficulties were being realised in finding aircraft and flying hours for training. Moreover the training task was growing. The need to replace airborne training was seen to be an important requirement'.[10] STE became a method of supplementing those conventional live training processes by allowing students to learn in a virtual environment, albeit, when compared with modern STE, frequently crude.

One of the other catalysts for the increased adoption of synthetic training was the growing complexity of modern combat aircraft, the so-called 'technical revolution' in aircraft.[11] This 'training gap' could be seen when considering the Hart and Whitley bombers, both in service at the same time during the late 1930s.[12] The Hart differed little from aircraft flown during the First World War while the Whitley featured retractable landing gear, a cantilever wing, constant speed propellers and variable position flaps.[13] This 'training gap' is exemplified when considering the differences between the Second World War Spitfire and the Lancaster and the First World War SE5 and DH9. The latter fighter-bomber combination could be flown

by a 'universal pilot'; while the former aircraft were technically far more complex, therefore requiring training specialisation.[14] The result was an increased emphasis on cockpit drills, especially as far as single-pilot aircraft were concerned. Issues such as taking off with course pitch selected or landing without lowering the under carriage were costly in terms of pilots and aircraft. This particular training requirement led to the development of the Hawarden trainer for use by Fighter Command.[15] This was a fuselage trainer that allowed pilots to practise cockpit and emergency drills and, by the end of 1940, the use of these type of trainers was growing such that, by May 1941, there were shortages.[16]

Despite the emergence of ground based training aids, the RAF had a 'marked preference for giving as much instruction as possible in the air'.[17] Air Ministry policy was that such systems were 'to assist but in no way replace aircrew training in the air'.[18] Given the preponderance of pilots filling senior staff appointments during the interwar years and the general pilot-centric approach of the Service, this was hardly surprising. Although this policy worked well up until the acceleration of the RAF's expansion schemes where the throughput of trainees threatened to overwhelm the training system.[19] The relatively small size of the inter-war RAF and the 'peace-time [*sic*] economy complex' meant that the output of pilots to feed the service did not require a particularly sophisticated training pipeline.[20] In 1933, for example, the RAF was training 300 pilots a year; by the end of 1941, this figure had risen to 22,000 pilots and 18,000 other full time aircrew trades.[21]

The importance of synthetic training systems to Bomber Command was highlighted by the Air Officer Commanding (AOC) No.6 (Training) Group, Air Commodore MacNeece Foster, during a visit to No.10 Operational Training Unit (OTU) at RAF Abingdon by members of the Aircrew Training Conference on 28 January 1942. After telling delegates that the RAF should be sending its best pilots to Bomber Command in light of the complex nature of the four-engine aircraft types that they operated and the need to fly long range missions at night, he moved on to discuss a topic that he referred to as 'half-true'.

> One such slogan is, 'Nothing can take the place of hours in the air'. That is…true, but is at the same time quite untrue. You cannot give the hours in the air necessary to give every member of a crew his full training. Consequently, you have got to use every ingenuity on the ground so that when they go up in the air, they have reached that acquaintance with their subject which ensures they can take full advantage of their air training.[22]

Today, the use of complex digital simulators is quite common both for military and commercial airline pilot training. The fidelity of the modern simulator is so great that commercial airline pilots can undertake conversion training to a new familial type of aircraft in the Full Flight Simulator (FFS) such that the first time that they fly the actual aircraft it will contain fare-paying passengers.[23] From a modern military perspective, a number of established air forces now conduct 50% of their training in the flight simulator with the German Air Force seeking to undertake 95% for its Airbus A400 flight crew in the near future.[24] A simulator is defined as

'a device that imitates the dynamic behaviour of a real system' to give 'the illusion...of responding like the real system...'.[25] The simulator can therefore be described as an holistic training device capable of high-fidelity replication that draws together sub- or part-task training events. Such a sophisticated and all-encompassing solution was not available in the period before and during the Second World War and the terms trainer, training device and synthetic trainer or synthetic training device were more common than simulator. These training devices were clearly not carrying out the full spectrum of training that would be the case in a modern FFS and so they are best considered as Part Task Trainers (PTT). The word 'simulation' was used initially by the RAF to describe the collective use of such training devices, but then replaced by 'synthetic training' from May 1940.[26] According to Director of War Training & Tactics (DWTT), the term 'synthetic training' was first coined by Air Vice-Marshal Ludlow Hewitt in 1940.[27]

As the pressure built on the training pipeline, in parallel with subsequent expansion schemes in the lead up to the Second World War, the RAF rapidly turned towards the increased use of synthetic training to download specific training tasks from the aircraft, or to improve training transfer. The latter can be defined as 'the degree to which trainees effectively apply the knowledge, skills, and attitudes gained in a training context to the job and maintained over time'.[28] As previously discussed and as policy dictated, synthetic training was not designed to replace time in the air, at least theoretically, but to make the time in the air more productive and thereby improve efficiency and reduce training costs. This idea of STE not replacing time in the air was perhaps semantical in that if a student pilot in a Link Trainer could master flying from Airfield A to Airfield B in instrument conditions, he would, *de facto*, require less time in the aircraft to do it for real. In other words, time in the Link Trainer had reduced time in the air. The other key benefits afforded by synthetic training were that training could be undertaken in all weathers day and night; this meant night and instrument flying could be carried out on a bright sunny day or when inclement weather or training aircraft availability prevented flying. Training could be made scalable in that the difficulty of the training task could be increased in line with the pupil's growing proficiency; and finally; that the training was repeatable such that training tasks could be reproduced using the same parameters.[29] This would allow students from the same cohort to receive exactly the same lesson so instructors could undertake comparative analysis as well as repeating exactly the same exercises for students that found initial assimilation difficult. It is also a truism, as Caro has stated, that the real aircraft provided a 'poor learning environment' and that the training device was better 'from the transfer-of-training standpoint'.[30] This 'transfer-of-training' was not only relevant to the individual but was also vital in respect to training large crews to work together, as in the case of heavy bombers.

The RAF fully understood the benefits of STE from before the war, but this was made clear from the collective training standpoint as it affected Bomber Command in early 1942. As this statement in the RAF's *Illustrated Catalogue of Synthetic Training Devices* highlighted: 'Synthetic training is the exercising on the ground of air crews in their different roles in

conditions as similar as possible as those met in the air. The object is to avoid unproductive time in the air by first making crews as conversant as possible with their air duties on the ground'.[31]

The first major steps in adopting flight simulation in the RAF were taken in October 1935, when the Director of Training, Air Commodore Tedder, sent three officers to the United States to examine US Army Air Corps (USAAC) training methods with an emphasis on the Link trainer.[32] The cost saving benefits of the Link Trainer, that 'ingenious American invention,' were not lost on Lord Swinton, Britain's Secretary of State for Air between 1935 and 1938.[33]

'Sitting in a cabin in a room, for the cost of a few pennyworth of electricity, the pupil pilot can sit at the controls and drive [*sic*] his plane [*sic*] on a long journey under artificial conditions which reproduce the conditions he would encounter on a voyage of a thousand miles'.[34]

The Link Trainer was the turning point in the RAF's recognition of the benefits of using other ground based training devices (examined later) although it was not the first major system to be introduced. The 'Bombing Teacher' was the initial major synthetic training system to be adopted by the RAF and, 'provided an excellent method in training personnel in the use of the bombsight without the necessity of going up in the air, thereby saving time, wear-and-tear on an aircraft and flying hours'.[35] It was also fundamental in providing a training medium to counter-balance the shortage of bombing ranges in the UK.[36] As far as the importance and future applicability of synthetic training equipment was concerned, the RAF was again quick to realise innovation could assist in training delivery.

Following its visit to the USA to view the Link Trainer, the Air Ministry ordered 51 devices that the Air Member for Training's *Notes on the History of RAF Training 1939-44* said entered service in September 1937.[37] By this time the RAF had realised that its standard of instrument flying was poor, there was a shortage of training aircraft; notably with the Don and Magister that were suffering from design issues; and that the formation of the RAF Volunteer Reserve (RAFVR) in 1936 combined with successive expansion schemes had placed increased strain on the training pipeline.[38] During a meeting of the Air Council in April 1938, the Air Member for Personnel, Air Marshal Sir William Mitchell, stated that aircraft shortages were impacting training, 'leading to a measure of stagnation'.[39] In short, 'training expansion [was] not keeping pace' with the rapidly increasing size of the RAF.[40] The Link Trainer therefore provided a method of addressing some of these issues but its adoption was not without challenges, particularly as far as how the trainer was to be used, how it was to be maintained, and how the provision of instructors to operate them was concerned.[41] Many of these issues took nearly a year to resolve but this did not stop the RAF ordering another 150 Link Trainers on the basis that 'it was soon found that the standard of instrument flying was being steadily improved as a result of this synthetic device; although it does not assimilate flying conditions in the same manner as an aircraft, e.g. absence of noise, it served and still serves well for instrument flying practice'.[42] This observation, written in 1944, highlighted the RAF's enthusiasm for the Link Trainer and this appreciation of synthetic training provided the impetus for the development of nearly

200 different trainers by 1942. An exemplar of such enthusiastic innovation and adoption was in the creation of the No.5 Group Bomber Command's Crew Training School (CTS) at RAF Finningley in January 1940 that was designed for crew (collective) training within the Group.[43] The formation of the school also highlighted how seriously Bomber Command and the wider RAF viewed synthetic training and how it was contributing to evolving and enhancing operational training.

As this paper highlights, the RAF, and Bomber Command in particular, embraced the use of STE throughout the war. According to Kreipe and Koester, this was not the case with the *Luftwaffe*, although many of the training shortfalls seen in Germany mirrored those of the RAF, such that: '…operational readiness within the flying units was extremely uneven. The most significant gaps in training were those felt by the bomber units, primarily as a result of insufficient training in night and instrument flight'.[44] As to the use of STE, German *ab initio* flying training schools [so-called A and B schools] 'had fuselage models [mock ups] with which to drill students' and limited numbers of Link Trainers 'for preliminary training in instrument flight'.[45] Link Trainers were mainly used at the multi-engine, or so-called C Schools.

> Unfortunately, there was not enough of these valuable machines [Link Trainers] available. They did have certain defects, of course, and because of this their use was opposed by some, but they were extremely useful in teaching the student to think in terms of his position in space and in preparing him for practical flight training in real aircraft. Their use saved a good many flight hours.[46]

C School students, the majority of which were to be bomber pilots, also used refurbished crashed aircraft that were re-wired 'so that the students could practice all the manual operations required for take-offs and landings and learn to work the landing flaps and tail-gear'.[47] Indeed, according to Adams, it was the C Schools that provided 'the only instance in which the Link Trainer [was] used in instruction courses for the German air force,' an opinion at variance with Kreipe and Koester's account.[48] In *Fighter*, Deighton claimed pilots arriving in operational bomber squadrons had 250 flying hours and '50 hours of simulated blind flying on the Link trainer'.[49] Deighton's source was C.G. Grey, editor of *The Aeroplane*, who visited the Luftwaffe in 1935.[50] The use of STE in the Luftwaffe was never exploited like the RAF and that, in part, led to the Luftwaffe's 'generally inadequate training program [sic],' that failed due to a lack of, 'uniform guidance and supervision'.[51] In comparison, the RAF used the Link Trainer at every stage of its training process from the Elementary Flying Training School, including during holding at an Aircrew Personnel Reception Centre and in the operational squadron. Typical total Link Trainer hours following the end of an operational tour varied from over 60-70 hours while a pilot, then posted to become an instructor, would expect to accumulate over 90 hours in the Link Trainer.[52]

In comparison, the lead service for STE in the US was the US Navy and work on the topic was carried out in the Special Devices Section, later to become the Special Devices Division, part

of the Bureau of Aeronautics (BurAe) and the direction that it took was clearly based on the experience of the RAF. Much of the information to enable the development of US Navy STE policy was furnished by a Special Naval Observer attached to the US Embassy in London in October 1941. Commander Luis de Florez had 'the primary goal of studying and observing the British approach to synthetic flight training devices and training methods'.[53] Upon his return to the US, he documented his findings in a *Report on British Synthetic Training*. De Florez's observations and his findings greatly influenced the future of the Special Devices Section. In the report, de Florez cited several key benefits of synthetic training. He wrote that: '… synthetic training increased the quality and quantity of training by providing familiarization with operational equipment to the point of instinctive response; allowed instructors to handle large numbers of students and allow them to "freeze" the action to point out student errors; constant practice on the ground trainers permitted crews to be sent into actual [flight] conditions far more safely than other techniques; valuable equipment would not be tied up as training aids'.[54] The importance of de Florez to the development of US Navy air training policy and delivery can be seen today in the fact that the US Naval Air Warfare Center Training Systems Division (NAWCTSD) headquarters in Orlando is housed in the de Florez complex.[55]

Development of RAF STE Policy

The creation of a coordinated STE policy had its roots in the establishment of the No.5 Group Crew Training School at RAF Finningley that was announced by AOC No.5 Group, Air Vice-Marshal A.T. Harris, on 18 January 1940.[56] The high-level discussions surrounding the school did much to frame the RAF's policy towards STE and promote the topic to a wider audience. In a typical forthright Harris communication, the AOC No.5 Group was not asking permission from the Air Ministry to establish the new training school but declaring that a 'proposed' Elementary Ground Training Organisation was to be 'immediately introduced within the resources of this Group,' so as to put all crews 'through their individual procedure under realistic conditions on the ground,' before crews reported to their operational squadrons. Harris' aim was to remove the training load from the squadrons and 'to get crews 'pat' with the latest procedure and tactics...'.[57] The drills were to be repeated until every crew was 'procedure perfect'. As part of the Crew Training School, as Finningley was to become known, Harris requested the recruitment of three school masters that have 'the inborne [*sic*] ability and qualities to apply and instil knowledge and that this type of instruction cannot be done by the ordinary RAF personnel who has [*sic*] little or no knowledge in the art of teaching'. Combined with the RAF's established recognition of the benefits of the Link Trainer, the correspondence generated by Harris' Crew Training School circulating at Air Council level led the Chief of Air Staff and Air Officer Commander-in Chief (AOC-in-C) Bomber Command staffs to start to define a policy for the use of STE.

This ground training school was an interesting development in terms of how it reflected the innovation of the RAF at the time. Personnel would recognise a 'training gap' and design and develop their own training aids to fill it. Although a commendable approach, it did have shortfalls, particularly concerning maintaining common standards in training and not adopting

best practice solutions; the latter with the possibility of creating to so-called 'negative training'. Harris' ground training school was not only innovative but highlighted his ability to identify a training problem and then find a solution; for example, using an old Hampden fuselage and a Link Trainer, the CTS provided a collective training environment for the complete crew. In providing an environment to practise individual skills, the CTS was also the catalyst for the training regime later adopted by the Group Pools/Operational Training Units. Each three week course comprised 12 pilots and 12 WOp/AGs and, with a new intake every week, the CTS contained 72 aircrew. Initially the CTS drew considerable support when with the Director of Staff Duties, Air Commodore R.P. Willock, said that 'A.V.M. Harris is well known for producing bright ideas...and that the CTS, should be adopted in Operational Training Units'. Willock finished by saying that '[m]y contention has always been that the more training that can be done on the ground to simulate conditions in the air, the higher standard we shall attain'.[58]

Although clearly a significant concept that addressed the need to coordinate the training of multi-crew aircraft, the CTS faced a number of hurdles. The first of these was ironically provided by Harris who originally stated that the CTS would be staffed from No.5 Group resources but then requested an establishment of 13 officers and 19 other ranks to run the facility.[59] The second retardant to the project came from No.6 Group – Bomber Command's Group Pool Squadron organisation (Group Pools were renamed Operational Training Units (OTU) in early April,1940), which was formed on 16 September 1939. The Group considered that the CTS course was 'too complicated and tends to restrict the flow of trainees unduly'. Although somewhat contradictory, No.6 Group also said that it would keep the same training but alter the syllabus.[60] This was perhaps damning by faint praise, but the third factor casting doubt on the CTS was that the three-week course took place after the Group Pools/OTU phase and thereby delayed even longer, the time taken for aircrew to reach their operational squadrons.[61]

Considering these newly formed Group Pools had to evolve to become effective before a working syllabus could be defined, it was clear that No.5 Group's CTS was well advanced in providing ground based synthetic training, but it was not unique in generating innovative STE solutions. At RAF Harwell, for example, No.3 Group Pool, which became No.15 OTU in April 1940, designed a wireless operator training device that was to become known as the Harwell Box.[62] This provided the wireless operator with 'similar conditions to the aircraft' that included sound effects to provide a realistic environment for him to practise obtaining fixes, using the aircraft's DF loop antenna, operating his radio and conducting fault-finding. Along with the Link Trainer, Bombing Teacher and the Harwell Box, Group Pools/OTUs, gunnery schools and operational squadrons were equipped with different types of turret trainers that fired live rounds on outdoor ranges or indoors using cine films to allow gunners to track targets.

According to Rolfe and Bolton, 'The suggestion was made …that Finningley should become the Central School for Synthetic Training…[but]…The proposal was not approved'.[63] Considered on balance, an extra three weeks training; the establishment of 32 personnel to run the CTS and the retention of 72 aircrew in the training pipeline, when there was a major shortage of aircrew

not only within Bomber Command but the RAF in general, meant that the No.5 Group CTS was untenable. What it did achieve, however, was to highlight the need for a policy to try and standardise STE delivery and, to an extent, the design of STE, leading to the establishment of a number of committees to oversee the growing enthusiasm now being shown towards simulation. Harris, however, continued to lobby for his Group's CTS.

In a letter to Willock, Harris offered what was clearly a bribe when he agreed to release, on posting, an officer from CTS, requested by the Air Ministry, in exchange for Willock pushing the 'establishment through, which is held up by some lethargical [*sic*] office wallah in some pigeon hole or another....'[64] In this letter, Harris made some interesting observations about synthetic training as well as showing much of his character: 'Incidentally, although I do not mind for myself [he clearly did], I would suggest that a word of appreciation on the efforts made here to institute synthetic training and to design and organise the first of the synthetic trainers would surely not be out of place. At the present time, one hears all sorts of sideways references as to the value of these new methods of training, and the ingenuity displayed by those who thought of it and first put it into force. Unfortunately, signs are not wanting that although I originated it in my office, in conference with a few of my staff, and then proceeded in conjunction with the C.O. at Finningley entirely off our own bats to institute the whole business, there are a most astonishing number of claimants in the field already, outside the Group, to having thought of it and instituted it first'.[65]

Harris' comments on 'a word of appreciation' clearly got through as, later that month, Group Captain Maycock, the Station Commander and its parent CTS, received a letter from the Air Council saying that 'their attention [had] been drawn to the noteworthy services which you [had] rendered'.[66] Harris' initiative may have been recognised but the pressures on the CTS were too great and, perhaps ironically, proceeding the Air Council's letter of recognition, DWTT stated that the CTS could not be established and the training developed at Finningley should be transferred to the bomber OTUs.[67] This was a major policy decision that began to define the future roles of the newly established OTUs.

Harris's CTS initiative still retained support, at least in HQ Bomber Command. The AOC-in-C Bomber Command, Air Marshal Portal, told the Air Member for Supply and Organisation (AMSO), Air Marshal Courtney, that the CTS 'was quite indispensable at present and I must ask you at all costs to let it be established temporarily,' and that the school had a 'far reaching effect throughout the Air Force,' which provided a stay of execution. Portal argued that closing the CTS would be 'false economy' as it was 'preventing the loss of crews' and 'increasing operational efficiency'.[68] This appreciation of Harris's efforts and support shown to him is illuminating given Portal's patience with him in the latter stages of the war when Harris attacked the transportation plan in the run-up to D-Day in favour of continued strategic bombing.[69] Although the CTS worked on using its own resources for a number of months, the subsuming of OTUs within No.6 Group and the adoption of the synthetic training methods developed by No.5 Group within the OTUs gradually reduced the need for the extra training.[70]

Combined with the arrival of more Link Trainers, No.5 Group's creation of a range of other synthetic ground-based trainers, and the disagreements between HQ Bomber Command, DWTT and AMSO on how such training equipment should be used, the Air Ministry decided to create a committee to focus on synthetic training to better define its application and to formalise STE policy. Initially, Ludlow Hewitt, AOC-in-C Bomber Command, suggested forming a separate branch of the Air Ministry to coordinate synthetic training policy, but this idea was subsequently dismissed by Willock as DWTT and it was decided to opt instead for a committee.[71] As a result, the 'Simulation of Air Training on the Ground Committee' held its first meeting on 11 March 1940.[72] The creation of this committee was a significant step by the Air Ministry and highlighted how seriously it viewed the adoption of synthetic training. With the DDWTT, Group Captain H.G. Crowe, as its chairman, the aims of the committee were defined to:

a. Study the requirements of aircrew training and determine what training devices could be used, 'including cinematography'.

b. Prioritise the development of synthetic training equipment.

c. Issue recommendations on the provision and installation of synthetic training equipment.

d. Liaise with the Army and Royal Navy concerning their use of synthetic training equipment.[73]

From the third meeting in May 1940, the committee had grown from 18 members at the March meeting to 27 and had changed its name to the Synthetic Training Committee.[74] DWTT Air Commodore Willock stated that now the war 'had started in earnest, the necessity for conserving petrol, engine hours, and operational aircraft, was of vital importance' and there was a requirement, 'to make the greatest possible effort towards the introduction of further facilities for synthetic training'.[75] These 'further facilities' were certainly forthcoming, either as a result of individual or unit innovation to address a specific training need, or through the procurement of synthetic training equipment from industry. In short, 'the diversity of suggestions, ideas, and methods increased steadily'.[76] It could be argued that the RAF was pursuing the adoption of this synthetic training equipment with single-minded zealousness. The challenge they faced however was twofold; firstly, the manufacture of training equipment 'was on a low priority'; secondly, equipment designed by individuals and units was not standardised and was therefore frequently being 're-invented'. In addition, it did not take advantage of pooled best practise in terms of design knowledge, technology or policy.[77]

The power of the Synthetic Training Committee was boosted from June 1940 with the creation of a new Air Council post, the Air Member for Training, who would now assume responsibility

for the Committee. At an Air Council Meeting of 21 June 1940, the Secretary of State for Air, Sir Archibald Sinclair, said that 'the biggest question of all' faced by the Air Ministry 'was the production of pilots and crews'.[78] The importance of this task was reflected by the appointment to the Air Council of an officer 'who would be in executive control of training in all its aspects' who had 'direct access to the Secretary of State'. The new Air Member for Training would take over the Air Ministry's Directorate of Training and 'certain branches of DWTT (T.W. 1, T.W. 2, and T.W. 3)'. The position of Air Member for Training (AMT) was officially established by an Order in Council dated 26 June 1940 and Air Vice-Marshal A.G.R. Garrod was appointed to the post by Sinclair on 28 June 1940, in the rank of (Acting) Air Marshal.[79]

In January 1941, the coordination of synthetic training was being managed within the AMT's T.O. 5 branch.[80] Synthetic training methods were becoming increasingly popular such that the STC meeting in early March 1941 drew 45 attendees, 'many of whom could not get near the table'.[81] As popular as synthetic training was becoming, standards applied to its use were problematic. In his report following visits to Bomber Command OTUs in December 1941, the RAF's Inspector General, Air Chief Marshal Ludlow-Hewitt, said that '[i]t is very gratifying to note how well synthetic training has developed at these OTUs' but warned that 'some are much better than others' and officers that are responsible for synthetic training should visit the better OTUs 'to see how it should be done'.[82] There were also problems of supply and demand. Priorities and production difficulties limited the amount that could be turned out, either by RAF units or by manufacturers, and the introduction of synthetic training was, in consequence, severely handicapped throughout 1940 and 1941.[83]

Another example of this shortfall was the use of sodium flares with which to practise night landings during the day. According to Ludlow-Hewitt's report, following his visit to OTUs in December 1941, a shortage of sodium flare training systems, combined with aircraft serviceability issues, were the reasons for, 'the main bottle-neck delaying the completion of the flying syllabus at OTUs…'[84] The sodium flare training devices featured the pilot wearing smoked lens goggles that blacked out normal vision less for the sodium flares and the system therefore simulated landing using a flare-path at night. The issues surrounding the paucity of such training systems were already being communicated between April and June 1941. In a letter to Director General of Production – Aircraft Equipment - DGP (AE), AMT Air Marshal Garrod said that 'serious concern is being felt by the restriction on the expansion of our Bomber Force' by a lack of 'sodium flare paths'.[85] To address these difficulties, the terms of reference for the Synthetic Training Committee were altered in March 1942, giving it greater control over its decisions. The additions included 'laying down policy,' to 'approve final specifications and to recommend scales of issue,' and to 'direct the programme of work at the STDU [Synthetic Training Development Unit],' and the ATDU [Armament Training Development Unit].[86] The result was a tightening of the STC's grip on synthetic training policy and management. The delays in providing STE, in this case, sodium flare paths, also highlighted how easy it was for the training pipeline to be disrupted by what on the surface, was a minor occurrence.

Procurement and Management of STE

The majority of the STE to enter service with Bomber Command was domestically made and to address issues of standardisation, the RAF began to issue Synthetic Training Committee Papers (STCP) that could be used by units to build devices to a common design. This initiative was supplemented by the creation of the Navigation Synthetic Training Development Unit (NTSDU) that was collocated with the Phillips & Powis factory at Woodley aerodrome in April 1941. Comprising three officers and seven civilian draughtsmen, engineers and a secretary, the organisation was tasked with designing and building training devices for map reading, dead reckoning navigation, astro-navigation and 'incidental devices'.[87] A number of devices were designed by the unit and these included the Air Navigation Instructor, the DR Instructor, the Celestial Observer Stellascope, the Practice Drift Indicator and Pictorial Britain; not all were accepted by the RAF. The NSTDU changed its name to the Synthetic Training Development Unit (STDU) in early 1942 where its role was broadened to reflect a growing need for STE.[88]

The STDU had three main aims: to develop synthetic training devices for aircrew, with the exception of armament, signals and radar; to examine and filter new ideas and assist in the development of those approved; and, finally, to standardise training devices 'as far as possible'.[89] The STDU's efficiency was questioned due to a failure to prioritise training system development and its role was subsumed within the Ministry of Aircraft Production and the Training Aids Development Unit was established at RAF Cardington in April 1943.[90] The real issue faced by the RAF, with this rapid adoption of synthetic training equipment, was a lack of knowledge as to the manpower requirements involved in terms of maintenance support and the provision of instructors. This issue was highlighted with the Link Trainer where these challenges – along with the scale of issue of trainers - were addressed in late 1938, but it took until 1942 for the challenges to be fully resolved.[91]

Although the STC was providing STE policy, the management involved in controlling production, standards, testing and quality assurance was clearly lacking. This applied to both the unit manufactured devices contained in the STC Papers and the more formal manufacturing processes seen with the NTSDU/STDU organisation, and later, when it was subsumed into the MAP TADU conglomerate. Although UK process had clear issues that impacted how STE was managed and procured, Dawson has argued that it had advantages over the US 'sequential design, test, redesign' approach before 'manufacturing and procurement' started.[92] Although the British process was more risky, de Florez decided to adopt it in the US Navy's Special Devices Section, 'to save time' and foster innovation.

One key factor to affect overseas procurement concerned the growth of the US Army Air Corps (USAAC) and its subsequent call on the Link company for synthetic training equipment. It is highly likely that Roosevelt's policy, 'that powerful United States Air Forces must be created and maintained and that every appropriate aircraft built in the United States should be manned and fought by American crews,' also had an impact on STE.[93] Already successful in selling Link Trainers around the world to countries such as Japan, Germany, the USSR and

France, a growing focus on the home US market meant that the RAF suffered increasing supply issues.[94] By early 1941, the RAF's adoption of the Link trainers was being retarded by a lack of spares and a failure by the Link company to meet deliveries.[95] The issue of Link prioritising US orders over those of the UK can be seen with the development of the Link Crew Trainer – initially referred to by Link as the Starglobe.[96] Again, Harris played a central role through his assistance in procurement of this device following his posting to the US as the head of the RAF delegation to the British Military Mission following commanding No.5 Group and holding the post of DCAS.[97] This device, also referred to earlier by the RAF's preferred nomenclature, the Celestial Navigation Trainer, was developed by the Link Company in conjunction with the RAF and was designed to train pilots, navigators and bomb aimers in long range navigation – a critical skill as part of the strategic bomber offensive as well as in ferrying aircraft from the US across the Atlantic.[98] Service trials on the device were conducted at No. 31 School of Air Navigation at RAF Port Albert in Ontario.[99] In his covering letter to the trials report, head of the British Air Commission, Air Marshal Sir Roderic Hill, highlighted the need to place orders before factory output went to the US Navy and US Army Air Corps. 'The necessity for placing an early order for these Trainers cannot be over emphasized in view of the fact that it is understood that 90 of these Trainers are being ordered by the U.S. Army and Navy'.[100]

The report itself was highly supportive of the device and stated that it was 'an ideal instrument for the training of air observers and crews. Its immediate adoption in the RAF is most strongly recommended'. The report continued that, 'a large proportion of the air observer training may be carried out better in this instrument than it can be in the air' and that the device will 'improve vastly the quality of graduates and will enable their training to reach a standard that has hitherto been impossible'. With the Celestial Navigation Trainer 'dramatically' reducing flying time and reducing 'considerably the cost of training,' it is perhaps surprising that the device was not bought in larger numbers; here, financial pressure and poor project management were at the root of the problem.[101]

The RAF dithered in ordering the device for a number of reasons. The major issue was the 'prohibitive cost' of the device at £80,000 each (this equates to £5.17 million in 2023 prices).[102] In his Minute Sheet comments, Air Commodore Huskinson, Director of Armament Development (D Arm D), the initial Air Ministry procurement authority for the Link Crew Trainer, also highlighted an 18-24 month delivery schedule and that such a timescale would mean that the device, in D Arm D's mind, would have 'missed its usefulness as far as our war effort is concerned'.[103] This comment was clearly loaded with the foresight that it did not merit. Further negativity was added with the comment that 'the U.S. Government will probably obtain priority' for the devices. Here another reason emerges for failure to procure the devices earlier.[104] In support of D Arm D's views, a cipher from the British Air Commission in Washington to the Air Ministry in February 1941 had stated that the US Army and Navy were about to place an order for 70 Link Crew Trainers, further adding to the idea that the RAF 'had missed the boat'.[105] This caused little alarm within the Air Ministry as in March 1941 MAP had refused to sanction orders until the trial had been completed in Canada.[106] This risk-averse view was

not universal. AMT, Air Marshal Garrod, sent the Head of RAF Staff in Washington, Air Vice-Marshal Harris, a cipher in August 1941 recommending ordering the devices and saying that he was looking for a funding stream for procurement.[107] In September, Harris wrote to Air Commodore Cochrane, the Director of Training under AMT, to inform him that he was attending a meeting and that it was 'most urgent' that he be told how many devices the RAF required. Harris continued that he needed an 'immediate decision' but 'feared it might already be too late'.[108] The response again highlighted financial issues: 'it is not practicable to give speedy decisions. Haven't got two-and-a-half million dollars'. The Air Ministry went on to say that 'if they are to be obtained at all' it will have to be through 'lend-lease arrangements'.[109]

The lend-lease requisition, BSC.6464, was filed by the BAC for 100 Link Crew Trainers on 21 October 1941. The first deliveries were expected to commence in June 1942 and proceed at a rate of five per month.[110] This number was later reduced to 60 with the first device not being fully ready for training until early 1943.[111] The problem was that of output as the US had placed requisitions for 87 for the US Army Air Corps and 34 for the US Navy.[112] According to Rolf and Staples, not all of those devices destined for the UK entered service with some passed back to the US under the terms of reverse lend-lease.[113]

Application of STE

Before the Bombing Teacher entered service with the RAF, the Service was using the camera obscura during the First World War and it remained in-service up until 1939. According to Pattinson, '[the] pupil flies over the camera obscura which throws an image of his aircraft on to a table. He makes a bomb dropping signal [normally a light or radio signal], and that is plotted in the camera obscura office, and the man operating the camera obscura will tell the pilot where his bomb would have gone'.[114] The Operational Record Book of No.12 (Bomber) Squadron, highlights that camera obscura exercises would normally last a week.[115] To achieve correction for wind direction and strength, the camera obscura operator marks 'the point at which the image of the machine appears on the chart at the time of the signal is noted' before calculating the aircraft's height and speed along with wind strength and direction.[116] Being such a small and portable device, camera obscura were frequently located in towns to make the training exercises more realistic.[117] Although the device remained in service up until 1939, STE, such as the Bombing Teacher, and later, Celestial Navigation Trainer, overtook the earlier device. Larger bomber crews also meant that the need arose to conduct collective training that involved the complete crew.

In that regard, one of the most significant training exercises to emerge from Finningley and that was later to be adopted by all bomber OTUs was the Ground Operational Exercise (GROPE).[118] GROPEs took place in a Crew Procedures Trainer (CPT) that comprised cubicles for each crew member and frequently a Link Trainer for the pilot. The cubicles contained the main equipment and instrumentation for each discipline, with hydraulic and electrical power being provided from 'external sources'. The exercise was managed from a control table at which sat the exercise controller, a signaller and a plotter. GROPE exercises featured sound

effects, navigation plots shown on an epidiascope and bright lights to simulate searchlights. Throughout the exercise, engine noise as well as that of simulated flak where appropriate, was fed into the cubicles via speakers. Each exercise was conducted with what is now referred to as a Master Events List (MEL) that drove the scope of the exercise and crews went through the whole process of pre-flight briefings, the flight itself and then post-flight debriefings. The introductory briefing paragraph of GROPE No. 5 is shown below and describes the scope of a typical exercise.

As in the case of Ground Operational Exercise No. 4, Grope No. 5 has been designed primarily for training crews in the location of targets at night. The normal navigational problems are included in the exercise, particular stress being laid on the plotting of loop bearings obtained in conjunction with the re-diffusion loop trainer. Four examples of the plotting of astronomical bearings are also included, so that those trainees who have received instruction in this form of navigation may have practice, and the normal operational identification procedure, etc., is provided.[119]

This instruction to GROPE No.5 makes reference to the loop trainer and indicates how by 1942, the RAF was using a range of different individual synthetic training devices before using collective trainers such as the Crew Procedures Trainer.

Conclusion

As this paper has shown, the RAF had a pragmatic appreciation of the benefits of STE and integrated numerous training devices into its operational flight training syllabi in the period running-up to the Second World War and during the war itself. It can be seen that STE saved fuel and wear-and-tear costs in comparison to using real aircraft. Its adoption also added another layer of air safety by aiming to increase a crew's preparedness before they undertook exercises in the air. Although the RAF always maintained that the use of STE would not reduce actual flying hours, the ability to practise on the ground ensured that time in the air was not wasted. In short, the adoption of such devices provided improved levels of training transfer and, in the case of multi-crew aircraft, an excellent collective training environment where individual crew members could work together. In addition, training devices, such as the Link trainer, offered a relatively high fidelity level of training in the period of expansion when training aircraft and airspace were at a premium. The wartime RAF was at the forefront of using STE in an integrated training environment and must be considered as the premier exponent of STE during its expansion and early war years especially when compared to the *Luftwaffe's* minimal use of such technologies. The RAF's STE policy and application was also the catalyst for the development of synthetic training in the US Navy as evidenced by the de Florez report.

Another observation on the use of STE by the RAF centres on the enthusiasm shown by individuals and units for its adoption. This is epitomised by organisations such as No.5 Group's CTS at RAF Finningley and 15 OTU at RAF Harwell where innovation, initiative and a desire to improve training delivery came together to provide a driver for the RAF's approach to STE,

especially as far as its policy, procurement, management and application was concerned. Despite some difficulties surrounding procurement and domestic manufacture, the use of STE by Bomber Command was a major boost to the effectiveness of its operational training and its adoption and growth were significant catalysts for the delivery of improved training as the war progressed.

Notes

[1] TNA AIR 10/5551, *Flying Training Volume 1, Policy and Planning*, p. 27. As to the US use of the Link Trainer see for example, K.P. Werrell, 'Flying Training: The American Advantage in the Battle for Air Superiority against the Luftwaffe', *Air Power History*, Vol. 61, No. 1, Spring 2014, p. 37.
[2] https://comoxairforcemuseum.ca/heritage-team-project-link-trainer/. Accessed 15 February 2021 and taken from L. Kelly, *The Pilot Maker* (New York: Grosset & Dunlap, 1970), p. 68.
[3] TNA AIR 41/4, AHB, *Aircrew Flying Training 1934-1942*, p. 563.
[4] M. Baarspul, 'A Review of Flight Simulation Techniques', *Progress in Aerospace Sciences*, Vol. 27, No. 1, 1990, p. 7.
[5] R.L. Page, *Brief History of Flight Simulation*, paper delivered at SimTect Conference, Feb 2000.
[6] Baarspul, 'A Review of Flight Simulation Techniques', p. 8.
[7] Ibid., pp. 8-9.
[8] TNA AIR 2/3940, Letter from AOC-in-C Fighter Command to AOC-in-C Bomber Command discussing the joint servicing of the devices at Bentley Priory and Uxbridge, 26 May 1939.
[9] P. Dawson, 'Luis de Florez and the Special Devices Division' (PhD Thesis, George Washington University, 2005), p. 86.
[10] J.M. Rolfe & M. Bolton, 'Flight Simulation in the Royal Air Force in the Second World War', *RAeS Aeronautical Journal*, October 1988, p. 315.
[11] TNA AIR 10/5551, *Flying Training Vol. 1, Policy and Planning*, p. 8.
[12] O. Thetford, Aircraft of the Royal Air Force Since 1918 (London: Putnam, 1976) provides service details of the aircraft.
[13] Ibid., p. 15.
[14] TNA AIR 20/1347, *Notes on the History of RAF Training 1939-44*, AMT, January 1945.
[15] TNA AVIA 15/1428, Minutes of the 5th Meeting of the Synthetic Training Committee, 6 September 1940.
[16] TNA AVIA 15/1428, Minutes of the 13th Meeting of the Synthetic Training Committee, 2 May 1941. For the growth of such devices, see TNA AIR 20/1348, Minutes of the 7th Meeting of the Synthetic Training Committee, 8 November 1940.
[17] TNA AIR 41/4, p. 560.
[18] TNA AIR 20/1347, *Notes on the History of RAF Training 1939-44*.
[19] RAFM. A look at the Air Force Lists during the inter-war and early war years shows that pilots were undertaking all key staff functions.
[20] TNA AIR 20/1347, *Notes on the History of RAF Training 1939-44*, refers to the reduction in the training organisation to the minimum and subsequent lack of investment.
[21] TNA AIR 10/5551, *Flying Training, Vol. 1, Policy and Planning*, p. 8.

[22] TNA AIR 20/1334, Aircrew Training Conference, Minutes of the Opening Meeting held in the Air Council Room, on 23 January 1942, p. 4.
[23] T. Nash and G. Ebbut (eds.), *IHS Jane's Simulation & Training Systems 2018-2019* (London: Jane's, 2018), p. 357. Referred to as zero flight time training and conducted on a FAA Level D full flight simulator.
[24] https://www.shephardmedia.com/news/training-simulation/premium-new-a400m-simulator-opens-network-opportun/. (Accessed 19 March 2021).
[25] JSP 822, Part 2, *Training and Education Glossary*.
[26] TNA AIR 20/1347 contains the Minutes of the Air Ministry's Simulation of Air Training on the Ground Committee.
[27] TNA AIR 2/8644, Minute Sheet, DWTT to ACAS(T), 20 February 1940.
[28] https://research-methodology.net/forms-of-training-transfer/. (Accessed 23 March 2021).
[29] Nash and Ebbutt (eds.), *IHS Jane's Training and Simulation Systems 2018-19*, pp. 16-18.
[30] P.W. Caro. 'Aircraft Simulators and Pilot Training', *Human Factors*, Vol. 15 No. 6, 1973, p. 6.
[31] TNA AIR 20/6058, *Illustrated Catalogue of Synthetic Training Devices*, AMT, May 1942.
[32] V. Orange, 'Tedder and the Air Ministry', P.W. Gray & S. Cox (eds.) *Air Power Leadership – Theory and Practice* (London: The Stationery Office, 2002), p. 230.
[33] H. Montgomery Hyde, *British Air Policy Between the Wars: 1918-1939* (London: Heinemann, 1976), Appendix III.
[34] Lord Swinton, *I Remember* (London: Hutchinson, undated), p. 124, quoted by Orange in 'Tedder and the Air Ministry'.
[35] TNA AIR 20/1347, *History of RAF Training 1939-1945*.
[36] L.A. Pattinson, 'The Training of a Royal Air Force Pilot', *RUSI Journal*, 83 Feb/Nov 1938, p. 16.
[37] TNA AIR 20/1347, *Notes on the History of RAF Training 1939-44*, p. 272.
[38] TNA AIR 6/33, Minutes of the 117th EPM of 15 March 1938.
[39] TNA AIR 6/33, Minutes of the 121st EPM of 12 April 1938.
[40] TNA AIR 10/5551, *Flying Training Volume 1, Policy and Planning*, p. 28.
[41] TNA AIR 2/3940, contains considerable correspondence between the Air Ministry Director of Training, 26 Group, Commands and the Under Secretary of State for Air dated between October and December 1938 concerning the establishment and support for Link Trainers. A conference was held at the Air Ministry on 14 November 1938 'to discuss the basis of establishment of link [*sic*] trainers'.
[42] TNA AIR20/1347, *Notes on the History of RAF Training 1939-44*, p. 272.
[43] TNA AIR 2/8645 and AIR 2/8646 contain correspondence between AOC No.5 Group, HQ Bomber Command, Director of War Training & Tactics and CAS.
[44] Kreipe and Koester, *Pilot and Aircrew Training in the Luftwaffe 1921-1945*, p. 47.
[45] Ibid., p. 134.
[46] Ibid., p. 234.
[47] Ibid.,, p. 311.
[48] J.E. Adams, 'The Luftwaffe', *Flying Magazine*, March 1944, p. 51.
[49] L. Deighton, *Fighter* (New York: Alfred A. Knopf, 1978), p. 109.
[50] NAL, C.G. Grey Papers, Section 11, letter to General Milch, 1935.

[51] Kreipe and Koester, *Pilot and Aircrew Training in the Luftwaffe 1921-1945*, pp. 282-3.
[52] Pilot Flying Log books for Flt Lt J. Cox, Sqn Ldr M. Beetham and W/O C. Goff https://internationalbcc.co.uk/history-archive/digital-archive/. (Accessed 15 January 2021).
[53] P. Dawson, 'Luis de Florez and the Special Devices Division' (PhD Thesis, George Washington University, 2005), p. 99.
[54] Ibid., p. 100.
[55] https://www.navair.navy.mil/nawctsd/node/511. (Accessed 15 February 2021).
[56] TNA AIR 2/4168, Letter from AOC No.5 Group to HQ Bomber Command, 18 January 1940.
[57] TNA AIR 2/4168, Letter from AOC No.5 Group to HQ Bomber Command, 18 January 1940.
[58] TNA AIR 2/8645, Minute Sheet comments by DSD, 5 February 1940. This minute sheet comment referred to a letter from HQ Bomber Command to No.5 Group, dated 1 February 1940, giving authority for the CTS.
[59] TNA AIR 2/8646, Letter to Air Ministry from HQ Bomber Command, 25 May 1940.
[60] TNA AIR 2/8646, Letter from HQ Bomber Command to Under Secretary of State for Air, 18 May 1940.
[61] TNA AIR 6/33, Minutes of 149th EPM held on 11 January 1939.
[62] TNA AIR 41/40, pp. 14-15.
[63] Rolfe and Bolton, 'Flight Simulation in the Royal Air Force in the Second World War', p. 316.
[64] TNA AIR 2/8646, Letter from AOC No.5 Group to DSD, 2 June 1940.
[65] Ibid.
[66] TNA AIR 2/8646, Letter from Air Council to OC 106 Squadron, RAF Finningley, 26 June 1940.
[67] TNA AIR 2/8646, Letter from DWTT to HQ Bomber Command, 19 June 1940.
[68] TNA AIR 2/8646, Letter from AOC-in-C Bomber Command to AMSO, 26 June 1940.
[69] Harris, *Despatch on War Operations*, p. 23.
[70] TNA AIR 41/4, *AHB Narrative, Aircrew Training 1934-1942*, p. 238. The term OTU replaced Group Pool from April 1940. No.6 Group took over responsibility for Group Pools, later OTUs, from September 1939. See TNA AIR 2/4168 Loose Minute from DSD to HQ Bomber Command, 9 September 1939.
[71] TNA AIR 2/8644, DWTT comments on Minute Sheet, 20 February 1940.
[72] TNA AIR 20/1348, Minutes of the Simulation of Air Training on the Ground Committee, 1st Meeting held on 11 March 1940 in Harrow.
[73] TNA AIR 20/1347, *Notes on the History of RAF Training, 1939-1944*.
[74] TNA AIR 1348, Minutes of the Synthetic Training Committee Meeting, 16 May 1940.
[75] Ibid.
[76] TNA AIR 41/4, *AHB Narrative, Aircrew Training 1934-1942*, p. 562.
[77] TNA AIR 20/1347, *Notes on the History of RAF Training 1939-1944*.
[78] TNA AIR 2/4550, Notes of a Meeting Held on the 21 June 1940, 24 June 1940.
[79] TNA AIR 2/4550, Order in Council, 26 June 1940.
[80] TNA AIR 41/4, *AHB Narrative, Aircrew Training 1934-1942*, p. 561.
[81] TNA AIR 2/8645, Memorandum T.O.5 to S.2.A., 10 March 1941.
[82] TNA AIR 20/2769, RAF Inspector General Report No. 218, Visits to Operational Training Units in Bomber Command, 15-23 December, 25 December 1941.

[83] TNA AIR 41/4, *AHB Narrative, Aircrew Training 1934-1942*, p. 563.
[84] TNA AIR 20/2769, RAF Inspector General report No. 218, Visits to Operational Training Units in Bomber Command, 15-23 December 1941, 25 December 1941.
[85] TNA AIR 14/1931, Letter to DGP (AE) from DOT, 28 June 1941.
[86] TNA AIR 2/8785, Letter DOT, Air Commodore E.S. Goodwin to Under Secretary of State for Air, 24 March 1942.
[87] TNA AIR 32/113 Navigation Synthetic Training Development Unit notes, undated.
[88] TNA AIR 20/1347, *Notes on the History of RAF Training 1939-1944*.
[89] Ibid.
[90] Rolfe and Bolton 'Flight Simulation in the Royal Air Force in the Second World War,' p. 316.
[91] TNA AIR 2/3940, Notes on a Conference Held at the Air Ministry on Monday 14 November, 1938, to discuss the basis of establishment of link [*sic*] trainers, 14 November 1938.
[92] Dawson, 'Luis de Florez and the Special Devices Division,' p. 101.
[93] 'The American-British Memorandum of Agreement dated 21 June 1942 – The Arnold/ Towers/Portal Agreement'. https://history.state.gov/historicaldocuments/frus1941-43/d299. (Accessed 9 March 2021).
[94] Baarspul, 'A Review of Flight Simulator Techniques,' p. 9.
[95] TNA AVIA 38/769, Secret Cypher from BAC to MAP, 21 March 1941.
[96] TNA AVIA 38/769, Telegram from Air Ministry to British Purchasing Committee, 30 August 1940.
[97] H. Probert, *Bomber Harris His Life and Times* (London: Greenhill Books, 2006), p. 116.
[98] TNA AVIA 15/38, Secret Cypher from BAC to MAP, 25 August 1941.
[99] TNA AIR 20/4113, The Link Celestial Navigation Trainer - Report of a Trial done at No. 31 School of Air Navigation, RAF Port Albert, Ontario, 1 September 1941.
[100] Ibid.
[101] TNA AIR 20/4113, The Link Celestial Navigation Trainer - Report of a Trial done at No. 31 School of Air Navigation, RAF Port Albert, Ontario, 1 September 1941.
[102] TNA AIR 20/4113. Minute Sheet comment by D.Arm.D., 25 April 1941.
[103] H. Probert, *Bomber Harris – His Life and Times* (London:Greenhill Books, 2006), p. 117 and 420. Harris was Head of British Air Staff in Washington from 27 May 1941 until 22 February 1942. Harris worked closely with the British Air Commission, the purchasing agency for US aircraft and equipment that represented MAP.
[104] TNA AIR 20/4113. Minute Sheet comment by D.Arm.D, 25 April 1941.
[105] TNA AIR 20/4113, Secret Cipher from BAC to Air Ministry, 15 February 1941 and Secret Cipher from the US Air Attaché to Air Ministry, 15 February 1941.
[106] TNA AIR 20/4113, Minute Sheet comment by A.D.T.O., 6 March 1941.
[107] TNA AIR 20/4113, Secret Cipher AMT to Head of RAF Staff BAC Washington, 27 August 1941.
[108] TNA AIR 20/4113, Secret Cipher Head of RAF Staff BAC Washington to DOT, Air Ministry, 17 September 1941.
[109] TNA AIR 20/4113, Secret Cipher Air Ministry to Head of RAF Staff BAC Washington, 20 September 1941.
[110] TNA AIR 20/4113, Secret Cipher from BAC to MAP, 27 November 1941.

[111] TNA AIR 2/8785, Agenda for 33rd Synthetic Training Committee Meeting, March 1943.
[112] Ibid.
[113] Rolf & Staples, *Flight Simulation*, pp. 26-27.
[114] L.A. Pattinson, 'The Training of a Royal Air Force Pilot', *JRUSI*, 83 Feb/Nov 1938, p.16.
[115] TNA AIR 41/39, *The RAF in the Bomber Offensive Against Germany – Vol 1, Pre-War Evolution of Bomber Command 1917 to 1939*, p. 44.
[116] Wonders of World Aviation published Part 22, 2 August 1938, https://www.wondersofworldaviation.com/mobile/auxiliary.html. (Accessed 9 March 2021).
[117] For example, 57 Sqn undertook bombing exercises between 17-19 October 1932 over Northampton, Portishead and Cardington. https://57squadron.wordpress.com/between-the-wars/. (Accessed 8 March 2021).
[118] TNA AIR 20/6056, *Bomber Command Synthetic Training Manual*, published 1943.
[119] Ibid.