The Dam Busters Raid

By Wg Cdr Tim Webster

At 2128 hrs on the evening of 16 May 1943 the first aircraft of the newly formed 617 Squadron, AJ-E piloted by Flt Lt Barlow, lifted from the grass runway of RAF Scampton and set course for Germany. So started Operation CHASTISE, an attack that had been in planning on and off since October 1937[1] and that would come to be recognised as Bomber Command's most spectacular operation of World War II. By dawn the next day two major German dams had been breached, significant areas flooded, over 1,250 deaths caused and the industry of the Ruhr Valley disrupted. On the British side, 8 aircraft and 53 aircrew had been lost.

The British would use post-raid reconnaissance pictures to show the world the damage caused to the dams, to the countryside below them and, by implication, to the industrial complex of the Ruhr Valley. The post-raid propaganda was not confined to Britain but was trumpeted around the Empire in newspapers in the United States and in leaflets dropped into Occupied Europe.

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The understandable wartime use of the raid for propaganda purposes may have led to overstatement of its success. The publication of Webster and Frankland's review of the air offensive against Germany brought a re-evaluation of the raid — while acknowledging the precision of the attack— held that the physical outcome of the raid was neither "of fundamental importance nor even seriously damaging".[2]

This paper will use published sources to examine the context of, and build up to, the Dams Raid, to recount the raid itself, to assess the damage directly caused and the German response to it, to outline the lessons that were or could have been learned from the raid, and finally to place the raid in perspective.

The background to the raid

Contrary to popular belief, the origins of the Dams Raid did not lie with Barnes Wallis, the Vickers' engineer who designed the bouncing bomb[3] used against the dams. As early as October 1937 planners within the Air Ministry were developing attack options for the expected war with Germany: these were called Western Air (WA) Plans and there were 13 of them. Plan WA5 required Bomber Command "to attack the German War Industry including the supply of oil with priority to that in the Ruhr, Rhineland and Saar".[4]

This was refined by Bomber Command into a plan to achieve the same effect by attacking the Ruhr's 45 power and coking plants: it was believed that these could be destroyed in a fortnight's bombing (amounting to about 3,000 sorties) with an expected aircraft loss rate of about 6%. That these estimates were wildly inaccurate was shown by the 11.5% loss rates of the RAF's then-heavy bombers in the period of the Phoney War[5] and the Butt Report's conclusions on Bomber Command's accuracy[6], which on simple arithmetic alone (and taking no account of the doubtful effectiveness of the bombs with which the RAF started the war), would suggest that perhaps 12,000 sorties would have been required. Extrapolating these figures, a loss of approximately 1,400 aircraft might have been expected.

Even on the basis of the original estimates, the loss rate for the new plan was considered unacceptable and the Air Ministry's Air Targets Sub-Committee turned to devising an alternative means to achieve the same end: the result was a plan to attack the Mohne and Sorpe dams instead. The logic behind this plan held that the Ruhr's heavy industry was dependant on the water the dams held for industrial processes, for power generation and for drinking water: if the dams could be destroyed then industry would grind to a halt.

Assuming that the logic contained no flaws, the next step was to identify a way to attack the dams themselves. Considerable effort went into this, concentrating particularly on the Möhne, which was a gravity dam[7]. Suggestions included attacking the air side of the dam with semi-armour piercing bombs, dropping high explosives onto the dams or attacks with multiple torpedoes from the waterside. None of these was considered feasible and the development of a guided-bomb based upon an anti-aircraft target drone was, for a while, considered the best option. Unfortunately, the fall of France placed the target out of the range of such a weapon.

Even before the fall of France Wg Cdr Finch-Noyes, under the auspices of the Research Department Woolwich, was working on alternative means for attacking the Möhne dam. After reviewing the papers already produced, he proposed that a 20,000 lb explosive charge detonated 40 ft from the top of the dam on its water-side and in contact with it (or a succession of 2,000 lb charges close together) would have a reasonable chance of destroying it.

His proposed weapon would be launched from an aircraft at low level, propel itself into the dam, sink and then be exploded by hydrostatic fuses at the desired depth.[8] Practical considerations meant that no single weapon could be used, no RAF aircraft was yet capable of delivering it to the target, and so multiple smaller weapons would have to be substituted. The Wellington bomber could carry a 2,000 lb charge weapon under each wing to be dropped at height and distance from the dam and,

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with the weapon propelling itself after hitting the water, skip over any intervening torpedo nets, strike the dam, sink and explode.

It was proposed to use a total of 16 weapons, but by April 1941 Bomber Command had decided that this plan, too, was fraught with technical imponderables and it was quietly shelved. Before the Dams Raid took place other means of attack were put forward: Combined Operations suggested floating a charge down the reservoir and onto the dam, while the Special Operations Executive proposed an attack by parachutists who would place explosive charges against the dam.[9]

Weapon development

Work on the design of the weapon that would eventually be used on the Dams Raid started in the autumn of 1939. The man behind it was Barnes Wallis, an aero-structures engineer with Vickers-Armstrongs' Aviation, who was already well known for his work on the R100 airship and the Vickers Wellesley and Wellington bombers. Wallis had come to the view that modern warfare depended on industrial production, which in turn relied on sources of power. He further argued that while production could be dispersed making it relatively invulnerable to the bombs then available to the RAF, sources of power such as coalmines, oil fields and hydroelectric dams could not. They were, however, equally invulnerable to the bombs available to the RAF.[10]

Wallis believed that much heavier bombs could be effective against dams and coalmines, and he had started to work, with the blessing of the Ministry of Aircraft Production (MAP), on a massive 22,000 lb bomb, similar in shape to his R100 airship,[11] which was expected to achieve supersonic speed in its fall from altitude. This would be suitable for these targets as it buried itself deep in the earth before exploding and caused shockwaves that would shake structures apart: the same effect could be achieved by exploding the bomb in the water close to a dam.

In autumn 1940 experiments were started at the Road Research Laboratory to determine just how much explosive would need to be detonated at what distance from the Möhne dam to destroy it. Initial experiments were on 1/50 scale models, working upwards to progressively larger models and eventually to a one-off test on the disused 180 ft long, 35 ft high Nant-y-Gro dam near Rhayader, which on 24 July 1942[12] proved conclusively that such dams could be destroyed by an underwater explosion in contact with the dam, although this was not yet Wallis's intention.

The early model tests gave Wallis the information needed to support his *A Note on a Method of Attacking the Axis Powers*,[13] which he circulated widely. He argued that his massive bomb dropped from high altitude would be effective against the Möhne dam, but there was no RAF bomber

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capable of carrying it to the required altitude and so the project ran in parallel with a proposal for an equally large bomber to deliver it. The Air Staff rejected both.

Wallis, however, was not to be put off. Somehow, in June 1941, he gained the support of MAP's Aerial Attacks against Dams committee for further experiments on the effects of explosives on dams. Progress was slow, however, and Wallis himself admitted: "the growing conviction that my original suggestion was impracticable . . . led me to seek for other methods".[14] Early in 1942 he hit upon the idea of ricocheting a spherical weapon across the surface of the reservoir thus avoiding torpedo nets and other surface defences, striking the dam, sinking and then exploding in contact with it at a predetermined depth thanks to hydrostatic fuses. Wallis could not account for how he got the idea: the mythology relates it to skimming stones across a pond, but there are similarities to Finch-Noyes's earlier plan.

By the end of April 1942, Wallis had gained important support from Professor Blackett, a scientific adviser to the Admiralty, and from Sir Henry Tizard, who had influence with the Air Council, MAP and the Chiefs of Staff Committee. Their support gained him access to the National Physical Laboratory's water tanks to perfect the delivery technique that now definitely included the backward rotation of the weapon. Why Wallis decided on this is unclear although he claimed three advantages: "it increases the distance which the missile will travel after release from the carrier, before striking the water; it diminishes the tendency of the missile to plunge downwardly on impact with the water surface; it increases the distance which the missile will travel whilst ricocheting."[15]

In mid-June 1942 Wallis demonstrated his 'bouncing' spheres (the weapon was at this stage spherical in shape even though Wallis was beginning to have doubts about this) to interested spectators from both MAP and the Admiralty. The Royal Navy was quick to grasp the potential of the weapon for attacks on capital ships. By the end of June 1942 MAP had granted permission for a Wellington bomber to be used for tests involving mock-up spherical bombs commissioned by the Admiralty.

The first ground spinning test did not take place until 20 October 1942[16] and the first air test until 2 December 1942 but it was then proved that it was possible to spin the weapon without shaking the aircraft apart. Two days later the first dropping trials took place at Chesil Beach in Dorset; they were unsuccessful, the spheres were destroyed as they hit the water. A further series of experimental drops continued until early February 1943 as Wallis sought to overcome this major problem.

At this stage it seemed that Admiralty interest in a medium-sized version of the weapon (codenamed Highball) to be used by Mosquito aircraft to attack ships, and the Tirpitz in particular, was greater than Air Ministry interest in the full-sized version (codenamed Upkeep) for attacks against the dams. There was also a small-sized version (codename Baseball) meant for launching against ships from a mortar in the bows of a fast attack craft.

Wallis continued to lobby for his weapon and in early February 1943 he gained support from Churchill's scientific adviser, Prof Lindemann, previously not just sceptical but actively hostile to the plan. Things also seemed to speed up at the Air Ministry and MAP although there was concern that if Wallis devoted his time to developing Upkeep, the development of the projected Vickers Windsor bomber would be neglected[17]. Indeed, Vickers was forced to admit that work on the Windsor was already behind schedule due, in part, to work undertaken to convert de Havilland Mosquito aircraft to carry Highball.

On 14 February 1943, as Bomber Command was preparing to open the 'Battle of the Ruhr', its Senior Air Staff Officer wrote a paper for his Air Officer Commander-in-Chief, the redoubtable 'Bomber' Harris, describing both Upkeep and Highball. At this time, although the Germans were being beaten in Russia, in North Africa and in the Atlantic, with the Russians calling for a second front in Europe only Bomber Command had the capacity to take the war to the continent. Its task had been set at the Casablanca meeting of the Combined Chiefs of Staff that January:

"[The] primary object will be the progressive destruction of the German military industrial and economic

An Upkeep mine on Gibson's own Lancaster

Development of Upkeep and the specially modified Lancaster that would carry it now began in earnest

system, and the undermining of the morale of the German people to a point where their armed resistance is fatally weakened."[18]

Harris interpreted this as giving him a free hand to attack any large German city: this having the effect of attacking both the industry located there and the local population despite the uncertainty of the evidence over the effect of such attacks on civilian morale. He went so far as to state that his task was "destroying the main cities of the Ruhr".[19]

There is no doubt that Harris was unimpressed by Upkeep: he claimed that it would shake the carrying aircraft apart if not perfectly balanced when spun and that the ballistics would not work. It has been noted in a number of sources that Harris did not seem initially to grasp the difference between Upkeep and Highball; it also seems he did not grasp that the concept had already been trialled or he would surely not have raised the objections he did. Harris' own account of the Dams Raid is brief in the extreme and makes no mention of his scepticism. Indeed, on the subject of Upkeep he wrote: "It was one of the weapons designed for the Command outside the official Ministry of Aircraft Production and Air Ministry organisations . . . it could be taken almost as a rule that such weapons were successful."[20]

This contrasts with his missive to Portal, the Chief of the Air Staff, in which he railed against: "enthusiasts and panacea mongers . . . careering round MAP suggesting the taking of about 30 Lancasters off the line to rig them up with this weapon, when the weapon itself exists so far only in the imagination of those who conceived it."[21]

Harris's further assertion that "we have made attempt after attempt to pull successful low attacks with heavy bombers. They have been, almost without exception, costly failures"[22] was undoubtedly a more reasonable objection.
On 21 February 1943 Wallis was finally, at the instigation of Cochrane (AOC 5 Group), able to show his film of the Chesil Beach tests and the National Physical Laboratory tank tests to a still-sceptical Harris.

By now Portal had authorized the conversion of three Lancasters for use in the development of Upkeep and on 26 February 1943 a formal decision to go ahead was taken with the weapon. It was to be ready for use that year, the latest date for its use to achieve maximum effect being just three months away. Maximum effectiveness required the dams had to be full of water, which meant the attack must occur before the end of May 1943. Time was going to be extremely short.

Development of Upkeep and the specially modified Lancaster that would carry it now began in earnest. Responsibility was split between Vickers and Royal Ordnance for Upkeep, and Vickers and Avro for the aircraft. Gradually Upkeep evolved through the series of trial drops at Reculver Bay on the North Kent coast rather than at Chesil Beach. By trial and error it became a cylinder, not a sphere, and lost the originally intended wooden covering.

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Wing Commander Guy Gibson

The trials were not perfect, the test pilots having difficulty effecting the drops from the right height and at the right speed: unsurprisingly, therefore, Upkeep did not behave as expected and as late as 2 May 1943 further trial drops were authorised.[23] The extra, successful trials were all to be flown at 60 ft at a groundspeed of 210-220 miles per hour with Upkeep being spun at 500 revolutions per minute. The final trial drop was on 13 May 1943: Upkeep was ready for use but only just in time.

Meanwhile, the Admiralty and the Air Ministry were still debating whether Upkeep or Highball should be used first or whether attacks against the dams and the Tirpitz should occur simultaneously. The apparently confused Chiefs of Staff had set up a committee to monitor both Upkeep and Highball developments[24] but despite, or perhaps because of, multiple and varying 'expert' opinions on the validity of the different targets it was difficult to reach a conclusion. Finally on 13 May 1943, having been informed that Upkeep trials had been successful while Highball trials had failed, the committee agreed that Operation CHASTISE (the Dams Raid) should proceed. The Chiefs of Staff who were in Washington for discussions with their American opposite numbers confirmed the decision the next day.

Preparation for the raid

Responsibility for execution of the Dams Raid fell to Bomber Command. On 15 March 1943, Harris passed that responsibility to Cochrane who had been responsible for Harris seeing Wallis's films. He was told to form a special squadron (Harris having already nominated the experienced and highly-decorated Wing Commander Guy Gibson to lead it) to attack the dams, but that this would not be the squadron's only mission. Gibson had significant control over the selection and training of the aircrew, was allowed to devise the means to reach the target and to suggest amendments to the Operational Order, and was given control of his force in attacking the dams: an early example of mission command in the Royal Air Force.[25]

That Bomber Command was well aware of the potential propaganda value of a successful raid was

Air Marshal (later Marshal of the RAF) Sir Arthur Harris, Air Officer Commanding -in-Chief, RAF Bomber Command

shown when 5 Group informed Gibson that he would be required to write a book about the mission.[26] Indeed, Harris' own account of the Dams Raid follows on immediately from comments on the difficulty of gaining public support for the Royal Air Force, which included:

"The Air Ministry had certainly had the idea that it would be a good thing to get the support of the Press and to have the operations of the Air Force reported as fully as possible. No doubt it was hoped to compensate in this way for the obvious inability of the Air Ministry, by comparison with the ministries of other services, to get the attention and the favour of those who matter; public support was to be called in to redress the balance."[27]

Harris intended to draw the new squadron's aircrew from volunteers within 5 Group who had completed or nearly completed two operational tours but this did not happen; many of the aircrew had actually completed less than 10 operational sorties and some of the flight engineers none at all. Equally, not all of them were volunteers. The original intention to draw the aircrew from amongst the very most experienced members of 5 Group, while partly meant to reduce disruption to line squadrons suggested the formation of an elite unit and also acknowledged the difficulty of the task.

Harris was on record as opposing elite units, he had opposed the Pathfinder Force saying, "I am not prepared to accept all the very serious disadvantages of a Corps d'Elite in order to secure possibly some improvement of methods . . . at a serious loss of morale and efficiency to the other squadrons."[28] But Harris himself said 617 Squadron was to be "a Special Duty Squadron under the operational control of AOC 5 Group" to undertake missions "that entail special training and/or the use of specialist equipment."[29] The difficulty of the task can be gauged by comparison with the efforts of Bomber Command's Main Force at around the same time: on 6 March 1943, 293 aircraft attacked Essen, but only 153 were found to have bombed within three miles of the target.[30]

Notwithstanding the new squadron's elite status, rigorous and realistic training would be required if they were to achieve the required standards of bombing accuracy. Cochrane's original instructions to Gibson, while giving no details of the proposed targets, made it clear that mastery of night-time low flying over water would be required. Gibson himself, with two of his senior pilots as passengers, tried out the required night-flying skills over the Derwent Reservoir: the results were not encouraging. The squadron commenced its low-level, cross-country training on 31 March 1943 and by the end of April, following intensive training in which over

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a thousand flying hours were logged, was able to "navigate from pinpoint to pinpoint at night at low level by map reading; they could bomb accurately using a special rangefinder sight; and fly safely over water at 150 ft."[31]

Not all of 617 Squadron's night-flying training was actually done at night. A system, grandly called Synthetic Night Flying Equipment was used to simulate night-flying conditions. Blue celluloid covered the cockpit transparencies while aircrew wore amber-coloured flying goggles of varying intensities: the combination of blue and amber effectively cut the light levels transmitted from outside the cockpit to approximately that of good moonlight, but cockpit instruments could be clearly seen through the goggles. A safety pilot without goggles was able to see the outside world clearly through the celluloid. One apparently unexpected side-effect of prolonged use of the celluloid-goggle combination was that when goggles were taken off outside the aircraft, the world appeared red.[32]

A further medical problem encountered during low-flying training was airsickness. Few of the aircrew would have had much experience of low-flying in the Lancaster, an aircraft that was not designed for it and in which some of the crew sat at an angle to the line of flight. The situation was sufficiently severe to cause the squadron's medical officer to fly on a training flight to experience the problem for himself: thereafter airsickness sufferers were treated with chlorobutanol.[33] Low-flying did not just cause medical problems: concerns were raised about its effects on the aircraft's structure after a number of bolts on one airframe were found to have sheared.[34]

On 26 April 1943, having mastered flying at 150 ft, the squadron was required to cut the bombing height to 60 ft and the release speed to 210 miles per hour. Over the next week they trained intensively again, dropping nearly 300 practice bombs that on average fell within 120 feet of the aiming point. Training now concentrated on the Eyebrook Reservoir near Uppingham, the Abberton Reservoir near Colchester and, deputising for the Sorpe dam, the Derwent Reservoir near Sheffield. The screens previously used at the Wainfleet range to mimic the towers of the Mohne dam were now transferred to Eyebrook.

If constant practice under realistic conditions had allowed the aircrew to master the necessary flying skills[35], although none of them had yet dropped the new weapon and would not do so until 11 May 1943, there were still a number of technical problems to be overcome. One of these was the difficulty of achieving, particularly at night over water, the precise 60 ft altitude required to drop Upkeep accurately. A number of unsatisfactory solutions were tried before Lockspeiser, Director of Scientific Research at MAP, suggested the use of intersecting spotlights. This was not a new idea, Harris himself had tried it in flying boats and, having failed to make it work, was once more sceptical: Coastal Command had also tried it unsuccessfully as an aid to nocturnal, shallow-water attacks on U-boats.

617 Squadron was duly sceptical and difficulties were encountered in making the system work adequately, particularly at such low altitude. The two spotlight beams were set to meet on the water (which on a reservoir could be expected to be sufficiently smooth not to interfere with the functioning of the system) just forward of the port wing. Here it was difficult for the pilot to monitor and this duty fell to the navigator who was thus responsible for altitude[36] as well as for navigating to and from the dams.

Having devised a means to drop Upkeep from the correct height, it was now necessary to find a means to drop it from the correct range. Dropped too close it might simply bounce over the dam endangering the aircraft as the mine exploded out of the water[37] or if dropped too far away simply never reach its target. A simple device was devised at Boscombe Down to overcome this problem: a triangular sight using the bomb-aimer's eye at the base of a triangle completed by two nails mimicked the desired drop position of the aircraft in relation to the dam's towers.

In effect, with the sight correctly held by the bomb-aimer, the aircraft was in the right position to drop Upkeep when the nails obscured the dam's towers. Some crews used this sight but others used their own variations on the theme, often including a length of string and chinagraph pencil marks on the clear-view panel.

The breached Möhne dam

It was now possible to drop Upkeep at the right speed, at the right height and from the right range. If the weapon worked as advertised the dams should be destroyed. But Upkeep and the aircraft to carry it were in short supply and could not be wasted in unnecessary attacks. It would be possible after each attack to see if the dam had been breached and aircraft could be diverted elsewhere. Accordingly, Gibson needed to be able to control the attack, to call a halt when the objective was achieved and to divert aircraft to subsequent targets.

In normal area bombing practice such control was not necessary and Bomber Command's aircraft were not fitted with radios that allowed such control to be exercised. The standard TR 1196 radio was perfectly adequate for air-to ground use (and would be used to communicate with HQ 5 Group during the raid) but was found to be unsuitable for air-to-air use, especially at night. Specialist advice was sought and the fitting of the TR1143 radio used in fighter aircraft was suggested. This, with a few extra tweaks, proved suitable and was flight trialled by 617 Squadron's two flight commanders one week before the mission. In the meantime a series of booths acting as a radio simulator had been rigged in the squadron's crew rooms to enable procedural training to take place before the radios had been fitted to the aircraft.

The raid

The attack on the dams was made in three waves. Gibson led the first consisting of nine aircraft to attack the Möhne dam. The second wave, five aircraft, was led by McCarthy (it actually took off first although its leader was delayed by problems with his aircraft) and was to attack the Sorpe dam (correctly identified by the Ministry of Economic Warfare as a vital target if the raid was to achieve its desired endstate) even though Upkeep was not designed to be used against that earth-bank type of dam. The third wave, led by Ottley, comprised a further five aircraft: they were briefed to attack either the Möhne or Eder dams but also had alternate targets. Instructions as to which target they should attack would be passed by radio from HQ 5 Group as the progress of the raid became apparent.

The nine aircraft of the first wave made their way at low-level to the Möhne, losing one aircraft (Astell) to anti-aircraft fire en route. On arrival Gibson made a trial run before actually dropping his Upkeep: this appears to have fallen short and did not breach the dam. Hopgood followed but dropped his weapon too late: it bounced over the dam and destroyed the dam's power station instead. At the same time Hopgood's aircraft was shot down by the gunners on the dam. Third to attack was Martin whose Upkeep fell both short and wide of the target and failed to breach it. Young's was the fourth attacking aircraft: his mine exploded in contact with the dam and Maltby, next

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to attack, reported that there was a breach in the dam before releasing his own Upkeep. Maltby's mine also exploded in contact with the dam causing a definite breach.[38]

Once the breach had been confirmed, Gibson led the aircraft which still had an Upkeep to use (plus Young as deputy leader) to the Eder dam. Maltby and Martin headed for home. Achieving the correct position from which to drop Upkeep proved very difficult at the Eder, Shannon had three unsuccessful goes before handing over to Maudslay who had two unsuccessful attempts. Shannon then tried two more times before finally getting the right alignment and dropping his Upkeep such that it exploded in contact with the dam but did not breach it. Maudslay came next and finally released his weapon on the third attempt but the release was too late, the mine hit the dam's parapet and exploded damaging Maudslay's aircraft.[39] Finally the last aircraft of the first wave, Knight, attacked: he took one practice run but on the next run Upkeep was successfully dropped and the dam breached. Gibson ordered a return to Scampton but Young's aircraft was shot down by anti-aircraft fire on the way home.

Informed by radio that both the Möhne and Eder dams had been breached, Harris — at HQ 5 Group — placed a call to Portal who was in Washington for a conference with his fellow British and American Chiefs of Staff[40] to inform him of the success. Portal in turn informed Churchill.

The second wave, intended to attack the Sorpe, actually left before the first. McCarthy should have led but his aircraft had mechanical problems and he had to change to another: he finally left well behind the rest of his wave. In the end, though, McCarthy was the only one of the wave to reach the target. It took him 10 attempts to satisfactorily drop Upkeep; the dam was damaged but it was not breached. Barlow's aircraft, which actually led off the raid, was shot down by flak over Germany and the Upkeep failed to explode in the crash. As a result the Germans captured Upkeep intact, rapidly worked out how the weapon worked and produced (but never actually used) their own, more complicated, version.

Next came Munro whose aircraft was severely damaged by flak over Holland and forced to return to Scampton. He was followed by Byers who was shot down by anti-aircraft fire over Holland, and by Rice who had Upkeep wrenched off by impact with the water without the aircraft crashing while flying too low over the Afsluitdijk. Rice had no option but to return to Scampton and so only one of the five aircraft originally destined to attack the Sorpe reached its target.

The third wave was a reserve force. Each had its own intended target such that all six dams in the Operational Order[41] might have been attacked but could be re-tasked by HQ 5 Group to attack the Möhne, Eder or Sorpe dams as required. Ottley led the wave but was shot down before 5 Group could divert him to the Sorpe, while Burpee, always destined for the Sorpe, was shot down over Holland. Brown came third and attacked the Sorpe. As with McCarthy, he and his crew found it difficult to place their Upkeep appropriately and, although they did hit it, the dam was not breached.

The fourth aircraft — Townsend's — was tasked against the Ennepe. Difficulty was experienced in finding the target and, although Upkeep was dropped, the dam was not damaged. Uncertainty exists about which dam Townsend's crew attacked. They were sure they attacked the Ennepe, but the War Diary of the Oberkommando der Wehrmacht records that the Bever dam was attacked that night and not the Ennepe.[42] Last of all was Anderson's aircraft — originally tasked against the Diemel, but diverted to the Sorpe — which never found its target and returned to Scampton: Upkeep was unused.

The effect in Germany

Breaching the Möhne and Eder dams unleashed huge amounts of water. At the Möhne 116 million cubic metres of water escaped within the first 12 hours (approximately 88% of the total contents of the reservoir) while at the Eder, 154 million cubic metres of water were lost (approximately 76% of its total contents). Downstream of the Möhne, in addition to the damage done to its two electricity generating stations, significant damage was inflicted by the passage of the flood-water. Bridges were destroyed up to 50 km away and buildings up to 65 km away.

The official German figures give the final death toll for the Möhne as 1,294 killed or missing while 11 factories and 92 houses were destroyed, 971 houses and 32 farms damaged, 2,822 hectares of farmland made useless with a further 1,221 hectares damaged, and over 6,300 cattle and swine killed. In addition, nearly 50 road and railway bridges were damaged and several kilometers[43] of railway embankment required repair. On top of this, a large number of power or pumping stations and gas or water supplies were damaged[44].

The results below the Eder caused less loss of life. Only 47 people were killed, but the effects reached far from the dam. Floods requiring the use of boats for mobility were recorded up to 140 kilometers away and the damage to the river system was considerable: both the Rivers Fulda and Weser had to be dredged to restore them for navigation.

seem likely[45]. In such a climate, the loss of around 1,300 lives was considered entirely acceptable in the pursuit of the disruption of German industry; Harris even defended the results of the attack on Hamburg:

"In spite of all that happened at Hamburg, bombing proved a comparatively humane method. For one thing, it saved the flower of the youth of this country and of our allies from being mown down by the military in the field, as it was in Flanders in the war of 1914-1918."[46]

Albert Speer who had responsibility for the German war economy as Minister of Armament and War Production led the German response to the raid. He flew from Berlin the following morning to inspect the damage, initially from the air. Speer recorded that the flooding of the valley

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Over 5 km of riverbank needed rebuilding and 50 hectares of land was made unusable. It is worthwhile to digress at this point on the morality of this attack and the legality of the target. By today's standards the collateral damage, the loss of non-combatant life would be unacceptable: the current RAF would not countenance attacking such a target. But in 1943 high levels of civilian casualties were part and parcel of the strategic bombing offensive. The need to aim at city centres because bombing accuracy was insufficient to allow anything else was bound to mean significant levels of collateral damage.

The civilian casualties caused by Operation CHASTISE would be eclipsed within 3 months by the Battle of Hamburg. On the night of 27-28 July 1943, Bomber Command's incendiary attack raised a firestorm, which within 30 minutes, had covered 22 sq km of the city. The exact casualty numbers will never be ascertained but figures of 40,000 killed with a similar number of injured

below the Möhne had caused the "seemingly insignificant but grave consequence that the electrical installations at the pumping stations were soaked and muddied, so that industry was brought to a standstill".[47] He rapidly mobilised manpower to repair the damage: 7,000 men were diverted from constructing defences on the Atlantic Wall to repair the dams.

Sweetman[48] records that a further 20,000 workers, again many of them drawn from the Todt Organization's workers on the Atlantic Wall, were diverted to help with the clean-up. It seems likely, therefore, that a total of over 10,000 construction workers were diverted from constructing defences against the invasion of Europe, which would occur the following year for a period of several months. What impact might the fortifications that they would otherwise have built, have had on that invasion? In addition to construction workers, both military and civilian specialists of many types were involved in the clean-up operation.

Hitler was furious . . . he blamed the Luftwaffe for failing to prevent the attack. This failure reinforced Hitler's prejudices about air power; he did not believe that an effective defence against bombing could be mounted

In order to restore electricity and water supplies in the Ruhr, Speer ordered the requisitioning of electric motors and the importation of experts from elsewhere in Germany regardless of the consequences. His aim was to restore armament production in the Ruhr to half-production within one week and to full production within two weeks[49]. While this did not represent the total or prolonged suspension of production that Wallis and others had hoped for, it did represent the loss of three-eighths of the Ruhr's monthly production: not an insignificant achievement considering that it takes no account of production losses elsewhere caused by the concentration of efforts into the Ruhr.

Any attempt to quantify the actual production losses caused by the raid is fraught with difficulty. At this stage of the war, the German economy was (surprisingly) still transforming itself onto a war footing and output was rising rapidly so production losses are difficult to show definitively. What can be shown is that water production in the Ruhr dropped by 75% in the aftermath of the raid and took six weeks to return to normal levels, Ruhr steel production of over 300,000 tonnes was lost in both May and June (normal production loss was less than 100,000 tonnes per month) and gas availability fell by 50%.[50]

Commentators have argued that this did not represent a good return on the training time invested in preparation for the raid or on the lives of the aircrew lost. The flying hours put into training for Operation CHASTISE were approximately equivalent to those taken up in a 500-bomber raid on the Ruhr, yet CHASTISE caused far more damage than any normal raid. No normal raid halved the Ruhr's production for a week and, at a 4.7% loss rate[51], a 500 aircraft raid would have expected to lose 23 or 24 aircraft compared to Operation CHASTISE's eight: for the effect achieved the loss was acceptable, if heavy to bear for a single squadron.

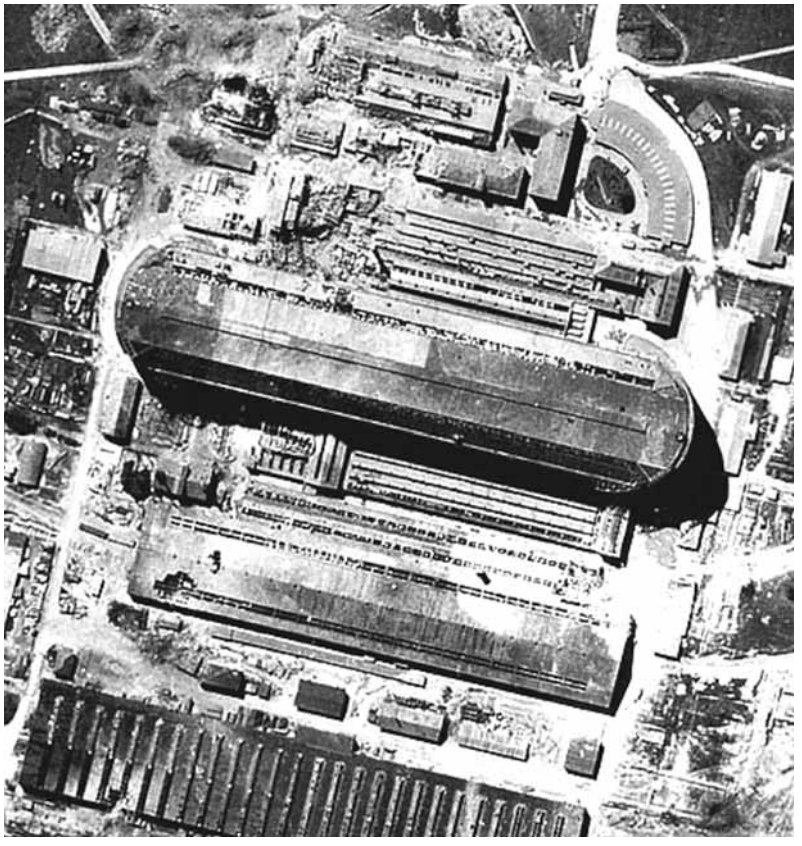
Another rapid response to the raid was the strengthening of defences around German dams. The level of commitment can be illustrated by reference to the Eder dam. A total of 48 barrage balloons, nine searchlights, six rocket-launching vehicles, 36 anti-aircraft guns varying in calibre from 20-88 mm and a smokescreen system were provided. In addition, there was an infantry company to guard against parachute attacks so that up to 1,500 men were tied up in protecting one dam. Taking all the German dams into account 10,000 front-line troops were involved, the equivalent of a full division that could not be employed elsewhere.[52]

The final effect, and surely not one that the Allied planners intended, was that on German air plans. Hitler was furious: an entry in the Reich's Propaganda Ministry's log recorded: "The Führer is extremely angry and impatient at the inadequacy of our defensive measures"[53] and he blamed the Luftwaffe for failing to prevent the attack. This failure reinforced Hitler's prejudices about air power; he did not believe that an effective defence against bombing could be mounted. He refused to allow the Messerschmitt Me-262 to be developed as a pure fighter (a role in which it was pre-eminent) instead insisting that it be developed as a fighter-bomber.

Allied effects

With the surviving aircrew back at Scampton and a reconnaissance Spitfire on its way to Germany to photograph the aftermath of the raid, the Air Ministry set to exploit the publicity and propaganda benefits of the raid. The news was broken by the BBC's morning news bulletin, the Air Ministry's communiqué coming too late for the morning newspapers. They would not report the raid until their 18 May 1943 editions but they made up for the delay with the enthusiasm with which they greeted the news in their headlines. In a generally more restrained era these included, "Huns Get A Flood Blitz" (*The Daily Mirror*), "Floods Sweeping Ruhr From Smashed Dams – RAF's Major Victory" (*The Daily Sketch*) and "RAF Blow Up Three Key Dams in Germany" (*The Daily Telegraph*). Every front page carried aerial reconnaissance pictures of the destroyed dams, but already inaccuracies were creeping in, as evidenced by *The Daily Telegraph* headline's implication that three dams had been destroyed.

News of the attack was quickly spread in the United States: Portal briefed the Combined Chiefs



The RAF had now proved that it had the potential ability to apply his concept to other 'choke points' in production and other such attacks would be undertaken

The Zeppelin factory on Lake Constance, considered to be an important 'choke point' in German radar production

of Staff on 17 May 1943. On 18 May 1943 the *New York Times* reported: "The RAF has secured another triumph" and hailed the "unexampled daring, skill and ingenuity".[54] Such headlines must have been welcome to the British contingent at the Trident conference: they were facing an American military establishment which was, to say the least, sceptical about British military capability. Churchill made the most of the opportunity in his address to the US Congress on 19 May 1943 saying, to cheers from the floor of the House:

"You have just read of the destruction of the great dams which feed the canals and provide power to the enemy's munition works. That was a gallant operation costing eight out of 19 Lancaster bombers employed but it will play a very far-reaching part in German military output. It is our settled policy, the settled policy of our two staffs of war-making authorities — to make it impossible for Germany to carry on any form of industry on a large or concentrated scale, either in Germany, in Italy, or in the enemy-occupied countries . . . In the meanwhile, our air offensive is forcing Germany to withdraw an ever larger proportion of its war-making capacity from the fighting fronts."[55]

Such declarations were doubtless aimed also at the Russians who, already fighting the Germans on the Eastern front, were as we have seen calling for the opening of a second front in Europe. The raid dramatically demonstrated Bomber Command's ability to take the battle to Germany. A successful precision raid was also useful for propaganda purposes in occupied France. The British War Cabinet had debated the effect of inaccurate British bombing on support there. Leaflets were dropped both in France and in Holland which used pictures of the aftermath of the raid accompanied by explanatory text to stress the precision of the operation: factual accuracy was not complete here as the text claimed a breach of nearly 100 metres at the Sorpe, in addition to the Möhne and Eder successes.[56]

On a less positive note, the realisation soon dawned in Britain that if an unexploded Upkeep had fallen into German hands, as Barlow's had, it would be possible for them to reverse-engineer their own version and use it to attack British dams: the Heinkel He-177 was, at least theoretically, capable of carrying such a weapon.[57] The Ministry of Home Security continued to debate the problem for nine months without reaching a definitive conclusion although steps were taken to protect the dams above Sheffield. As it happened the Germans did not attack, neither did they reverse

Gibson had been the first to use the 'master bomber' technique, controlling the actions of formation and directing them from one target to another by radio

engineer Upkeep preferring an unsuccessful attempt to produce a more sophisticated version. This did not work effectively and was never used operationally.

Benefits and lessons

In addition to the direct results in terms of the damage caused by the floodwater, which have been detailed previously, there were a number of indirect benefits too. The most obvious of these was the continuing existence of 617 Squadron, albeit that it took some time to recover from the crew losses sustained. The presence of a squadron that had proved its ability to deliver novel weapons, using new techniques and with great precision enabled the RAF to look towards further such precision raids. The original variation of WA5, which envisioned crippling the industry of the Ruhr by attacking its power and coking plants, was a 'choke point' plan seeking strategic effect by targeting precise locations rather than by area bombing.

The RAF had now proved that it had the potential ability to apply his concept to other 'choke points' in production and other such attacks would be undertaken. An example was the 20-21 June 1943 attack (again carried out by crews from 5 Group but with the assistance of a small number of Pathfinder aircraft) on the Zeppelin factory on Lake Constance which was thought to be vital to German radar production. The concept of attacking 'choke points' remains firmly part of RAF doctrine, although more likely these days to be applied to attacks on infrastructure, logistic chains or communication nodes than to production facilities, a task made easier by the development of truly precision-guided weapons.

Allied to 617 Squadron's continued existence was a willingness by the Air Ministry and MAP to look more favourably at Barnes Wallis' other ideas for large bombs. These would evolve into Tallboy and Grand Slam: respectively 12,000 lb and 22,000 lb penetration bombs: 617 Squadron was to use the Tallboy with great accuracy on a number of occasions. In a four-week spell in June and July 1944 alone they successfully attacked the Saumur railway tunnel preventing the transit of a Panzer division on its way to attack the Normandy bridgehead, the E-boat installations at Le Havre and Boulogne, V-1 launch sites in the Pas de Calais and the first launch site for the proposed V-3 weapon.[58] In addition, the 617 Squadron-Tallboy combination destroyed the Dortmund-Ems canal, the Krebs Dam (using delayed-action fuses and low-level attack, not the high-level attack for which Tallboy was designed) and twice (in conjunction with 9 Squadron) attacked and finally sank the German battleship Tirpitz. The massive Grand Slam bomb was successfully used against the Bielefeld viaduct that had resisted all previous attempts to destroy it.

Gibson had been the first to use the 'master bomber' technique, controlling the actions of formation and directing them from one target to another by radio. Three months later Gp Capt Searby would attack as 'master bomber' in the raid against the V-weapons research site at Peenemünde. This raid was altogether larger in scale with nearly 600 attacking aircraft, controlled by air-to-air radio as Searby circled the site for the duration of the attack[59] and caused Goebbels to comment that, in relation to V-weapon attacks, "preparations were set back by four or even six weeks".[60]

The combination of this technique and of radio control from Group HQ would eventually lead to the development of sophisticated airborne command and control systems. The use of ground-spotters using ground-to-air radio to talk tactical aircraft onto targets would become common-place in Normandy following D-Day. In Afghanistan we have recently seen ground troops calling in close air support from B-52 heavy bombers via controllers in an orbiting AWACS aircraft.

Conclusions

If the sole criterion of success is the permanent paralysis of the Ruhr's munitions industry and Germany's consequent inability to prolong the war, then Operation CHASTISE was not successful. The Air Ministry and the Ministry of Economic Warfare both knew that the destruction of the Sorpe dam was vital if this aim was to be met, but that Upkeep was not really a suitable weapon for the task. It is interesting, however, to speculate on what might have happened if more of the second and third wave aircraft had reached and attacked

this target. If the disruption to German transport infrastructure reduced agricultural production and the diversion of labour from the construction of Atlantic defences are considered, a picture begins to emerge of the dams raid as a triumph.

As we have seen, however, there are other important factors to take into account. The raid had very important moral and psychological effects. It was one of a number of Bomber Command 'set pieces'[61] which raised both the British public's confidence in the Command's ability to take the fight to the Germans and public morale in general. Allied to this, the timing of the raid was fortuitous as it allowed the British to parade an aerial success before the Combined Chiefs of Staff Conference and Churchill to exploit that success before the United States Congress.

Furthermore, the dramatic pictures could be used both in persuading the Russians that Britain was doing its share against Germany and in showing occupied Western Europe that Britain could now attack precision targets. The Germans were not immune to the psychological effects: Speer records that the raid made "a deep impression on the Führer".[62] Reinforcing Hitler's prejudices as it did, this assisted the move to the misemployment of the Luftwaffe as an offensive rather than defensive force. In addition, fear of repeat attacks (never undertaken or even apparently contemplated) caused the equivalent of an entire regular division to be tied down protecting the remaining dams: in itself this was probably worth the loss of eight aircraft.

There were other gains for the RAF: the start of the 'master bomber' technique allied to the demonstration that bomber aircraft could be effectively controlled by radio; the demonstration that Bomber Command could undertake precision attacks (albeit with specialized training and selected crews); the creation of an 'elite' squadron which would go on to develop new techniques and undertake other precision or novel attacks; and the impetus the raid gave to the Command to take Wallis' other specialized bombs seriously.

At the time, it was undoubtedly — in Webster and Frankland's words— "the most precise bombing attack ever delivered"[63] even if their assertion of " a feat of arms which has never been excelled" smacks of hyperbole. Allying this precision to the dramatic post-raid reconnaissance photographs, the undoubted bravery of the crews involved and a pre-determination to use the raid for propaganda purposes, it is hardly surprising that the Dams Raid remains the RAF's most famous single operation and 617 its most famous squadron.

All in all, the Dams Raid was an all-round success and not a sideshow.

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Notes

1 Sweetman (1990) p.1.

2 Webster and Frankland (1961) p.168.

3 The "bouncing bomb" is part of the mythology of the raid. The weapon is more accurately described a ricocheting depth charge: it ricocheted across the water rather than bouncing and its explosion was triggered by hydrostatic pistols of the kind used in Royal Navy depth charges.

4 Sweetman (1990) p.1.

5 Sweetman (1990) p.12.

6 Quoted in Terraine (1985) pp.292-3, the Butt Report assessed the accuracy of Bomber Command's efforts for the period 2 June 1941- 15 July 1941 by studying the photographs taken when bombs were dropped. It reached the depressing conclusion that of all aircraft taking off on raids only about a quarter actually got within 5 miles of the target, and of those actually claiming to have attacked only one in three was within 5 miles of its target.

7 Two types of dams were involved. The Sorpe was an earth dam (a waterproof concrete core surrounded by earth banks on either side) and not susceptible to destruction by shockwaves; the rest were gravity dams which derive their strength from their own weight but are vulnerable to shockwaves.

8 Sweetman (1990) p.8.

9 Sweetman (1990) p.43. Neither plan progressed, though there is a suggestion that Combined Operations' effort was held in reserve in case the bombing raid should be unsuccessful. It is hard, however, to see how a charge floated down the reservoir could have avoided the Mohne's existing defences.

10 Sweetman (1990) pp.18-19.

11 Sweetman (1990) p.14. The intention was to achieve supersonic speeds in the drop from height to bury the bomb as deep in the ground as possible before it exploded.

12 Sweetman (1990) pp.32-34.

13 Sweetman (1990) p.18.

14 Sweetman (1990) p.28.

15 Sweetman (1990) p.30. The third point is counter-intuitive: most golfers realize that a back spun golf ball stops short on pitching rather than leaping forward. Wallis was a golfer; indeed he was working from offices at his own golf club.

16 Sweetman (1990) p.35. These timings appear to be correct. Although Wallis would later claim that initial dropping trials occurred in September 1942, there is no documentary evidence to support his assertion.

17 Andrews & Morgan (1988) pp. 387-9. The Vickers Windsor was a four-engine bomber developed to meet Specification B3/42 but which would, in fact, never enter series production: four prototypes were built of which only three flew.

18 Terraine (1985) p.514.

19 Terraine (1985) p.518.

20 Harris (1947) p.157.

21 Messenger (1984) p.119.

22 Sweetman (1990) p.44.

23 Sweetman (1990) p.56. It appears that the extra trial drops were requested by MAP and Air Ministry officials rather than by Wallis. At this stage the attack was only 2 weeks away and 617 Squadron were well into their training for the operation but the method of attack was not yet fully proved.

24 Sweetman (1990) p.76. Initially chaired by Rear-Admiral Renouf the appointment soon passed to AVM Bottomley, ACAS (Ops).

25 AP3000 p.1.3.4. Mission command gives instructions on what is to be achieved and why rather than what to do and how to do it.

26 Messenger (1984) pp.73-74. Harris was not averse to publicity. He had authorized the "Thousand Bomber" raid against Cologne in May 1942 as much for domestic propaganda reasons as for operational ones.

27 Harris (1947) p.156. One does not have to be unduly cynical to infer that the potential propaganda and public relations benefits of a successful attack on a high profile target helped to smooth the way for high-level support of the Dams Raid.

28 Messenger (1984) p.85.

29 Sweetman (1990) p.83. The statement suggests that Harris, despite his avowed dislike of elites, accepted from the start that 617 Squadron was to be an elite squadron kept in-being for specialised tasks.

30 Verrier (1968) p.220. Whilst these results clearly show that an average heavy bomber squadron could not bomb sufficiently accurately to destroy the dams, they also show that standards in Bomber Command were improving. By comparison with the Butt Report's one-third of attacking aircraft bombing within 5 miles of the aiming point, the Main Force was now achieving one-half bombing within 3 miles.

31 Sweetman (1990) p.64.

32 Sweetman (1990) p.66. This simulation was effective but is no longer used. A similar visual anomaly (magenta eye) is, however, experienced after prolonged use of night vision goggles. This is caused by suppression of the sensitivity of retinal green cones by the purely green light transmitted by night vision goggles while at the same time the sensitivity of red and blue cones is increased. The response of the eye when re-exposed to white light is to produce over-reaction to the red and blue frequencies and hence a magenta image.

33 The phenomenon of airsickness caused by low-level buffet in aircraft not originally designed for low-level flight is still encountered in the RAF where Nimrod MR2 rearcrew are particularly prone to it for precisely the same reasons. 617 Squadron's suffer-

ers were treated with chlorobutanol, now recognized as a hypnotic and sedative: it is interesting to speculate on the potential impact on performance of using such a drug in low-level flight. It is impossible now to establish whether any aircrew actually used chlorobutanol during the raid and whether their performance might have been degraded by it.

[34] Sweetman (1990) p.68. Bomber Command would have further experience of the damage done by low-level flight to aircraft not specifically intended for that role in 1965. The Vickers Valiant was designed as a high-speed, high-altitude unarmed bomber but in early 1964 was switched to the low-level role as high-altitude operations were deemed to be too dangerous. Less than a year later the entire fleet was grounded with fatigue damage to the wing main spar.

[35] In many ways this was an innovation as most World War II aircrew had to master their operational flying skills on operational sorties.

[36] Getting Upkeep on target was a genuine team effort: the pilot set the line, the air engineer who controlled the throttles was responsible for airspeed, the navigator monitored altitude and the bomb-aimer was responsible for the timely release of the weapon. Given the precise requirements in all parameters to drop Upkeep successfully, it is a testament to the crews' skill that the weapon was delivered with sufficient accuracy for it to function at all.

[37] This happened to Flt Lt Hopgood, the second aircraft to attack the Möhne. It is not entirely clear that the destruction of this aircraft was caused by the explosion of Upkeep and it is felt it was more likely to be due to defensive gunfire from the dam.

[38] It seems likely that, on balance, the Möhne dam was breached by the first Upkeep to explode in contact with it and that Maltby's mine merely widened the breach.

[39] The evidence on the fate of Maudslay's aircraft is unclear. At the time it was thought to have been destroyed by the mine's explosion but radio transmissions were heard afterwards and German records suggest that the aircraft was actually shot down by anti-aircraft fire on its way home.

[40] Euler (2001) p.40. The "Trident" conference was held to clarify future Anglo-American operations: these included confirmation of POINTBLANK, the joint strategic bombing offensive aimed at fatally weakening Germany. The directive was issued on 10 June 1943.

[41] Operation Order B.976. The six, in the order of importance attached to them, were the Möhne, Eder, Sorpe, Lister, Ennepe and Diemel dams.

[42] Euler (2001) p.108.

[43] Cooper (2000) p.72. Experience with flood damaged railway tracks in the US suggested that it took up to 25000 man-hours per mile to repair them and the Ruhr-Kassel railway line was, indeed, unusable for several months.

[44] Sweetman (1990) pp. 154-5.

[45] Terraine (1985) pp.546-7.

[46] Harris quoted in Terraine (1985) p.548.

[47] Speer (1970) p.281.

[48] Sweetman (1990) p. 162.

[49] Sweetman (1990) p. 162.

[50] Sweetman (1990) pp.180-2.

[51] Terraine (1985) p. 518. Bomber Command lost 872 aircraft out of 18506 sorties despatched during the 1943 "Battle of the Ruhr", a loss rate of 4.71%.

[52] Sweetman (1990) pp. 184-5.

[53] Quoted in Rumpf (1975) p.74.

[54] Sweetman (1990) p.174.

[55] Euler (2001) p.117.

[56] Sweetman (1990) p.175.

[57] Philpott (1980) p.114.

[58] Sweetman (1990) p.189.

[59] Terraine (1985) p.541.

[60] Morpurgo (1972) p.282.

[61] The first "Thousand Bomber Raid" against Cologne, for example, could be seen in the same light. Harris needed a major raid wreaking significant damage to demonstrate that his ideas on the employment of Bomber Command could work. Nonetheless, the need for 1000 aircraft rather than 900 was undoubtedly for propaganda purposes.

[62] Speer (1970) p.280.

[63] Webster & Frankland (1961) p. 168. It is a testament to advancing technology that what in 1943 was thought of as remarkable precision would be routine with today's laser and GPS guided weaponry.