2009.11.03

Randall T. Wakelam, *The Science of Bombing: Operational Research in RAF Bomber Command.* Toronto: University of Toronto Press, 2009. Pp. ix, 347. ISBN 978–0–8020–9629–6.

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Randall Wakelam's *The Science of Bombing* fills a gap in the vast literature of Britain's World War II strategic bombing campaign against Germany. There is no lack of published material on virtually every aspect of the campaign, but this is the first work to focus on the contribution of RAF Bomber Command's Operational Research Section (ORS). The civilian scientists of the ORS analyzed problems and sought solutions to increase the effectiveness of British bombing and cut the devastating losses of RAF aircraft and crew sustained early in the war.

Wakelam is director of research and symposia at the Canadian Forces College and assistant professor of Defense Studies at the Royal Military College. More pertinent to the writing of this book is his previous career "of some three decades in the air force including over 3000 flying hours, experience in command and staff appointments, and over a decade providing education programs for mid-level staff officers and senior commanders" (3).

That experience has made Wakelam skeptical about the value of operational research: "To be specific, not once ... did I see the active participation of the air operational research staff in providing advice on how best to organize for specific roles and missions, what equipment to purchase, or how to optimize the air force and its policies and procedures for the most efficient use of limited resources" (4). Moreover, his first look at some "neglected" material, including the Section's reports, and an unpublished history of the ORS written by the scientists themselves, suggested that these "brilliant" outsiders had delved "into areas of military technology and process for which they had no previous training. Despite this ... once they had 'won their spurs' ... the conclusions and advice they provided were accepted on all occasions" (4). As this did not fit Wakelam's own experience, he set out to discover how this could have come about. The result is the first close investigation of the role the ORS played within Bomber Command.

The war did not start well for Bomber Command. Britain's bombing concepts grew out of limited experience in the Great War, based on a belief that the bomber was the ultimate weapon, against which defending fighter aircraft would be ineffective. Bombing was to be carried out by day—difficulties in identifying targets made precision bombing at night problematic. RAF leadership did not fully realize the challenges of strategic bombing and was not prepared for it. "As the official history states bluntly, 'thus, when war came in 1939 bomber command was not trained or equipped to penetrate into enemy territory by day or to find its target areas, let alone its targets by night'"(15).

Evidence for the poor state of the RAF was there to see: "Between 1937 and 1939 there were no fewer than 478 cases of aircraft being forced down when the pilots became lost, and this over the United Kingdom.... It was concluded that the average pilot could only get his aircraft to within fifty miles of the target using dead reckoning" (15). By the end of 1939, RAF daylight attacks frequently had unsustainable loss rates of fifty percent. Night attacks brought relatively few casualties, but were ineffective (19). One commander described them as "'a never ending struggle to circumvent the law that we cannot see in the dark'" (20).

In October 1940, the new Chief of the Air Staff (CAS), Charles Portal, faced "the prohibitive losses of unescorted day bombing and the navigation problems of night bombing." His solution, to use "night precision attacks where illumination permitted, and area attacks when not," was disliked by many senior RAF leaders, who believed that precision bombing could be carried out at night. "Moreover, raid reports claimed outstanding navigation and bombing accuracy" (21).

In fact, the crews were reporting what they *thought* they were seeing, while reconnaissance photos taken after attacks "rarely showed evidence of bomb strikes reported by the crews." A study of photos suggested by the Prime Minister's scientific advisor showed that only one aircraft in three got within five miles of its target. Portal looked for solutions; among them was the establishment of an operational research section at bomber command (23).

Operational research was a new field. Wakelam offers several complicated definitions before settling on "the more straightforward and useful in this context: '[OR is] concerned with the allocation and planning in complex situations requiring scarce or limited resources'" (25). In any case, the scientists, or "boffins," would employ their particular scientific methods to identify the problems that hindered effective bombing, and then seek cures.

The nucleus of ORS was a few scientists already engaged with Bomber Command. Chosen as section head was physicist Basil Dickins, a rising star in his early thirties. He won the confidence of Bomber Command leaders and headed ORS for the remainder of the war (34–36). At its peak in 1943, ORS employed fifty-five scientists, ten lab assistants and about a dozen clerks.

When ORS came together in late summer 1941, the "first and most pressing task was to come to grips with the challenge of measuring the accuracy, and by extension efficiency, of bombing operations" (55). A new data collection process was established: Sortie Raid Reports prepared by each aircraft would be the basis for analysis. More importantly, cameras were to be installed in each bomber, not to assess damage, but to record the actual dropping of bombs. With that, "commanders would have the necessary information to know where their crews were and what they were doing" (51).

A new item of technology, T.R. 1335 or "Gee," showed great potential to ensure two essentials in hitting targets: "navigating to the target area, and finding the aiming point" (59). Signals from three ground transmitters were received by aircraft on a cathode ray tube as two position lines, or gee coordinates. A special map let experienced navigators pinpoint an aircraft's position in less than one minute. The signals were "line-of- sight" and limited Gee range to 300–400 miles. Bomber Command believed that, once started, Gee could be used for six months before the Germans learned how to jam it (59).

ORS developed attack scenarios and recommended trials. Experimental attacks proved the effectiveness of the proposed "Shaker" attack technique. Shaker would use "Gee-equipped flare-dropping 'Illuminators,' incendiary-dropping 'Target markers,' and finally, the 'Followers' bombing with high explosives," on the conflagration that marked the target (62).

Attacks by Gee-equipped bombers in March and April 1942 showed improved results, but not as good as expected. ORS recommended the use of Pathfinders, "special target-locating squadrons," that would find their targets with Oboe—a device like Gee, but much more accurate—and drop marker bombs for the "follower" aircraft. The ORS had raised the Pathfinder concept as early as the previous December. Finally, Sir Arthur "Bomber" Harris, head of Bomber Command, established the Pathfinder Force (PFF) in August 1942. Although opposed to creating a new "elite" force, "he was not in fact against the target-finding concept" (75).

As bombing effectiveness increased, ORS had to deal with rapidly improving German air defenses.

> It was also clear that concentration in both time and space was vital, not only over the target, but on the route as well. By sending in an attack en masse, the defenses could be overwhelmed.... In fact, one of the aims of the thousand bomber raids that would be launched in the summer was to show that concentration could lower losses.... According to Dickins, "we had to reduce it all to mathematics, and to work out the actual chance of a collision .... While a collision was a half percent risk, the chances of being shot down by flak or fighters was at three or four percent risk. So we could allow the collision risk to mount by quite a bit..." (81).

The scientists analyzed losses by cause and aircraft type. Since few returning aircraft had significant damage, it seemed "that losses must then be due to some catastrophic in-flight circumstances" that followed hits by flak or fighters. Investigations focused on in-flight fires and concluded that overall losses could be reduced through use of inert gas in the fuel tanks to minimize fires. "By April 1943 Bomber command was 'demanding' that all aircraft be so equipped" (90).

As for aircraft types, the Halifax was among the oldest and the slowest and suffered a series of problems that ORS identified and tried to resolve. Then the Lancaster, the most effective bomber of the force, was found to have a lower crew survival rate than the Halifax. In sixty-eight percent of Lancasters shot down, there were no survivors (151). ORS Chief Dickins believed he could have an explanation in "two or three weeks." It was four months before the problem was determined "to be due primarily to the more restricted space within the aircraft and to the poor rear escape hatch" (150). The ORS study, as was typical, had had to take on many related issues, from hatch design to crew training and the need for a new type of parachute, to fire-warning lights to alert crew in time to abandon the aircraft. The process often took many months.

As the war went on, Bomber Command made good use of new technology in large-scale operations. Concentration of the bombers over targets had an effect, until the Luftwaffe adapted to it. The introduction of Window—tin foil strips that interfered with German radar—made flak less effective and degraded the Luftwaffe's ground-controlled intercept operations. The fighters could not easily find the bombers—until German controllers reacted with a running commentary on the progress of the bomber stream that enabled fighters to find the stream and enter it, "until two-thirds of the [bomber] casualties were caused by fighters" (145). Bomber Command introduced new airborne jamming equipment like "Cigar," and equipped aircraft with receivers to alert crews to radar-equipped night fighters.

There were disappointments. H2S, a ground mapping radar, seemed the solution to lingering navigation and target identification problems, but brought difficulties of its own. By the end of 1944, however, "many of the other systems and tactics were producing a winning combination.... Bomber Command could, within limits, go pretty much where it wanted and when—and hit the target when it got there" (204). American long-range fighters helped neutralize German fighter defense, enabling Bomber Command to make raids day and night. "The final phase of the war from October 1944 to May 1945 was the most spectacular in terms of results achieved, 'but from the point of view of the operations themselves, it was perhaps the least interesting ....' For the decision makers, including the boffins, this was the denouement of the piece; it was almost anticlimactic to watch the bombers return op after op with general success and few casualties" (208).

Personalities do not figure much in this work, with the exception of Sir Arthur Harris, head of Bomber Command from February 1942. "Bomber Harris"—"Butcher Harris" to his critics—is central to Wakelam's thesis that ORS made its mark on the bombing campaign through influencing Harris's major decisions. Wakelam largely avoids the points of controversy—they are indeed beyond the scope of the book—but he does not agree with critics who "believe that Harris did not have a quick intellect" (66), or with the ORS scientist who saw Harris as a "commander in chief who accepted no criticism either from above or below, never admitted his mistakes, and appeared to be indifferent to the slaughter of his own airmen as he was to the slaughter of German civilians" (67). Nor does he see Harris's role as ruthless of unethical—area bombing had been adopted before his arrival at Bomber Command, he notes: "What Harris did do was direct the operations and staff activities of his force as effectively as possible, day in and day out for over three years, to ensure that when he did send his crews against the enemy they would be as effective, and safe, as possible" (7). He did so, Wakelam believes, by accepting many ORS recommendations. But the evidence adduced that Harris was not as rigid and dominating as he is often portrayed, will likely not convince the "butcher's" critics.

As a study of "questions of tactics and technique" (5), the book succeeds. As "an examination of how [Bomber Command] directed the strategic bombing campaign against Germany" (3), it does not. There are glimpses into decision making, particularly as Bomber Command implemented ORS recommendations, but any examination of the process is necessarily limited. ORS was just one of many entities that affected the functions of the RAF. We learn little of the others, their interaction with ORS and Bomber Command, or the extent of their influence on the bombing campaign.

The Science of Bombing contains interesting charts and photos and a useful glossary. The book's subject will appeal more to specialists than general readers. In particular, its detailed examination of the role of the ORS will be invaluable to aviation historians concerned with WWII in Europe.